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Contents of methylmercury and total mercury in Baltic Sea fish and fish products

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Abstract. Studies of the content of methylmercury in samples of selected Baltic fish species, products made of them and some imported fish were carried out in the period from 1996 to 1998. The aim was to evaluate the health quality of fish and fish products designated for human consumption. The method used for the determination of the content of methylmercury was first adapted to and then validated for the purpose of these studies. The concentrations determined were compared with the permissible levels of methylmercury set by countries such as Japan, the USA and Greece as well as with the permissible limits of total mercury set in Poland and other countries. The results of the studies confirmed that the methylmercury and total mercury content in Baltic fish and products made of them do not pose any threat to the consumer and therefore they can be eaten safely. In contrast, the content of methylmercury in samples of imported fish was close or even slightly higher than the permissible level, and this is why in the future, the monitoring of fish and fish products which are available on the Polish market should incorporate a larger number of imported fish samples.

Key words: mercury, methylmercury, Baltic fish, metalorganic compounds, organic mercury compounds

INTRODUCTION

Inorganic mercury is introduced into atmospheric precipitation, rivers, dust and industrial sewage from natural sources, and it also results from human activities. It enters the marine environment where it collects in the sediments (Bartlett *et al.* 1978, Baldi and Bargagli 1984). It is transformed into methylmercury by anaerobic microorganisms (Anon 1983, Anon 1986, Anon 1990a) and is accumulated in subsequent links of the food chain (Knauer and Martin 1972, Harada 1995). Studies conducted to date indicate that the high toxicity of mercury results from organomercurial compounds (Anon. 1983).

Since methylmercury is stable in the marine environment, highly toxic and poses health hazards (Goldwater 1971, Lofroth 1969, Marsh *et al.,* 1980, Taylor 1979, Eichler 1989, Gerstner and Huff 1977), it is necessary to investigate and monitor concentrations of it in the marine environment, fish and fish products. Such investigations were carried out within the framework of the project entitled "Methylmercury in Baltic Fish" conducted by the Testing Laboratory of the Sea Fisheries Institute in Gdynia from 1996 to 1998. The project was financed within the scope of state services by the Ministry of Transport and Marine Economy.

The aim of the project was:

– to adapt a method for the determination of methylmercury and to validate it in accordance with the requirements of the Quality System in the certified laboratory;

– to determine the methylmercury content in fish from the Baltic Sea in accordance with EU Directive 493/91 and recommendations in HELCOM Report No. 64B, 1996 (Anon.1996);

– to evaluate the health quality of Baltic fish and fish products made of them;

– to compare the results obtained from 1996 to 1998 with those obtained by the Department of Oceanography, Sea Fisheries Institute in 1973 and other results obtained by Polish researchers.

In order to carry out the proposed studies, it was necessary to select the proper method for the determination of the methylmercury content in fish which would meet the criteria of modern analytical methodology (Anon. 1997, Huber 1998) and which would be possible to conduct at the SFI Testing Laboratory. The method had to have good reproducibility, repeatability and a high degree of the recovery of the determined substance (accuracy). It had to be relatively fast, easy and inexpensive and not yield large amounts of post-reaction waste. Finally, the results obtained had to be confirmed by another, independent method. It is recommended to conduct simultaneous total mercury determinations with methylmercury determinations since this provides ongoing verifica-

Table 1. Permissible levels of total mercury and methylmercury in several countries [μg Hg/g of wet weight of raw material or product] (Anon.1989, Food Safety Regulations)

Country	Fish	Total mercury	Methylmercury
Japan	all	0.4	–
	all non–predators	–	0.3
Greece	all	–	0.7
USA	all	–	1.0
Holland	all	1.0	–
Portugal	all	1.0	–
Italy	all	0.7	–
Spain	all	0.5	–
France	all non–predators	0.5	–
	predators	0.7	–
Germany	all non–predators	0.5	–
	predators	1.0	–
Denmark	all non–predators	0.5	
	predators	1.0	–
Canada	all	0.5	–
Poland	all non–predators and products made from them	0.5	–
	predators and products made from them (including liver and eggs), cephalopods, crustaceans, mollusks	1.0	–

tion of the analytical results obtained and facilitates calculating the percentage of methylmercury in total mercury.

The methodology applied in our laboratory for methylmercury determination was based on the critical evaluation of several publications (Hight 1987, Rubi *et al.* 1992, Anon. 1992, Lorenzo *et al*. 1993, Yess 1993) as well as the authors' own results. It was based on extracting methylmercury with toluene in an acidic medium. Then the extract was cleaned with hydrochloride cysteine and the methylmercury content in the clean extract was determined using the atomic absorption technique. Results obtained in these investigations from 1996-1998 were compared with unpublished data from 1973. Both sets of results were obtained using the same methylmercury extraction procedure. The only difference was in the final determination. Data from 1973 were obtained from GC-ECD while those from 1996-1998 were obtained using atomic absorption technique. Therefore, it was necessary to examine whether results obtained from GC and AAS can be compared.

The aim of this project was to evaluate the health quality of Baltic fish and its products with regard to mercury and methylmercury content. Results obtained in the 1996-1998 period were compared with permissible levels of methylmercury set by some countries only, as is shown in Table 1.

MATERIALS AND METHODS

The material for the study was comprised of various Baltic fish species caught during research cruises in 1996-1998. The cruises took place annually in spring and autumn in the southern Baltic Sea at fishing grounds where commercial catches are taken; these included the Gulf of Gdańsk, the Pomeranian Bay, the Słupsk Furrow, the Vistula Lagoon and the Kołobrzesko-Darłowskie fishing ground (Fig. 1). The data from 1973 which were used

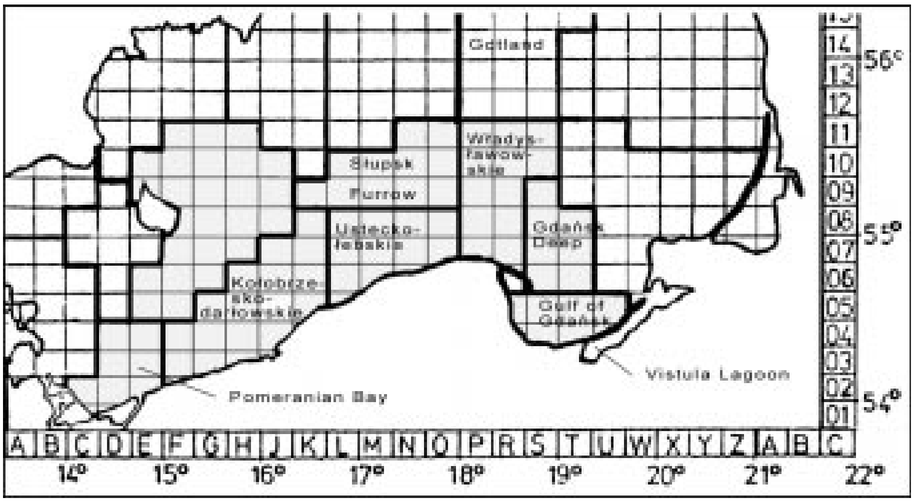

Fig. 1. Fishing grounds in the southern Baltic where study samples were collected.

for comparison with our results were obtained from the Department of Oceanography of the Sea Fisheries Institute (Kuźma, Taper and Nakonieczny 1973 unpublished data).

The fish chosen for our studies were those whose contribution to Polish catches is the greatest (herring (*Clupea harengus*), sprat (*Sprattus spratus*)), predatory fish which are at the top of the trophic chain (cod (*Gadus morrhua*), perch (*Perca fluviatilis*)), and benthic fish flounder (*Pleuronectes flesus*), eelpout (*Zoarces viviparus* (L.)). The following imported fish were chosen for study: salmon (*Salmo salar*), halibut (*Hippoglossus hippoglossus*), haddock (*Melanogrammus aeglefinus*), horse mackerel (*Trachurus trachurus* (L.)), mackerel (*Scomber scombrus),* roundnose grenadier (*Coryphaenoides rupestris* (Gunnerus)) and canned tuna availabled on the Polish market. The methylmercury content of products made of Baltic fish (canned sprats, smoked fish, fish in aspic and oil, marinated fish and salads) and imported fish (frozen fillets, smoked fish, canned fish) was also determined. The products were either purchased from the manufacturers or from shops located in the Tri-Cities. These samples were obtained throughout the year.

The samples used in the study were skinned fish fillets. Each pooled sample from a particular catch location consisted of 3-6 specimens of cod and eelpout of a selected length, 6-15 specimens of herring, flounder and perch and 20-30 specimens of sprat. The sampled fish were filleted and then the fillets were homogenized. The homogenate of fish or product was frozen on Petri dishes and then freeze-dried and granulated. The freeze-dried samples were used in the determinations of methylmercury.

The following is a detailed description of the methodology adapted in our laboratory for obtaining clean methylmercury extract in these investigations.

Approximately 0.5-1.0 g (to the nearest 0.001 g) of the freeze-dried sample or 2.0-4.0 g of fresh, homogenized sample is weighed out. The next step is to remove fat from the samples in order to avoid creating an emulsion in the following cleaning stages. Prior to acidification, fresh or freeze-dried samples must be shaken subsequently with acetone, toluene and hexane. After each shaking, the sample must be centrifuged and supernatant must be removed.

Then the weighed, defatted sample is placed in a 50 ml centrifuge tube with glass stopper and 2.5 ml of hydrochloric acid diluted with water at 1:1 and 5 ml of toluene are added. The test tube is shaken for 10 minutes in a shaker or placed in a ultrasonic bath. The test tube is then centrifuged for 30 minutes at 3000 rpm. The upper layer is decanted into a 10 ml screw-top vial, and then 5 ml of toluene is added to the remainder. The tube is shaken again for 10 minutes and then centrifuged, as above. The combined toluene extracts are treated with 1 ml of 1% hydrochloride cysteine solution in a 20% sodium citrate solution, shaken for 10 minutes and centrifuged, as above. Prior to determination, the upper layer (toluene) is removed with a syringe and the mercury content in the extract of methylmercury complexed with cysteine is determined using an AMA 254 mercury analyzer. The sample blank was subtracted from the sample values.

The detection limit was 0.02 ng Hg.

RESULTS

The repeatability of the method was validated by conducting 12 parallel determinations of methylmercury and total mercury contents in the TORT-2 and 8 parallel determinations of methylmercury in IAEA 142 – 2 certified reference materials (Table 2) and seven parallel determinations in two samples – skinned muscle tissue from fresh sprat and smoked mackerel (Table 3). The accuracy of the method was also determined on the basis of the analysis of extracts from the certified reference materials which contained methylmercury in two different concentrations (Table 2). The values determined were compared with the reference values. The recovery of the method applied in our studies was between 87-99 %.

The reproducibility of the method was verified and confirmed in inter-laboratory calibration exercises organized by the European Commission in October 2003. The subject of the study was IMEP-20 freeze-dried tuna meat. The certified content, expressed in mg/kg dry weight, provided by the organizers was Hg – 4.32 ± 0.16 and methylmercury – 4.24 ± 0.27. The values obtained in our laboratory were Hg – 4.3 ± 0.30 and methylmercury – 3.57 ± 0.34.

Table 2. Content of total mercury and methylmercury in the TORT-2 and IAEA 142 certified reference materials [µg Hg/g dry weight]

Determination number	TORT-2		IAEA 142
	Total mercury	methylmercury	methylmercury
1	0.281	0.149	0.0436
2	0.298	0.124	0.0393
3	0.225	0.153	0.0409
4	0.261	0.156	0.0420
5	0.267	0.186	0.0344
6	0.256	0.161	0.0422
7	0.272	0.135	0.0435
8	0.262	0.141	0.0436
9	0.267	0.120	–
10	0.266	0.121	–
11	0.277	0.136	–
12	0.281	0.134	–
13	0.276	–	–
14	0.266	–	–
Average value	0.268	0.143	0.0412
Standard deviation	0.015	0.018	0.0031
Variability coeff. [%]	5.6	12.6	8.96
Recovery [%]	99	94	88
No. of repetitions	14	12	8

TORT–2 Lobster Hepatopancreas Reference Material for Trace Metals
Certified total mercury content 270 ± 0.06 [µg Hg/g]
Certified methylmercury content 0.152 ± 0.013 [µg Hg/g].
IAEA 142 Mussel Homogenate for mercury, methylmercury and organic microconstituents.
Certified methylmercury content 0.047 ± 0.004 [µg Hg/g].

Table 3. Methylmercury content in samples of skinned meat from smoked mackerel and fresh sprat [μg Hg/g wet weight of fish muscle tissue]

Determination number	Smoked mackerel	Sprat
1	0.526	0.0091
2	0.388	0.0117
3	0.419	0.0112
4	0.427	0.0092
5	0.423	0.0105
6	0.390	0.0101
7	0.417	0.0093
Average value	0.427	0.0102
Standard deviation	0.046	0.001
Variability coeff. [%]	10.8	9.8
No. of repetitions	7	7

Table 4. The comparison of the results of methylmercury content in samples of herring obtained using AAS and GC-ECD method

Sample cod	Methylmercury content μg Hg/g ww	
	AAS method	GC-ECD method
125	0.062	0.044
128	0.021	0.014
116	0.012	0.010
107	0.020	0.023
101	0.018	0.024
114	0.038	0.035
119	0.013	0.008
117	0.024	0.020

We performed an experiment in which the final determination of methylmercury was conducted using both AAS and GC-ECD methods. Since similar results were obtained in both cases (Table 4), the data from these two methods can be compared.

The average content, standard deviation and the minimum and maximum values in the primary Baltic fish species during the 1996-1998 period are presented in Table 5. The lowest average content of methylmercury was determined in pelagic sprat and herring, which contribute the greatest mass to total Polish catches. Slightly higher methylmercury content was detected in benthic fish such as flounder and eelpout, and the highest levels were noted in predators such as cod and perch. The average methylmercury content calculated for the various species was similar throughout the study period and was independent of catch location.

During the 1996-1998 study period, determinations of methylmercury and total mercury were also done on products made of Baltic and imported fish (Table 6). The lowest methylmercury content was observed in canned sprat (0.011 μg Hg/g of product) and samples of cod in aspic (0.017 μg Hg/g of product). The methylmercury content in other products varied from 0.020 to 0.065 μg Hg/g of product. The methylmercury concentrations were many times higher, from 0.106 (smoked halibut) to 0.494 (Norway haddock – carcass) μg Hg/g of product, in samples of fish that were not of Baltic Sea origin.

Table 5. Total mercury and methylmercury concentrations in selected Baltic fish species by year from 1996-1998

Species	Length [cm]	Year	Number of samples[n]	Total mercury content [μg Hg/ g m.m.]				Methylmercury content [μg Hg/ g m.m.]				Methyl to total [%]
				average	Std dev.	min	max	average	Std dev.	min	max	
Herring	12-38	1996	14	0.034	0.025	0.018	0.071	0.027	0.0124	0.012	0.062	80.0
		1997	18	0.030	0.0096	0.018	0.058	0.025	0.0097	0.014	0.052	83.0
		1998	39	0.033	0.019	0.0082	0.1199	0.027	0.0186	0.007	0.170	82.0
Sprat	9-15	1996	9	0.024	0.011	0.015	0.049	0.020	0.0106	0.012	0.046	83.0
		1997	22	0.022	0.0065	0.008	0.033	0.016	0.0580	0.006	0.025	73.0
		1998	15	0.020	0.0067	0.0087	0.038	0.016	0.0080	0.006	0.038	80.0
Cod	25-88	1997	7	0.069	0.047	0.030	0.143	0.059	0.0304	0.020	0.111	86.5
		1998	16	0.0574	0.049	0.023	0.203	0.050	0.0593	0.018	0.178	87.1
Flounder	20-36	1998	17	0.047	0.024	0.026	0.1287	0.042	0.0200	0.027	0.110	90.0
Eelpout	13-35	1998	9	0.059	0.023	0.038	0.1012	0.052	0.0212	0.027	0.097	88.0
Perch	20-35	1997	11	0.115	0.040	0.065	0.170	0.104	0.0342	0.062	0.153	
		1998	6	0.048	0.015	0.027	0.067	0.044	0.0148	0.027	0.067	92.0

Table 6. Average content of methylmercury and total mercury in fish products in µg Hg/g of product wet weight

Product type	No. of samples	Methylmercury	Total mercury
Products made from fish of Baltic Sea origin			
Canned sprats	4	0.011	0.016
Smoked sprats	4	0.022	0.032
Flounder – carcass	1	0.032	0.033
Eel in aspic	1	0.030	0.038
Cod in aspic	3	0.017	0.021
Herring in oil, marinated	10	0.029	0.037
Smoked herring	5	0.043	0.051
Trout – fillets	3	0.020	0.024
Smoked trout	5	0.035	0.038
Salmon – salads	3	0.041	0.049
Smoked salmon	6	0.065	0.076
Products made from fish not of Baltic Sea origin			
Smoked roundnose grenadier	1	0.129	0.135
Smoked halibut	3	0.203	0.238
Smoked Norway haddock	1	0.192	0.233
Smoked salmon	3	0.115	0.127
Smoked horse mackerel	1	0.053	0.060
Norway haddock – carcass	1	0.494	0.518
Smoked Norway haddock	1	0.140	0.183
Smoked mackerel	1	0.417	0.419
Tuna in water	1	0.086	0.116

DISCUSSION

The results obtained were compared with the permissible levels of methylmercury set by different countries (Anon. 1989, Food Safety Regulation) and with acceptable limits of total mercury set in Poland (Anon, 2003 – Ministry of Health Regulation of January 13, 2003). Only some countries have set a maximum permissible level of methylmercury in fish.

The results obtained indicate that during the 1996-1998 period the methylmercury content in the Baltic fish species and products under consideration remained on a low level that was many times lower than the permissible level for both methylmercury and total mercury. These observations confirmed the fact that during this period significant amounts of this element were not introduced into the Baltic Sea. The methylmercury content in raw material and products made of Baltic fish was studied within the framework of this work only from 1996 to 1998. However, the Baltic Monitoring Program (Anon. 1981, 1990b, Protasowicki *et al*. 1993) has been ongoing since 1979, and it has provided many data on the total mercury levels in Baltic fish. Moreover, since 1995 the SFI Testing Laboratory has participated in a nation-wide program to monitor soil, vegetation, agricultural and food products which also includes determinations of the total mercury content in raw materials and products of Baltic Sea origin (Michna 1996a, 1997b, Bykowski *et al*. 1998, 1999, 2000, 2001, 2002). The results of all these studies indicate that raw materials and products of Baltic origin do not pose any threat to consumers in terms of total mercury or methylmercury content.

In comparison with the results from 1973 (Kuźma *et al.* 1973 – unpublished data; Table 7), those from 1996-1998 indicated that there was a clear decrease in the methylm-

Table 7. Methylmercury levels in selected species of Baltic fish in 1973 according to Kuźma *et al.* 1973 (unpublished data)

Fish species	Date of catch	Fishing ground	Methylmercury content [µg Hg/ g m.m sample]	Average value	Standard deviation	Minimum value	Maximum value
Herring	7.08.73	Gotland	0.04 0.04 0.13 0.09	0.075	0.0435	0.040	0.130
Herring	14.10.73	Władysła-wowskie	0.33 0.43 0.346 0.18 0.24 0.24 0.16	0.274	0.0966	0.160	0.430
Cod	29.08.73	Gdańsk Deep	0.22 0.11 0.10 0.15	0.145	0.0545	0.100	0.220
Cod	16.10.73	Ustecko-Łebskie	0.08 0.08 0.09 0.09 0.09 0.08 0.08 0.07	0.0825	0.00707	0.070	0.090
Flounder	05.09.73	Ustecko-Łebskie	0.23 0.17 0.41 0.20	0.253	0.108	0.170	0.410
Flounder	26.09.73	Kołobrzesko-Darłowskie	0.18 0.18 0.35 0.10	0.203	0.105	0.100	0.350
Flounder	17.10.73	Kołobrzesko-Darłowskie	0.08 0.13 0.15 0.10 0.08	0.108	0.031	0.080	0.150

ercury content of fish caught in the fishing grounds of the southern Baltic Sea. This comparison is particularly appropriate since the determination methods used in the two studies were based on the same principle and the samples were collected from fishing grounds in the southern Baltic Sea. The comparison of the current results with those obtained by Zimak and Ćwiertniewska (1976), who reported the following methylmercury levels – cod – 0.013-0.198, fresh herring – 0.010-0.030, frozen herring – 0.022-0.075, salt herring – 0.026-0.073 µg/g of wet fish meat weight, also indicates that levels of this element in Baltic fish are decreasing. Observations of declining levels of methylmercury and total mercury in fish from the southern Baltic fishing grounds are also reported by other authors. Protasowicki *et al.* (1993) reported that there had been a decrease in the total mercury content in the muscle tissue of Baltic fish from 1974 to 1988. This was related to the implementation of limits on the use of mercury. These authors also reported that Swedish researchers noted decreased mercury contents in coastal fish after a ban was imposed in Sweden on the use of mercury-based compounds in the paper industry and agriculture. The average mercury contents they reported were 0.026 µg Hg/g of herring wet weight in 1974 and 0.036 µg Hg/g of cod wet weight in 1978.

The report on the Codex Alimentarius Commission meeting in Bergen (Anon.1994) states that over a 20-year monitoring period the mercury content in flounder decreased. In 1975-1981 the average mercury content was 0.380 µg Hg/g of wet weight, while from 1982 the average value was around 0.230 and then fell to 0.060 by 1990.

The Helcom report from 1996 (Anon.1996b), showed that the mercury content in cod from the central Baltic Sea ranged from 0.020- 0.040 µg Hg/g of wet weight, in herring from the same area – 0.010-0.040 and in flounder – 0.150-0.200. The report from 2002 (Anon. 2002) states that the mercury content in the muscle tissue of Swedish coastal herring ranged from 0.016-0.083 µg Hg/g of wet weight in 1980-1990. The average mercury content in cod and herring muscle tissue determined in 1998 did not exceed 0.010-0.050 µg Hg/g of sample wet weight; this was proposed as the reference range for fresh fish from clean areas. The average values of mercury content derived during the current study from the muscle tissue of sprat, cod, flounder and eelpout do not exceed this range.

All of the results cited in this paper refer to total mercury, which is widely and systematically determined in many laboratories. This is not the case with methylmercury, which has been determined in fish very seldom in Poland (Zimak and Ćwiertniewska 1976). The data in the literature on Baltic fish generally refer to the total mercury content. Even so, they are worth citing in this paper since the data and laboratory results obtained by the authors confirmed that 73-92% of total mercury occurs in the form of methylmercury, depending on the mechanism of bioaccumulation (Anon. 1998).

The content of total mercury and methylmercury was also determined in several samples of fish from outside of the Baltic region. These results illustrate that total mercury and methylmercury content are several times higher in fish products not of Baltic Sea origin than in those made of Baltic fish. In some cases, e.g. Norway haddock, mackerel and halibut, the values determined were close or even slightly higher than the maximum permissible level of 0.5 µg Hg/g of sample wet weight recommended by the joint body of the FAO/WHO. In future, the monitoring of fish available on the Polish market should be planned so as to include more detailed studies particularly of imported fish.

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Sex ratio of herring and sprat from the southern Baltic basins in 1980-2000

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Abstract. The sex ratio of spring-spawning herring and sprat in the southern Baltic were analyzed. The study material was collected in the pre-spawning and early spawning seasons from 1980-2000 primarily from research catches in the Polish Exclusive Economic Zone. A clearer numerical share of females was noted among sprat than among herring with regard to the natural ageing of the fish and increasing length. In most of these instances, the correlation was statistically significant. The increase of the share of females in length classes was marked – in herring above 21.5 cm and in sprat above 12.0 cm; all the females from these length classes spawned. The numerical prevalence of males over females was noted primarily among the smallest length classes. The average numerical share of herring females in the 1990s did not exhibit a significant change from that in the 1980s; however, the share of sprat females increased both in the Bornholm Basin from 48.4 to 54.4% and in the Gdańsk Basin from 50.3 to 52.6%. In comparison with herring, the differences in the sex ratio of sprat from the Bornholm and Gdańsk basins were clear.

Key words: herring, sprat, sex ratio, length distribution, southern Baltic basins

INTRODUCTION

In publications from the past fifty years, the prevailing opinion is that the numerical share of males and females in samples of exploited fish stocks, including Baltic herring, were temporally and geographically differentiated (Woźniak 1956, Strzyżewska 1969, Parmanne 1990, Feldman *et al.* 2000, Kaljuste and Raid 2002). D'Angelo and Bowen (1985) reported analogous data for lake herring (*Coregonus artedii* LeSueur) from Lake Superior, by Lozys (1999) for perch from the Curonian Lagoon and by Stankus (2002) for turbot from the Lithuanian coastal zone.

During the years preceding the systematic estimation of stock resources of the main Baltic fish species by the working groups of the ICES, the determination of sex ratio and sexual maturity were elements in the wider study of the biology of these species and did not have utilitarian significance. Data on the sex ratios and sexual maturity of the stock of a given species has a decided impact on establishing the optimum level of the fishing mortality coefficient and the age at first capture and, when supplemented with data on female fecundity, they become a measure of the potential reproductive capability of a given stock (Berner and Vaske 1981).

In 2000-2001, the Sea Fisheries Institute in Gdynia undertook a study of the sexual maturity and sex ratio of Baltic clupeoids based on historical and contemporary materials. This work was conducted under the auspices of international scientific cooperation coordinated by the ICES (Baltic Fisheries Assessment Working Group, Study Group on Baltic Herring and Sprat Maturity).

The aim of this work was to analyze temporal (1980-2000) and geographic changes in the sex ratio in age groups and length classes of spring-spawning herring and sprat inhabiting the southern Baltic Sea.

MATERIALS AND METHODS

From 1980 to 2000, study material of Baltic spring-spawning herring was collected from January to April and of sprat from February to May (during the pre-spawning and early spawning seasons) in the Polish EEZ (Fig. 1). The majority of the material was collected during research surveys using a P20/25 bottom herring trawl fit with a fine mesh (6 mm mesh bar length) insert in the codend. A lack of data from some years was compensated for with material from Polish commercial catches, which were not sorted according to fish size group. The samples of herring from the Bornholm Basin collected between 1985-1989 originated mostly from commercial catches, which explains why the share of young individuals (< 16 cm length) is insignificant in comparison with the samples from the Gdansk Basin. In turn, the sprat samples from the Bornholm Basin collected in 1994 are incomplete due to the lack of fish from age group 1, samples from 1984-1985 are not

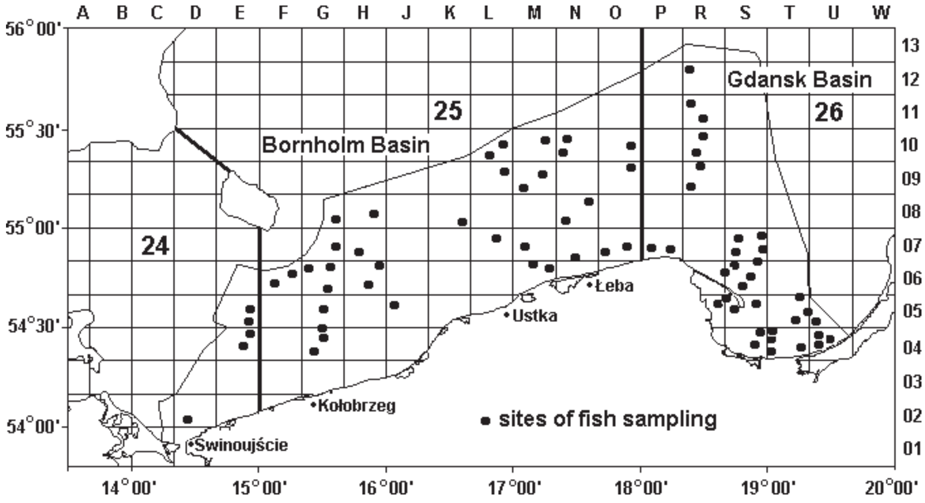

Fig. 1. Geographical distribution of herring and sprat sampling in the southern Baltic (within the Polish EEZ) in 1980-2000; 24, 25 and 26 – ICES Sub-divisions.

numerous, and in 1987 and 1999 the fraction of young fish (< 9.5 cm length) was relatively small.

Measurements of total length were taken on 33999 and 69268 herring sampled in the Bornholm Basin and the Gdańsk Basin, respectively in the period 1980-2000. Total length was measured also for 28358 and 31998 sprat caught in the Bornholm Basin and the Gdańsk Basin, respectively. During these measurements the fish were grouped into 0.5-cm length classes. The age, sex and stage of the gonads were determined in 4939 and 9090 herring from the Bornholm Basin and the Gdańsk Basin, respectively. The very same type of analyses was made for 5565 and 5682 sprat from Bornholm and Gdańsk basins, respectively.

The age of the fish was determined on the basis of the microscopic examination results of the morphological structure of otoliths. The range of age groups determined by the analyses was:

- male herring 1-10, sprat 1-9;
- female herring 1-12, sprat 1-11.

The length and age distributions of these species, separately for males and females, was determined based on a fish "length-age key" which was prepared annually for each basin.

In order to choose the aggregation level of the study results regarding the sex ratio of herring and sprat in relation to groups of years, as was done in analyses of sexual maturity (Grygiel and Wyszyński 2003), two factors were accepted for the first criterion – stock size (biomass and abundance) and the mean weight at age groups. The three following year groups for herring were determined:

1) 1980-1984 – with high values of mean weight at age and a higher than average long-term (1980-2001) stock biomass;

2) 1985-1989 – with average value of these two variables;

3) 1993-1999 – with low value of these two variables.

The five following groups of years were determined for sprat:

1) 1980-1981 – with high values of mean weight at age and a very low value of stock biomass and abundance;

2) 1991-1992 – with high values of mean weight at age and a stock biomass comparable with the 1980-2001 long-term average;

3) 1996-1997 – with low values of mean weight at age and a very high value of stock biomass;

4) 1980-1990 – with spawning stock biomass and abundance lower than the average long-term value;

5) 1991-2000 – with spawning stock biomass and abundance higher than the long-term average.

The second criterion for the aggregation of the collected material and study results was the geographical location of the two main southern Baltic basins – the Bornholm Basin (ICES Sub-divisions 24 and 25) and the Gdańsk Basin (ICES Sub-division 26).

RESULTS

Changes in the sex ratio in year groups

The mean numerical share of herring females during almost whole study period was quite similar in the Bornholm and Gdańsk basins at 52.7 and 50.7%, respectively, with 51.3% noted for the entire study area of the southern Baltic.

Slightly clearer differences in the herring sex ratio occurred among the various year groups, especially in the Bornholm Basin. The average numerical share of herring females in samples from mentioned basin in subsequent years 1980-2000 ranged from 45.6 to 58.1% (Table 1). The highest numerical share of herring females in comparison with males was noted in 1985-1989; the average value for the Bornholm Basin was 55.0% and for the Gdansk Basin - 52.5% (Fig. 2). In these years, the mean weight at age groups and the stock biomass of herring from the southern Baltic were equal to the long-term average (1980-2001). In 1993-1999, the share of females decreased to 49.9% in the Bornholm Basin and 49.8% in the Gdańsk Basin. The mean weight at age groups and the stock biomass of herring decreased significantly to a level which was below the average long-term (1980-2001).

Table 1. Annual (1980-2000) changes of the mean numerical share (in %) of herring and sprat females in samples from the Bornholm Basin

Year	Herring	Sprat
1980	58.1	44.1
1981	50.4	58.6
1982	50.6	43.5
1983	52.9	49.4
1984	48.6	36.3
1985	55.5	51.0
1986	53.4	43.0
1987	54.5	52.1
1988	53.0	49.8
1989	54.9	49.7
1990	50.3	48.9
1991	56.0	68.4
1992	56.9	49.9
1993	52.5	50.6
1994	50.0	32.4
1995	54.5	54.4
1996	49.2	58.2
1997	45.6	59.4
1998	54.0	60.9
1999	50.9	28.4
2000	53.1	53.8
Average	53.2	50.0

Differences in the sex ratio of sprat between the eastern and western regions of the southern Baltic and the groups of years (1980-2000) were clearer than for herring (Fig. 2). The highest percentage of sprat females was noted in the Bornholm Basin in 1991-1992 at 62.2%, while the lowest percentage of them was noted in the Gdansk Basin at 43.4%. The average percentages of sprat females throughout the 21 years of the study in the two basins were nearly the same – 51.7 and 51.6%, respectively. In turn, the numerical share of females in samples from the Bornholm Basin ranged in particular years from 28.4 to 68.4% (Table 1).

It should be emphasized that the average share of sprat female increased in the 1990s in comparison to the 1980s from 48.4 to 54.4% in the Bornholm Basin and from 50.3 to 52.6% in the Gdańsk Basin. The biomass and abundance of the Baltic sprat spawning stock was lower in the 1980s and higher in the 1990s than the long-term average. The comparison of the data above indicates that in the 1980-2000 period the sex ratio of herring from the southern Baltic was more stable than that of sprat.

Sex ratio in age groups

There was a slight increase in the share of spring-spawning herring females from age 1 to 9 in the 1980-2000 period, especially in the Gdańsk Basin (Fig. 3).

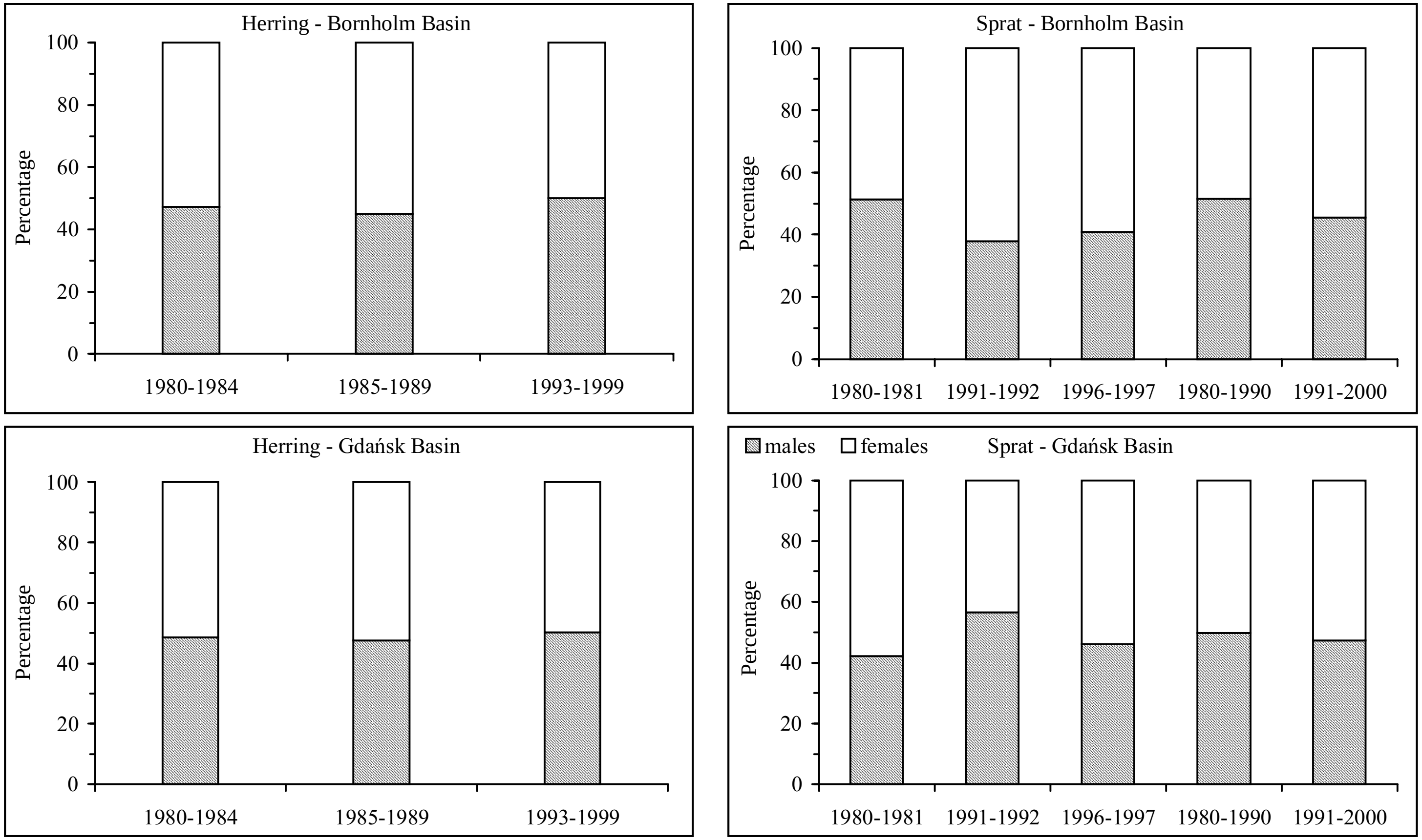

Fig. 2. Average sex ratio of herring and sprat in year groups from the 1980-2000 period in the Gdańsk and Bornholm basins.

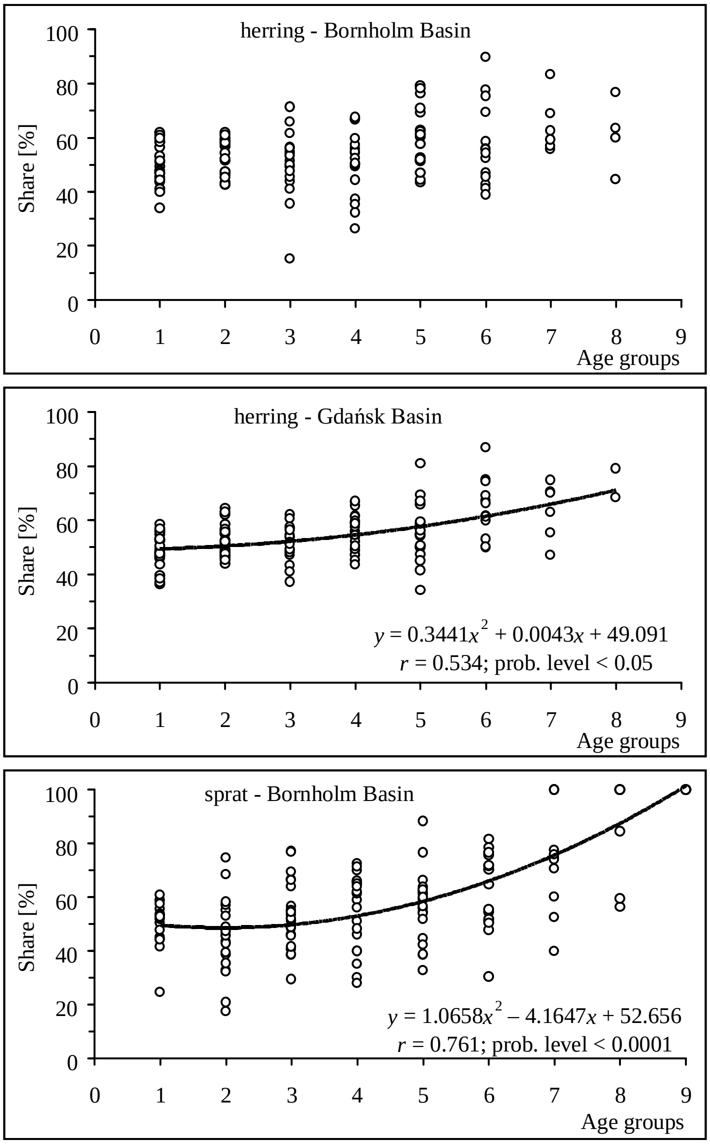

Fig. 3. Fluctuation of the herring and sprat female annual numerical share at age groups in the 1980-2000 period and regression analysis results (line plotted according to the best-fitted equation of the second order multinomial model applied).

The results of regression analysis between the average numerical share of herring females and age indicate that this correlation in the Bornholm Basin was statistically insignificant, while in the Gdańsk Basin it was at the margin of statistical significance. The model chosen, best fitted after applying the function of the second order multinomial, explained 29% of the variation of the dependant variable (correlation coefficient r was 0.53; Fig. 3).

In the Bornholm Basin, the increase in the numerical share of herring females was noted in the age groups from 1 to 5, i.e., in the 1980-1984 period the ratio ranged from 50.7 to 56.9%, and in the 1993-1999 period – from 48.2 to 64.5% (Table 2). The highest average share of herring females was noted in the 1985-1989 period and the lowest in the 1993-1999 period.

Table 2. Average numerical share (in %) of herring and sprat females in samples at age groups, in year groups (1980-2000) and southern Baltic basins

Herring

Age groups	Bornholm Basin			Gdańsk Basin		
	year groups			year groups		
	1980-1984	1985-1989	1993-1999	1980-1984	1985-1989	1993-1999
1	50.7	48.5	48.2	50.0	45.9	45.1
2	54.3	58.0	48.7	50.0	56.1	52.4
3	53.1	53.3	48.7	52.8	50.2	52.2
4	55.8	50.5	49.0	61.1	56.9	49.7
5	56.9	64.4	64.5	58.0	53.1	58.8
6	48.2	52.6	49.5	41.1	59.2	55.2
7	46.2	57.4	61.2	63.9	81.0	68.8
8	–	61.6	66.7	–	60.0	59.1
9	–	–	60.0	–	–	73.3
Average	52.8	55.0	50.0	51.5	52.4	49.7

Sprat – Bornholm Basin

Age groups	year groups					
	1980-1981	1991-1992	1996-1997	1980-1990	1991-2000	1980-2000
1	41.5	52.3	50.3	50.8	53.5	52.4
2	48.4	59.1	51.6	46.4	47.3	47.0
3	43.1	64.7	56.2	49.8	56.6	54.1
4	63.9	65.5	70.0	45.2	57.0	50.9
5	49.9	58.0	66.3	49.8	56.7	52.8
6	37.8	65.1	77.4	48.1	64.0	53.3
7	38.4	51.3	76.9	60.2	62.6	61.1
8	–	65.1	86.5	48.3	74.2	62.2
9	–	–	–	–	–	–
Average	48.6	62.1	59.1	48.4	54.4	51.7

Sprat – Gdańsk Basin

Age groups	year groups					
	1980-1981	1991-1992	1996-1997	1980-1990	1991-2000	1980-2000
1	56.1	50.9	57.6	49.2	53.2	51.0
2	56.4	35.3	47.9	48.8	37.7	42.7
3	58.2	40.8	46.2	50.0	51.3	50.8
4	53.5	50.5	63.3	50.9	65.5	59.7
5	72.8	45.5	62.9	54.9	63.8	60.3
6	55.5	58.4	65.3	64.6	72.5	70.3
7	58.8	15.9	72.6	46.2	58.5	53.5
8	–	–	63.0	67.8	80.3	77.1
9	–	–	–	55.7	–	50.5
Average	58.5	43.4	54.0	50.3	52.6	51.6

The results of the study of changes in the sex ratio of sprat indicate that females had a numerical prevalence in practically all age groups in both of the studied Baltic basins (Table 2). The increase in the percentage of sprat females from age 1 to 9 in the Bornholm Basin was much clearer than for herring (Fig. 3).

The average numerical share of sprat females in particular age groups and the average for all age groups was lower in the 1980s than it was in the 1990s. The average values of the mentioned variable in age groups 1-9 in the Bornholm Basin in the respective decades were 48.4 and 54.4%, while in the Gdańsk Basin they were 50.3 and 52.6%. The average long-term (1980-2000) numerical share of sprat females in both of the analyzed Baltic basins was very similar – 51.7 and 51.6% (Table 2).

The results of regression analyses between the average numerical share of sprat females from the Bornholm Basin and their age indicate that this dependency was statistically significant. The model used, best fitted after applying the function of the second order multinomial, explains 58% of the variance of the dependent variable (coefficient $r = 0.76$; Fig. 3).

Sex ratio in length classes

There was an increase in the relative share of females in the larger length classes – in spring-spawning herring above 21.5 cm, and in sprat above 12.0 cm, sampled in the period 1980-2000 (Fig. 4). All of the females of both species from these length classes spawned. The numerical prevalence of males over females was noted primarily in the smallest length classes – 6.5-12.0 cm for herring and 5.5-7.0 cm for sprat.

In the 10-12 cm length classes a characteristic decrease in the percentage share of sprat females was noted. The majority of sprat in these length classes belonged to age group 2, in which virtually 100% of specimens spawned for the first time in their life cycles.

The increase in the numerical share of herring and sprat females with increasing length classes during the 1980-2000 period was statistically significant in both basins of the Baltic Sea. The model used in the regression analysis, best fitted after applying the function of the second order multinomial, explained 53-71% of the variance of the dependent variable for herring (coefficient r equaled from 0.73 to 0.85). For sprat, the applied model explained 77-88% of the variance of variable y (coefficient r equaled from 0.88 to 0.94; Fig. 4).

Length distribution by sex

The range of the total length of spring-spawning herring males and females in all of the samples collected from 1980 to 2000 was 6.5–31.5 cm and 6.5–34.5 cm, respectively. The shape of the multi-modal curve of the length distribution of herring males and females was similar in the majority of the year groups; the exception was in the 1985-1989 period in the Gdańsk Basin (Fig. 5).

The range of the total length of sprat males and females in all of the samples collected from 1980 to 2000 was 5.0–15.5 cm and 5.5–17.0 cm, respectively. The sprat length

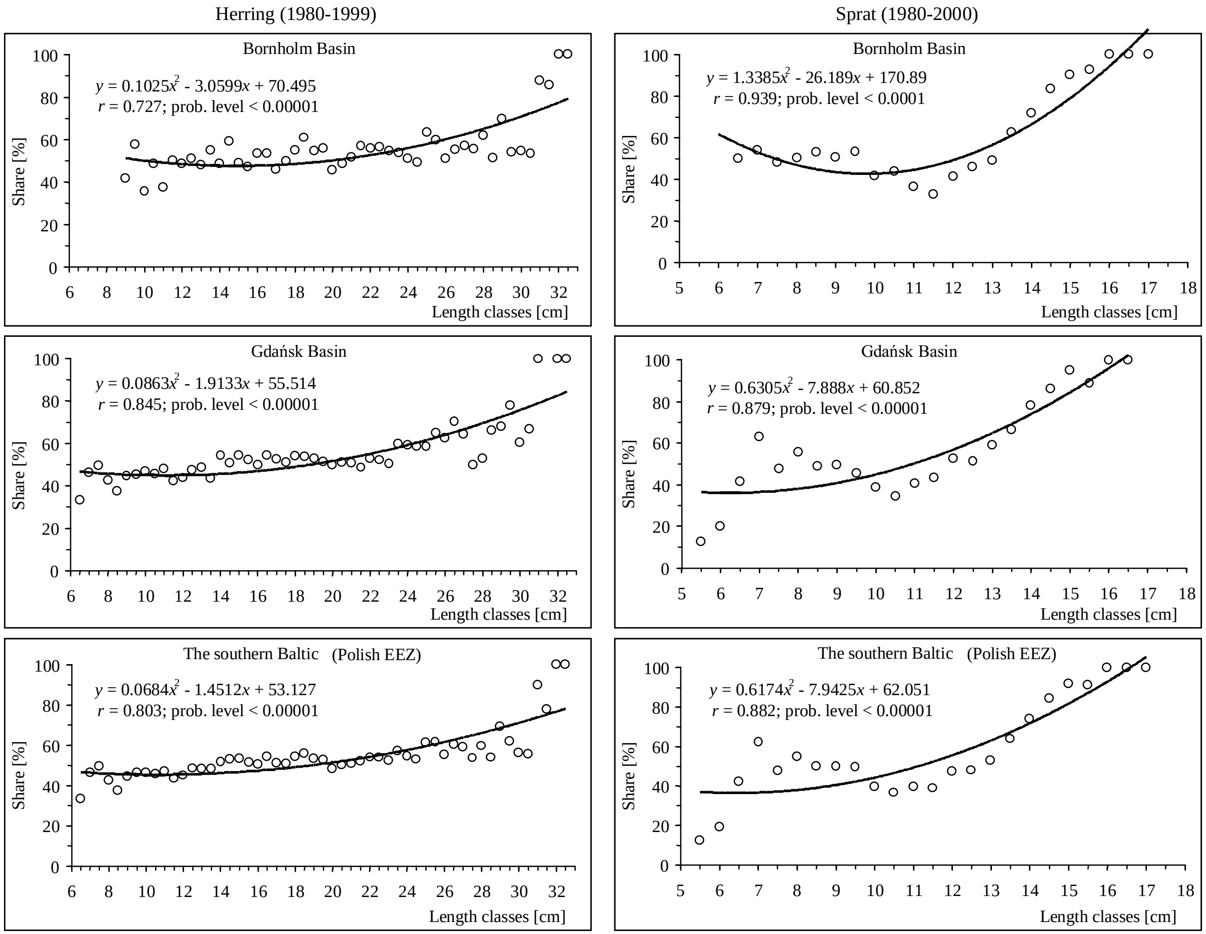

Fig. 4. Long-term (1980-2000) average numerical share of herring and sprat females in length classes (based on samples from the Bornholm and Gdańsk basins) and regression analysis results (best fitted according to the second order of the multinomial model applied) of the mentioned variables.

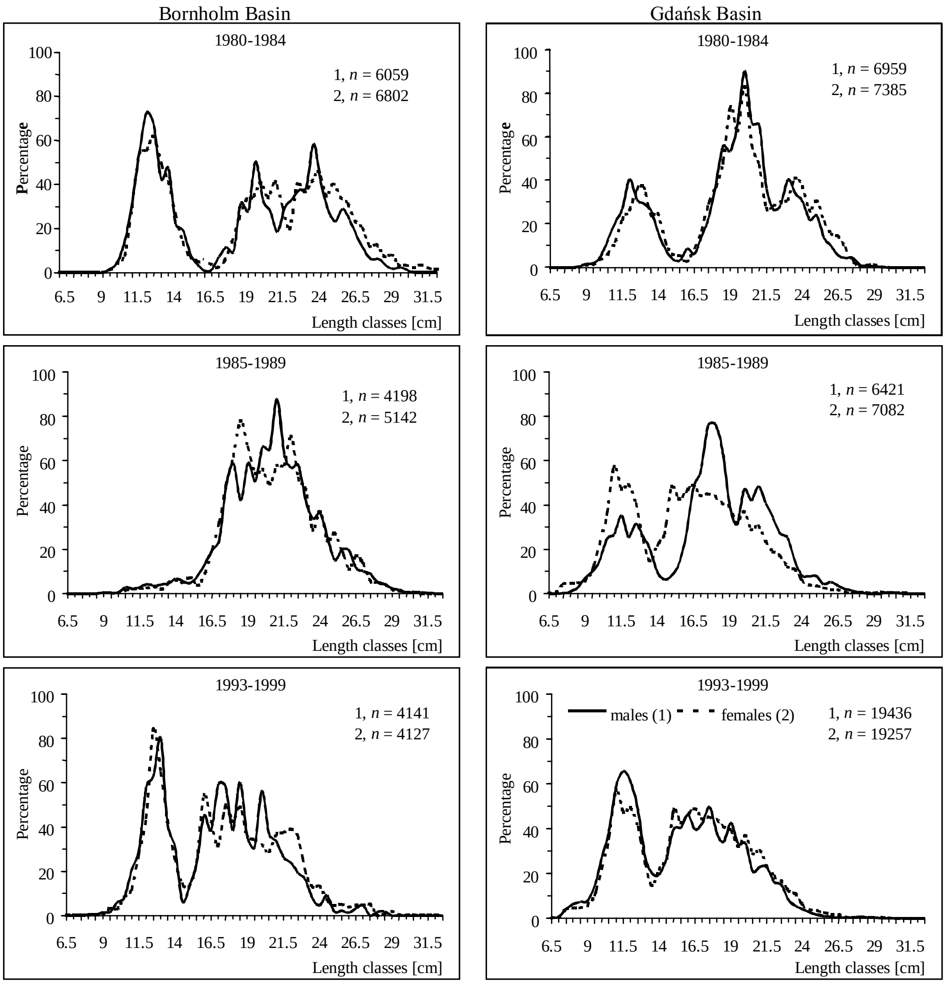

Fig. 5. Herring length distribution in year groups from 1980 to 1999 by sex and southern Baltic basins. Due to the very low numbers of females in length classes larger than 32 cm, these data were omitted.

distribution, dissimilarly to herring, was less complicated, with the exception of 1996-1997 (Bornholm Basin) and had two apexes (Fig. 6). Additionally, the apexes of these curves represented the dominating class. Females, in comparison with males were shifted by 1 cm towards the larger lengths. The modal length of both the males and females caught in the Gdańsk Basin was smaller by 1.0-1.5 cm in comparison with the sprat caught in the western part of the southern Baltic.

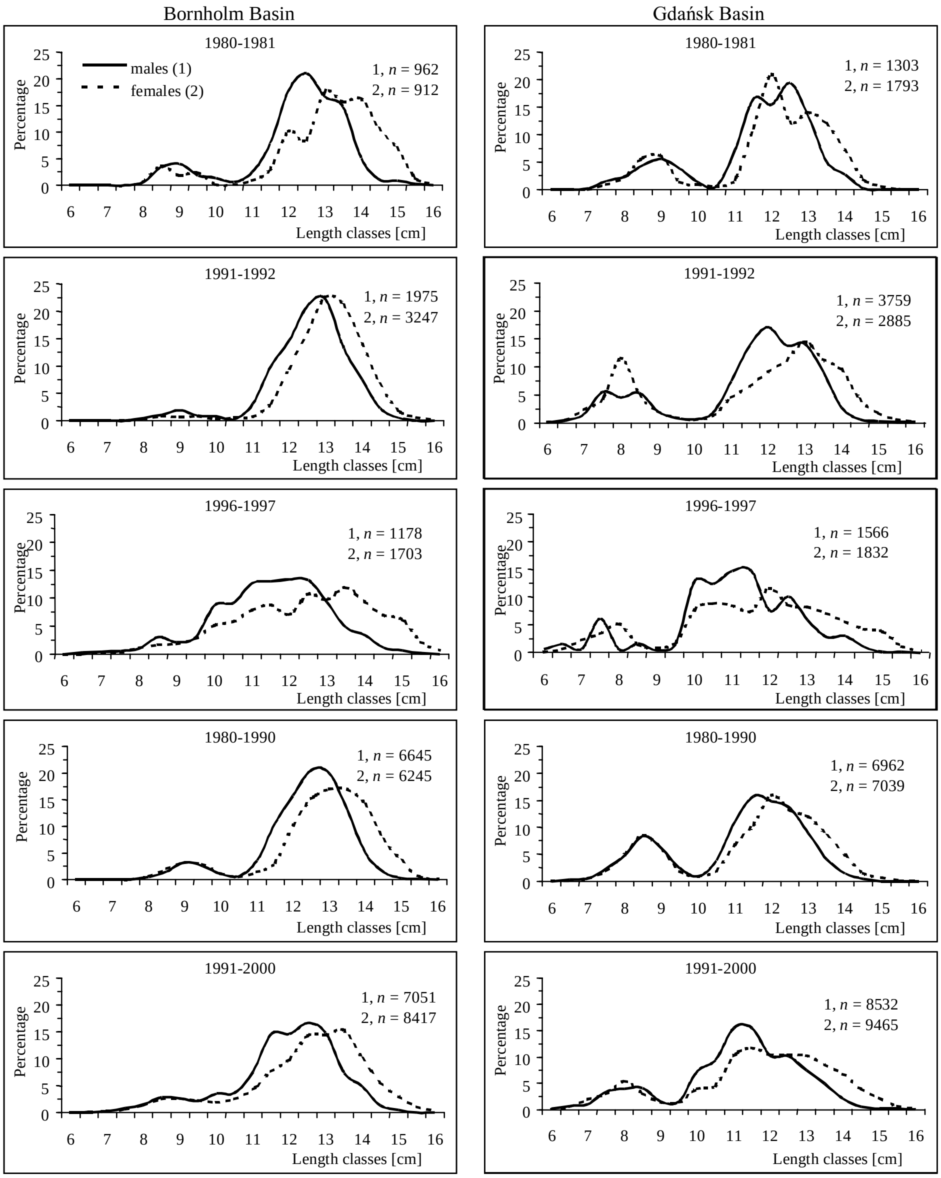

Fig. 6. Sprat length distribution in year groups from the 1980-2000 period by sex and southern Baltic basins. Due to the very low numbers of females in length classes larger than 16 cm, these data were omitted.

DISCUSSION

It is demonstrated that the sex ratio of herring and sprat from the southern Baltic underwent short- and long-term changes with respect to age group and length class as well as with regard to the regions inhabited by the stocks.

According to Strzyżewska (1969), the average numerical share of herring females in samples collected in the spring from 1961 to 1965 near Orłowo, Jastarnia and Rowy was 59.6, 50.0 and 48.5%, respectively. In turn, the numerical share of females in Finnish herring catches (1974-1988) conducted in various regions of the northern Baltic ranged from 45.9 to 56.1%, at an average of 50.4% throughout the studied region (Parmanne 1990). The average numerical share of sprat females during spawning (1985) also varied in ICES Sub-divisions 24, 25 and 26, decreasing from west to east in the southern Baltic from 65.8 to 53.3 and 40.2%, respectively (Grygiel 1987).

In the opinion of other authors, the sex ratio of sprat from the same regions of the Baltic undergoes temporal changes. According to Feldman *et al.* (2000), the numerical share of sprat females in samples from the southeastern Baltic in the first quarter of 1996-1999 was 57.6%, while in the second quarter it was clearly lower at 43.3%. In the 1980s and 1990s the percentage of female sprat in Estonian catches ranged from 41 to 56%, with an average of just above 50% (Kaljuste and Raid 2002). According to Woźniak (1956), the numerical share of sprat females in January 1954 in the Bornholm region was 73% and in March (beginning of spawning) the sex ratio was 1:1. In mid April the abundance of females in the spawning grounds fell dramatically and males dominated females 3:1. In the early 1950s the average numerical share of sprat females in the Bornholm region during spawning was 47%, while during the feeding (summer season) it was 64%.

The results of the authors' own investigations indicate that differences in the sprat sex ratio, in contrast to that of herring, between the Bornholm and Gdańsk basins, was clear in the groups of years analyzed. However, the long-term average (1980-2000) of the numerical share of sprat females in these basins was virtually identical (51.7 and 51.6%; Table 2). It should be emphasized that the average sex ratio of sprat from the Gdańsk and Bornholm basins, in year groups of the 1980-2000 period, seems to be "mirror images" (Fig. 2). One of the explanations of this fact is temporary fish migration between these two areas. The average share of sprat females in the authors' samples from the 1980s and 1990s was slightly higher (1.0-1.5%) than the data obtained by Woźniak (1956) in the Bornholm region, Feldman *et al.* (2000) in the southeastern Baltic or Kaljuste and Raid (2002) in the northeastern Baltic. The results of the numerical share of herring females obtained in the current study were similar to the data of Strzyżewska (1969) from the 1960s, but only with regard to some regions.

The results presented in this paper indicate that during the 1980-2000 period in the pre-spawning and the beginning of the herring and sprat spawning seasons in the southern Baltic there was a statistically significant increase in the numerical share of females with age, especially with regard to sprat, which corresponded to the natural ageing of the fish and increases in their length. Many authors also report that fish length and age are factors, which determine sex ratio (Birjukov 1980, Berner and Vaske 1981, Lozys 1999, Stankus 2002, Grygiel and Wyszyński 2003). Birjukov (1980) reported the following numerical shares of sprat females caught in the 1970s in the southeastern Baltic: age group 2-43%; age group 4-50%; age group 5-55%; age group 7-69%.

Data from the literature indicate that another factor which may also contribute to determining the sex ratio of fish is sexual maturity and the corresponding season of the year (Woźniak 1956, Feldman *et al.* 2000, Stankus 2002). Another such factor may be fish density during the maturation stage in a given region – when there was a higher population density in a given region males and females matured at a similar rate and the sex ratio was stable at a level of 50% (D'Angelo and Bowen 1985). Boehling and Lehtonen (1991) reported that the fishing gear type had an indirect impact on the length and age distribution as well as on the sex ratio of the fish caught.

In contrast to the generalities presented above, the publications of other authors indicate that the sex ratio of clupeoids was balanced according to temporal and geographic factors (Popiel 1955, Aneer 1975, Cristea *et al.* 1980, Hahtonen and Joensuu 1984).

One fundamental cause of differences in the numerical share of male and female fish in the youngest and oldest age groups is the varied developmental rate of the gonads of the two sexes. The males of most fish species mature more quickly for the first spawning in the life cycle (Popiel 1955, D'Angelo and Bowen 1985, Feldman *et al.* 2000, Grygiel and Wyszyński 2003). As a result of this, as Berner and Vaske (1981) explain in the case of western Baltic cod, males remain in intensively fished spawning grounds for a longer period of the year (approximately six months). Thus, they are characterized by a higher fishing mortality after attaining sexual maturity than are females and their share among older, larger fish is reduced. This generalization is indirectly confirmed by the results of studies on turbot in Lithuanian catches from 1998-2000, which indicate, among other things, that there is a larger range of age groups among females (1-16 years) than among males (1-11 year; Stankus 2002). The results of the authors' own studies also indicate that the range of age groups and total length classes of herring and sprat males from the southern Baltic in samples collected from 1980 to 2000 was smaller than that of females.

In comparison with sprat males, females from the southern Baltic in the 1985 spawning season were longer by an average of 0.3 cm and had higher weight by an average of 0.9 g, longer modal length by 0.5 cm and a wider range of length classes (Grygiel 1987). According to Elwertowski (1957), sprat females grow faster than males, and these differences increase with age. In turn, the statistical analyses conducted by Parmanne (1990) indicate that there is no significant difference in morphological characteristics between herring males and females (a lack of sexual dimorphism) from the northern Baltic.

The cause of differences in the length distribution of Danubian herring (*Alosa pontica*, Eichw.), according to Cristea *et al.* (1980), and of herring from the Gulf of Finland, according to Raid (1995) versus years and seasons, was varied migration intensity. The length distribution of herring from the Gulf of Finland did not change significantly during the pre- and post-spawning seasons in 1982, 1993 or 1994; this was due to the fact that these fish migrate little in these periods.

The results obtained by the authors indicate that length distribution of herring sampled in the period 1985-1989 differed from other year groups, especially in the Bornholm Basin (Fig. 5). Herring samples from the mentioned period were collected mostly from commercial catches (in other periods often from research surveys with different fishing gear) and this could also be an important factor in the determination of the high sex ratio observed during that period (Fig. 2, Table 2). In these years, the mean weight at age groups and the stock biomass of herring from the southern Baltic were equal to the long-term average (1980-2001; Grygiel and Wyszyński 2003). On the other hand, in the comparison with the years 1993-1999, when the mean weight at age groups and the stock biomass of herring decreased significantly to a level which was below the long-term average, the numerical share of females in samples decreased in both investigated basins (Table 2).

The length distribution and modal length of sprat from the Bornholm and Gdańsk basins were different in compared year groups (Fig. 6). One of the significant reasons that determine the mentioned differences is the varied growth rate of sprat in the two basins (Woźniak 1956, Grygiel 1977, 1987, Birjukov 1980).

The results of this and other studies indicate that the sex ratio of herring and sprat from the southern Baltic in the 1980-2000 period underwent short- and long-tem changes with regard to both the region of occurrence and the age and length of the fish. The range of age groups and length classes of herring and sprat females in relation to those of the males was higher in the 1980-2000 period. Females dominated numerically in the older age groups and the largest length classes. The males of the species studied mature for spawning more quickly than do the females in a given season, and their average length and age at fist sexual maturity is lower than it is for females (Grygiel and Wyszyński 2003). This is why in the spawning grounds clupeoid males are potentially available for fisheries exploitation earlier, and their life cycle is shorter than that of females.

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An estimation of stock dynamics of eastern Baltic cod using stock-production and difference models

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Abstract. In light of large inconsistencies in age reading of the eastern Baltic cod stock, production and difference models were tested and compared with results provided by age structured analysis (XSA). In one of the difference models cod cannibalism was simulated. The models were fitted under non-equilibrium conditions by minimizing the sum of squares of modeled and observed quantities. The survey results were used to estimate fishing effort (used in all models) and recruitment data (used explicitly in difference models). The bootstrap procedure was applied to estimate coefficients of variation of model parameters.

It is shown that both production and difference models produce cod dynamics estimates which exhibit similar trends of development as XSA. The CVs of some model parameters are high; however, they are especially so for the carrying capacity and maximum sustainable yield. All the models produced rather similar estimates of stock size in 2002, which ranged from 140 to 190 thousand tons (age 3 and older). Retrospective analysis indicated that there is a relatively consistent pattern of trends in biomass estimates.

Key words: cod, Baltic, production model, difference model

INTRODUCTION

Baltic cod fishery is supported by two stocks: the western stock (Sub-divisions 22-24, i.e. waters west of Bornholm) and the eastern stock (Sub-divisions 25-32, i.e. waters east of Bornholm). Generally, over the last five decades cod catches in the Baltic were first in value and second in volume (to herring). The total catches from the eastern stock were relatively stable from the 1950s until the late 1970s and ranged from 150 to 200 thousand tons. Following the recruitment of very strong year classes to the adult stock, catches increased significantly in the first half of the 1980s and exceeded 300 thousand tons. However, the eastern stock started to decline rapidly after 1985 as a result of intensive exploitation, which often exceeded 1 in terms of fishing mortality, and the lack of strong year classes. Consequently, the eastern stock has been considered by the International Council for the Exploration of the Sea (ICES) to be outside of safe biological limits since the late 1980s. The western stock has remained within save biological limits in most recent years.

In the 1990s the total allowable catch (TAC) set by the International Baltic Sea Fishery Commission (IBSFC) was restrictive, and this led to the underreporting of catches, which was especially high in 1992-1995. Although this phenomenon has been limited, it still occurs, and in 2000-2002 it was estimated at about 35% of officialy reported walues (ICES 2003). Exceeding the agreed TAC through unreported landings further contributed to poor state of the eastern stock, and its spawning biomass in 2003 is only about 15% of the high levels noted in the first half of the 1980s (ICES 2002).

The eastern stock needs to be rebuilt and a plan to do so was agreed upon by the IBSFC in 2001. However, for any plan to be successful all of the interested parties, i.e. managers, fishermen, scientists, must be convinced that it is reliable and realistic. Assessments of the eastern cod stock are problematic and often questioned. The stock is assessed by ICES using the XSA age-structured model (Shepherd 1999), in which catches are treated as exact. Thus, the XSA method needs correct estimates of total catches and consistent (among readers/countries) age determination in order to produce reliable estimates of stock size. Consistent age determination is another unsolved problem. It appears that there are two ways interpreting age – one generally supported by the former eastern countries and another applied by scientists from western states. Generally, the difference in aging is one year, even at younger ages (ICES 1999).

In consideration of the foregoing, it would be interesting to determine if assessment methods which are not based on the age structure of the catches/stock or are not treating catches as exact can produce useful estimates of stock dynamics. Stock-production models (Schafer 1954, Fox 1970, Pella and Tomlinson 1969) and difference models (Deriso 1980, Horbowy 1992, 1996) are such methods. They either do not require age structure or require it to a very limited extent, and under some conditions they can estimate bias (underreporting) in the catches.

The goal of the present paper is to test if stock-production and difference models can be applied to reliably estimate the stock dynamics of eastern Baltic cod.

THE MODELS AND DATA

Of the classical production models, the following were tested:

Schaefer model (1954)

$$dB/dt = rB(B_\infty - B) - qfB \ ,$$

Fox model (1970)

$$dB/dt = rB(\ln B_\infty - \ln B) - qfB \ , \qquad [2]$$

Pella and Tomlinson model (1969)

$$dB/dt = rB(B_\infty^{n-1} - B^{n-1}) - qfB \ , \qquad [3]$$

where B denotes biomass, t – time, q – catchability, f – fishing effort, and B_∞, r; n are parameters. B_∞ is interpreted as carrying capacity, i.e. the maximum biomass supported by the environment, r is the intristic growth rate (which indicates the biomass increase rate supposing environmental resources were unlimited) and n is the shape parameter. The models were applied in the form restructured by Fletcher (1978), in which MSY (maximum sustainable yield) is a parameter of the model.

The difference model of Horbowy (1992) was also tested. In this model, biomass in a given year is equal to that of recruits, *R*, plus the biomass from the previous year multiplied by the term which is a function of growth parameters and mortality

$$B(t+1) = \exp(vhw^{-1/3} - qf - M - k) * B(t) + R(t+1) \quad [4]$$

where *w* denotes the average weight in the stock, *v, h, k* – growth parameters (*v* – fraction of eaten food assimilated for growth, *h* – anabolism coefficient, *k* – catabolism coefficient).

In one of the Horbowy (1992) difference model options, cod cannibalism was simulated and the stock was divided into two components – young cod suffering from predation mortality (cannibalism) and adult fish. Predation mortality *M*2 was simulated with the following formula (Horbowy 1996):

$$M2 = h_P w_P^{-1/3} \frac{G_P B_P}{G_P B_P + OT}$$

where G_p is the suitability of young cod as food for the adult part of the stock, *OT* is "other" food, and *P* denotes the adult part of the stock (age 3+). Total natural mortality was the sum of predation mortality and residual natural mortality, usually denoted by *M*1.

The models were applied to simulate the dynamics of the eastern cod stock in 1982-2002. As fishing mortality affects mainly adult ages, the biomass at age 3 and older (3+) was modeled. In the difference model, which included cannibalism, the young fish component consisted of fish at age 1-2 and the adult component was age 3+ fish. The fishing effort was approximated as the ratio of cod catches to the index of stock size available from an international bottom trawl survey. Compiled survey results were taken from ICES (2002). The index of recruitment, which is an explicit part of the difference model, was also obtained from the same survey. The index was estimated as the geometrical average of the survey CPUE of a given year class at age 2 and 3. Finally, in model $R(t) = a*R_{index}$, where *a* is the parameter to be estimated. Difference models based on recruitment and fishing mortality estimates from XSA, which are believed to provide good quality estimates of both recruitment and fishing effort, were also fitted for the purpose of comparison.

Some of the difference model parameters could be taken from the literature or estimated outside of the model; these were the growth parameters, natural mortality and mean weight in the stock. Natural mortality was assumed to be 0.2 (ICES 2002), and the same value was used for residual natural mortality. The mean weight in the stock was estimated as the average of the weight-at-age weighted by the stock in numbers. Growth parameters were estimated from the average (1982-2001) weight-at-age data (ICES 2002). The h value was derived as the average of ratios at age of food ration to weight$^{2/3}$ (Andersen and Ursin 1977). The cod food ration was taken from ICES (2001). This reduced the number of parameters to be fitted within the model.

The other parameters of the models (e.g. catchability, initial biomass, MSY, carrying capacity, suitability of young cod as food for adult cod) were estimated under the assumption of non-equilibrium conditions by minimizing the sum of squared differences between observed and modeled landings and, in the option which includes cannibalism, the share of young cod in adult cod stomachs. In addition, a term showing deviations of the estimated initial biomass from the "observed" value was added to the minimized sum of squares in order to stabilize and produce realistic solutions. The general form of the minimized sum of squares was

$$SS(B0, \mathrm{MSY}, B_{\infty}, G, q, a) = \Sigma\,(\ln Y_t - \underline{Y_t})^2 + (\ln B0 - \ln \underline{B0})^2 + \\ + \lambda\,\Sigma\,[\ln(\mathrm{food\_comp.}) - \ln(\underline{\mathrm{food\_comp.}})]^2 \qquad [5]$$

where λ is the weighting factor taken as the ratio of catch variance along the fitted model to food composition variance, while the underlined parameters are modeled values and the others are observations. The food composition data were taken from ICES (2001).

The consistence of the model results was verified by retrospective analysis (Sinclair *et al*. 1991). This analysis entails first fitting the models with full data series, then, in each of the retrospective runs, the models are re-fitted with a data series which is one year shorter than the previous run. The standard errors of the parameter estimates were obtained with the bootstrap procedure (Efron 1982).

RESULTS

The recruitment and fishing effort used in the models are presented in Figure 1. The XSA (ICES 2002) estimates of fishing mortality and recruitment are presented for comparison.

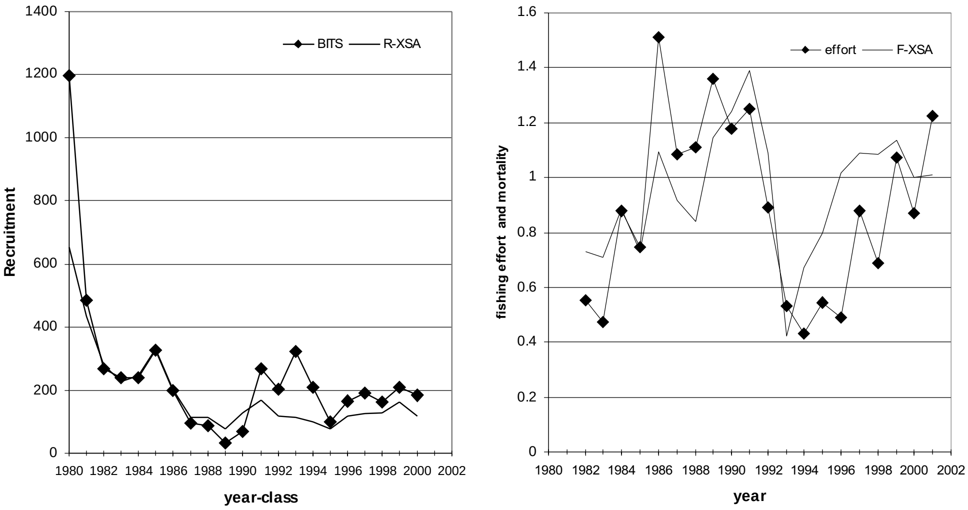

Fig. 1. Recruitment (milions) and fishing effort based on BITS compared with recruitment and fishing mortality *F* estimates from XSA (ICES 2002) (BITS – Baltic International Trawls Survey).

The correspondence between the values used for fitting the models and their XSA equivalents is relatively good, at least in terms of trends. However, some larger deviations also occur. The survey estimate of the strength of year class 1980 and of year classes from the first half of the 1990s are quite different from the XSA estimates. Smaller deviations are observed for data from the end of the 1990s. The fishing effort (estimated as the ratio of catches and index of survey biomass) and the XSA estimate of fishing mortality differ markedly in the mid 1990s and for selected years in the 1980s. If one assumes that XSA estimates of recruitment and fishing mortality are more reliable than the estimates of year-class strength and fishing effort used in the models, then the discrepancies mentioned may have some effect on the estimation of stock dynamics in the production and difference models. The von Bertallanffy parameters were estimated at 0.55, $1.92*kg^{1/3}*year^{-1}$, $0.51*year^{-1}$ respectively for *v, h,* and *k.*

The parameters of the fitted models with their CVs (coeficient of variation) are presented in Table 1. The model estimate of biomass in 2002 and its CV are also presented in this table. Two options for CV estimates are provided: one is based on all the bootstrap estimates of the model parameters and one (labeled with an asterisk) is based on estimates restricted to some values. In the later, some unrealistic estimates of parameters in the bootstrap runs, possibly resulting from solutions falling into local minima, are omitted. In some bootstrap simulations the MSY and B_∞ were estimated at levels of several thousand or even million tons, while some bootstrap estimates of q in the difference models could be at the level of a thousand. Thus, for the second option of CV estimation (further referred to as the restricted option), only estimates producing MSY < 1000 tons and $q < 10$ were used, and the limits of 1000 and 10 were arbitrarily selected.

The CVs of MSY and B_∞ in both the Shaefer (1954) and Pella and Tomlinson (1969) models were very high and reached 200-300% when all the bootstrap estimates of parameters are used for their derivation. Excluding some unrealistic bootstrap estimates of parameters from the CV calculations helped to decrease the CV of MSY and B_∞ to about 60% in the Schaefer model. However, in the Pella and Tomlinson model CV of B_∞ is still very high, as is that of n (about 200%). This shows that there is not enough information in the model to determine its curvature. In fact, the point estimate of *n* is 3.6 and its confidence limits contain values smaller than 2. The $n < 2$ reflects skew to a right relationship between productivity and biomass, this is in opposition to the relationship skew to the left which is reflected by $n > 2$. The CV estimates of other parameters and biomass in 2002 are moderate and range from 20 to 30%. The estimates of both MSY and B_∞ obtained within the Fox (1970) model are completely unrealistic. Consequently, the CVs of these parameters were not calculated.

With the difference models, the CVs of biomass (i.e. B_{1982}, $B_{2002)}$ are similar to those in production models. The one exception is the CV of biomass in 2002 for the difference model without cannibalism, where CV reaches 50%. The CVs of biomass in 2002 in both production and difference models are similar to that estimated from the age structured XSA, which is within the range of 30-45% (ICES 2003). The CVs of recruitment scaling factor and suitability are close to 40%.

The CVs of catchability mostly range from 0.2 to 0.6, which is slightly lower than those from XSA (ICES 2002). However, the catchability CVs are extremely high in the unrestricted option for the difference model with cannibalism.

Table 1. Estimates of the parameters of the models with their CVs (MSY and all biomasses in 000' tons). The estimates and CV of biomass in 2002 are also given.

	Model				
Parameter	Schaefer	Pella & Tomlinson	Fox	Horbowy no canibalism	Horbowy canibalism included
MSY	254	229	641	na	na
CV	3.14	1.94			
CV*	0.56	0.65			
B_{inf}	2,696	1,475	22895	na	na
CV	3.22	2.92			
CV*	0.66	4.31			
n	na	3.6	na	na	na
CV		2.02			
CV*		1.86			
q	0.47	0.50	0.48	0.74	1.06
CV	0.21	0.33		19.6	14.1
CV*	0.21	0.31		0.61	0.61
a	na	na	na	0.53	0.89
CV				0.46	0.38
CV*				0.42	0.36
G	na	na	na	na	0.68
CV					0.42
CV*					0.40
B_{1982}	1,004	989	1,014	596	591
CV	0.26	0.28		0.31	0.26
CV*	0.24	0.29		0.29	0.26
B_{2002}	148	140	154	188	143
CV	0.28	0.28		0.48	0.33
CV*	0.28	0.28		0.49	0.33

(na – not applicable)

*only estimates providing $m < 1000$ (in case of production models) and $q < 10$ (in case of difference models) have been used for CV estimation

The biomass (age 3+) and catch estimates from the models are presented in Figures 2a and b. For comparison, these figures also present the estimate of biomass from XSA (ICES 2002) and observed catches. In general, all the models show the same trend of stock biomass dynamics as the XSA. In classical production models the estimates of biomass are very similar, even if the basic parameters (MSY and B_∞) of the model are very different or unrealistic as in the Fox (1970) model (Table 1).

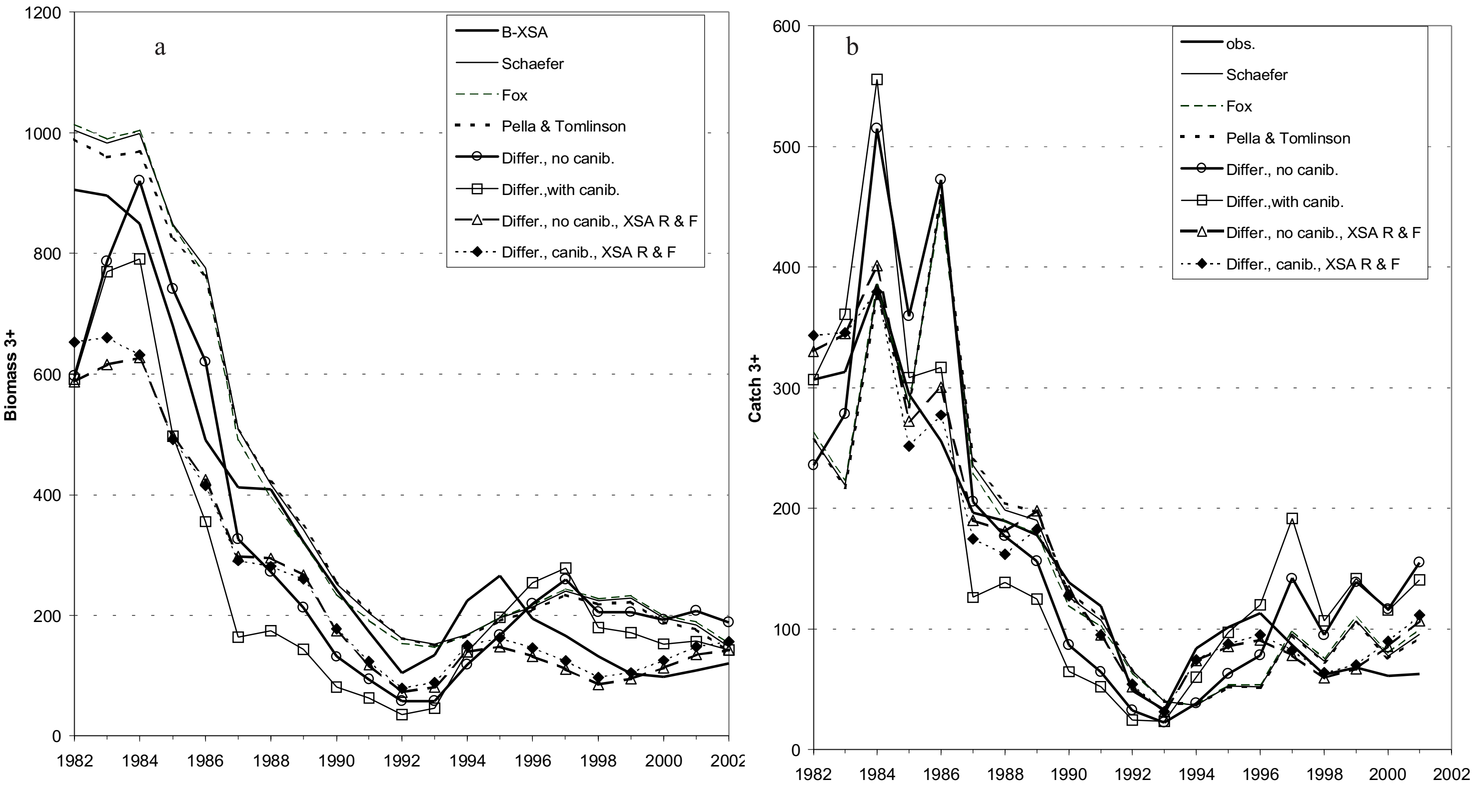

Fig. 2a, b. The biomass and catches (000' tons) of cod estimated by production and difference models. Difference models were fitted under two options: one includes and one excludes canibalism. For comparison, the XSA estimates of stock biomass (ICES 2002) and observed catches as well as difference models with recruitment and fishing mortality estimated with XSA are presented.

The large increase in biomass in 1983-84 in comparison to the 1982 level in the difference models is the result of a very high survey estimate for the 1980 year-class (Figure 1) which entered the adult biomass in 1983. The XSA estimate of recruitment did not confirm that the 1980 year-class was so strong. The estimates of stock size in the recent five years are much higher in the models considered in this paper than in the XSA. The reliability of the difference model estimates depends very much on the quality of fishing effort and recruitment data. The impact of this is smaller in production models which use fishing effort data only. The biomass from the difference models using XSA-based estimates of recruitment and fishing mortality (to represent fishing effort) are parallel to XSA biomass estimates for most of the years, except in the last three years (Figure 2a). The use of XSA-based recruitment and fishing effort did not provide marked improvement in the fit of the models.

The estimated catches for the last five years are higher than the catches used in the stock assessment, which may result from the underreporting of catches. In fact, in the ICES stock assessment conducted in 2003 underreporting was assumed to be at a level of 35% in 2000-2002 (ICES 2003).

Figure 3 shows examples of retrospective analysis plots for the Schaefer and difference models. The retrospective variance is lower for recent years than for those from the first half of the time series. A summary of the retrospective analyses is provided in Figure 4 as the CV of biomass estimates from retrospective runs at years. The average retrospective CV from all the years ranges from 13 to 20% The difference models show lower retrospective variance than do the production models until 1994. In the subsequent years the production models behave better, especially when compared with the difference model which includes the cannibalism option.

The fitted production models can estimate fishing mortality which produces MSY (Table 2). The estimates are 0.19, 0.25, and 0.08 for the Schaefer, Pella and Tomlinson and Fox models, respectively. The respective MSY values are 254, 229, and 641 thousand tons. The estimates of F_{MSY} and MSY from the Fox model are based on unrealistic estimates of the model parameters and are unreliable. The other estimates of F_{MSY} are not very different from $F_{0.1}$ of 0.16 derived from yield per recruit analysis and they are realistic. The difference models do not produce direct estimates of MSY, but these estimates can be approached by simulations which assume the long-term recruitment average. These simulations showed that MSY was at a level of 95-120 thousand tons, and F_{MSY} at one of 0.3-0.4. Higher MSY and fishing mortality were obtained with the option that includes cannibalism, while lower values were recorded for those which excluded it. The estimates of MSY obtained with the difference models are probably underestimated as exploitation with lower intensity would bring spawning stock biomass to a higher level and this higher level could produce higher recruitment. This mechanism was not simulated, however, in the MSY calculations. On the other hand, the MSY obtained from production models seems to be too high – catches exceeding 250 thousand tons were recorded only in the first half of the 1980s when the stock was supported by very abundant year classes. For comparison, the long-term average (1982-2001) catch at age 3 and older is 155 thousand tons; the average for the 1990s decreases to approximately 75 thousand tons.

The models allow for fishing mortality to be estimated by multiplying the estimated catchability by fishing effort. The 1982-2001 average of this estimate is 0.4 for production

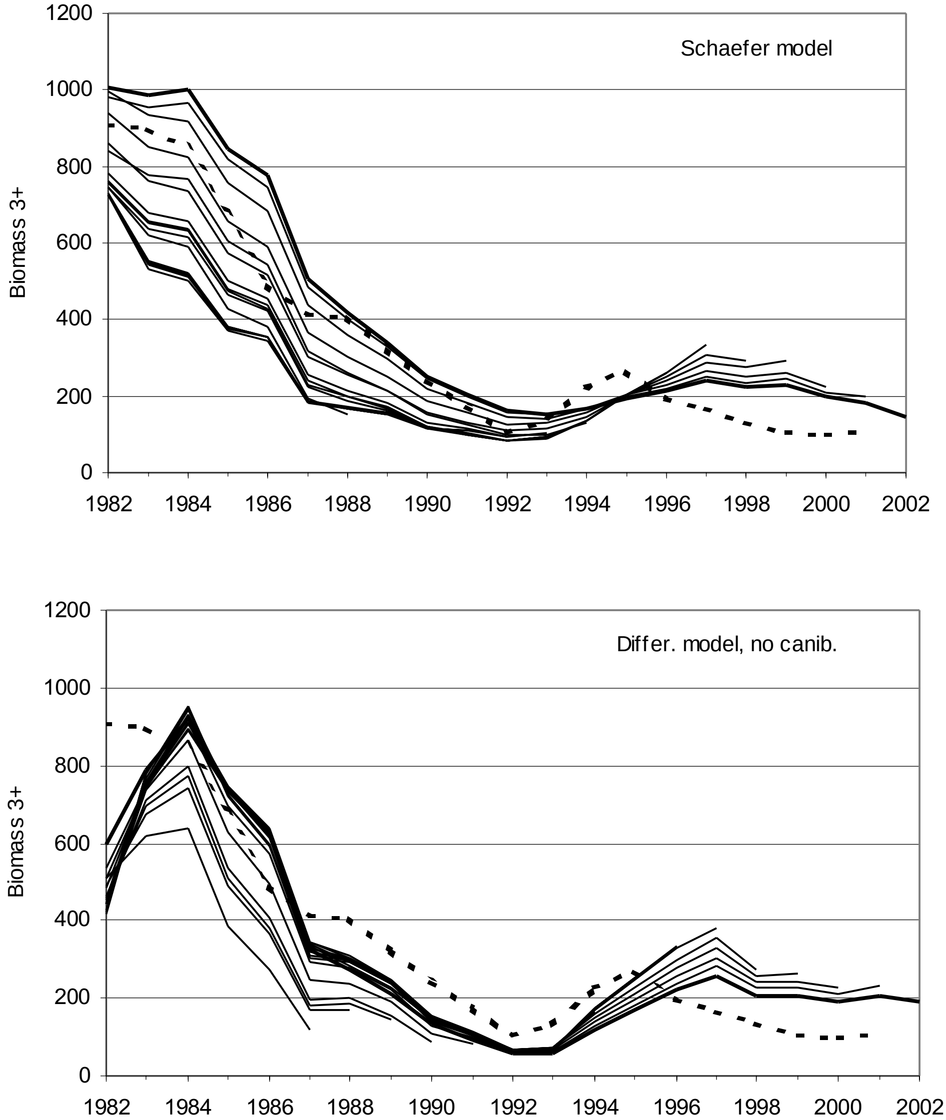

Fig. 3. Retrospective analysis of biomass (000' tons) for the Schaefer (1954) model and for the difference model (Horbowy 1992) excluding cannibalism. For comparison, the XSA estimate of biomass (ICES 2002) is plotted (broken line).

models and 0.66 and 0.94 for difference models which exclude and include cannibalism, respectively. The XSA average is 0.95, double the estimates derived from the production models, while the precautionary level assumed by ICES is 0.6 (ICES 2003).

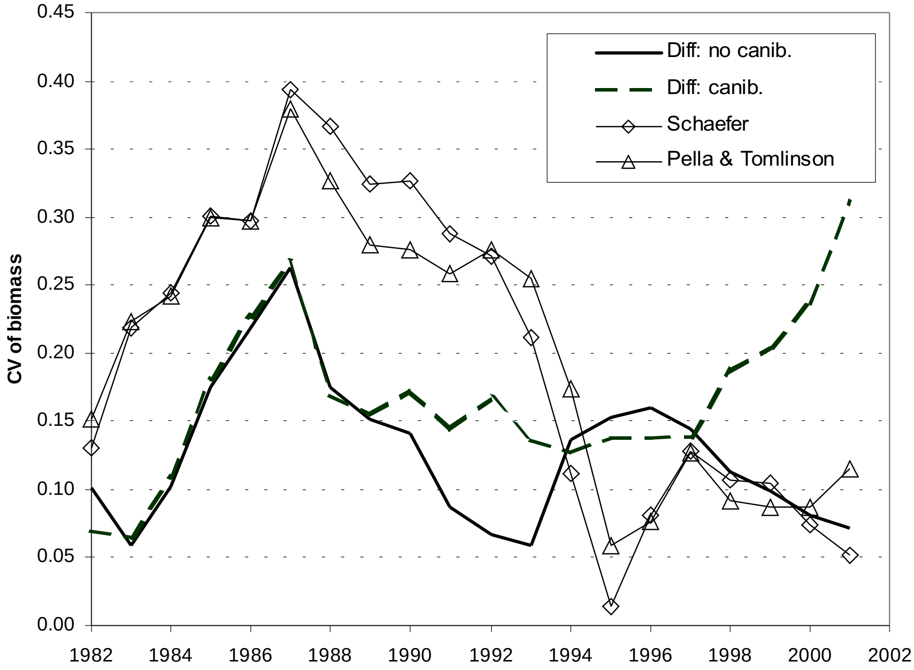

Fig. 4. Summary of retrospective analyses: coefficient of variation of biomass estimates at years from retrospective runs for Shaefer (1954), Pella and Tomlinson (1969) and difference models.

Table 2. Fishing mortality producing MSY and the MSY ('000 tons) estimated with the models

	Model				
Parameter	Schaefer	Pella & Tomlinson	Fox	Horbowy no canibalism	Horbowy cannibalism included
F-MSY	0.19	0.25	0.08	0.3	0.4
MSY	254	229	641	95	119

DISCUSSION

The assessment models applied in the paper do not take into account the mixing of the two Baltic cod stocks (e.g. Bagge *et. al.* 1994, Oeberst 2000). This mixing is observed in the Arcona and Bornholm Basins and may have an impact on the results. However, in the ICES assessment performed with XSA the mixing is also neglected, so the present and ICES approach are comparable in that sense. The historical estimates of the exchange rate between the two stocks would be necessary to include this phenomenon into the assessment models.

Both the models applied in the paper and the XSA referred to for comparison use the same data base with the exception that in the production and difference models the historical age structure is not needed. The use of similar data in the assessment models is consistent with the goal of the paper although it may help to get similar assessment results.

The availability of reliable fishing effort (production and difference models) and recruitment (difference models) indices is crucial for the reliable estimation of stock dynamics. This is especially important with the difference models considered in this paper as recruitment enters the models linearly. The quality of recruitment indices derived from surveys is not very good for the Baltic cod stock. Factors such as year, area, depth, quarter and age explain slightly more than 30% of the variation of survey CPUE (Horbowy *et al.* 2003). The R^2 between XSA and survey-based estimates of recruitment is below 0.6. The impact of data quality on model performance can be seen to some extent in the model fits. The survey-based model produced estimates of cod biomass that were more divergent from XSA values than the model in which recruitment and fishing mortality were taken from XSA.

The advantage of the applied difference models, in comparison to classical production models, is that the year-class abundance is an external variable, so the models can reflect changes in stock biomass caused by highly variable, possibly environmentally driven, recruitment. In production models changes due to recruitment, growth and natural mortality are lumped together and are dependent on current stock size only. Obviously, in these models, a sudden increase or decrease in recruitment cannot be reflected. This is apparent in simulations from the mid 1990s when an increase in stock size was observed followed by an increase in recruitment (Fig. 2). The difference models better reflected the stock dynamics of this period than did production models if XSA results are considered as a reference. The relatively good performance of the production models for Baltic cod in most of the simulated years results from rather low variation in year-class abundance in most of the studied period. Recruitment was high only at the beginning of the 1980s, following which it declined quickly and fluctuated moderately at low levels. So, marked changes in environmentally driven recruitment cannot be simulated in the production models. Although this may not be great problem for stocks with relatively stable recruitment, it may matter for stocks in which the process is highly variable.

The difference model which included cannibalism did not appear to be better in the performed simulations than that which excluded it. One of the reasons it lacked advantage may be recruitment estimates which come to the models from the survey as averages of ages 2 and 3. Predation by cod affects mainly very young fish, so at age 2 the year-class has already experienced the majority of cannibalism. The MSVPA estimates of predation mortality of young cod (ICES 2001) indicate that an average of about 65% of predation mortality occurs at age 0, about 30% at age 1 and only 5% at age 2. Good recruitment data at the beginning of age 1 or even at age 0 could be necessary to see possible improvement in the model due to the simulation of cannibalism.

The difference models presented here were developed in such a way that the demand for age-based data is constrained to the minimum. This feature of the models is very important in the case of Baltic cod stock since large inconsistencies in age reading exist (ICES 1999). The age data are needed mainly to estimate growth parameters. The length data can be used to estimate asymptotic length, but catabolism coefficient *k* must be estimated from the age data in most cases. Recruitment indices in both models were taken at a given age. With no aging, the strength of a year-class would have to be estimated based on the number of fish in a given size range, where this size range would approximately represent the recruiting age group. This may work well for populations with distinct size separations of young fish, but for other stocks such an approach may be imprecise.

The Deriso (1980) difference model was not applied here since in it growth is represented by the second part of the Brody growth equation which represents weight after it has passed the inflection point. With Baltic cod most of the observed weights at age refer to the acceleration phase of individual growth before the inflection point is reached. This happens due to intensive exploitation which allows only a few fish to pass the inflection point of growth in weight.

The retrospective pattern of the XSA assessment of cod (ICES 2002) is obviously better than that of the production models presented. However, this does not necessarily mean that the XSA produces more realistic estimates of stock dynamics. Convergence is an inherent feature of the XSA method provided that terminal fishing mortality is not too small (Pope 1972). The convergence, however, does not necessarily indicate a lack of bias, thus a worse retrospective pattern does not disqualify the production or difference models. Punt (1993) used Monte Carlo simulations to show that production models performed better than the ad hoc tuned VPA for cape hake of the west coast of South Africa. He stressed that his results may be species-dependent and should not be generalized.

It is difficult to draw firm conclusions on the utility of production and difference models for the assessment of the eastern Baltic cod stock as there is no firm reference assessment. However, the results presented in this paper indicated that these models can produce stock dynamics estimates which show biomass trends similar to those presently used by the ICES age-structured model of XSA.

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The growth rate and condition of asp *Aspius aspius* (L., 1758) from Międzyodrze waters

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Abstract. Juvenile specimens of asp (0 age group) were collected in 1996-2001 in canals of the Międzyodrze with fine-mesh fry seine. Adult specimens were collected from commercial catches in 1995-2003.

The length of fish at which scales began to appear (SL = 13.81 mm) was determined using the dependence between the number of sclerites on the caudal part of the scale and the standard length. A similar result of 13.41 mm was obtained in studies of the dependence between the scale radius and fry body length.

The average lengths in subsequent years of life were determined by reconstructing the growth rate of the studied fish using back-calculations from scales. The differences in the growth rate of females and males were statistically insignificant. The von Bertalanffy growth model was fitted to the data from the back calculations and the following values were obtained: L_∞ = 75.24 cm; k = 0.165; t_0 = 0.224 year; W_∞ = 7 463 g. The length-weight dependence can be described as $W = 0.0075\ L^{3.1964}$. The growth rate of asp from Międzyodrze waters is average in comparison with that of other populations of this species.

Key words: *Aspius aspius*, asp, growth rate, back-calculation, Oder River

INTRODUCTION

The asp is a large, predatory cyprinid species which occurs fairly abundantly in Poland predominantly in larger rivers, but also in the Szczecin and Vistula lagoons and some dam reservoirs and lakes (Zimdars 1941, Backiel 1964, Penczak 1969, 1996, Kozikowska 1970, 1984, Bieniarz and Epler 1972, Pęczalska 1973, Witkowski 1984, Fleituch 1986, Terlecki 1986, Martyniak and Heese 1994, Borowski and Dąbrowski 1996).

The asp also occurs commonly in the waters of the Międzyodrze (Figure 1), a deltaic-estuarine area in the downstream part of the Oder River above Lake Dąbie (Trzebiatowski 1999, Wolter *et al.* 1999). Since asp contributes only an average of 2% to the total catch made in the waters mentioned above, its commercial value is relatively low (Kompowski and Neja 1999, 2000). However, its ecological role as a predator is significant. It is also an attractive species for anglers. For the past 15 years Polish research on this species has been focused on obtaining spawners, artificial hatching, cultivating fry, stocking in open waters and introducing it into ponds as an additional stock (Jakucewicz *et al.* 1989, Wolnicki and Górny 1993, Kujawa *et al.* 1997, Kujawa *et al.* 1998a, b). Therefore,

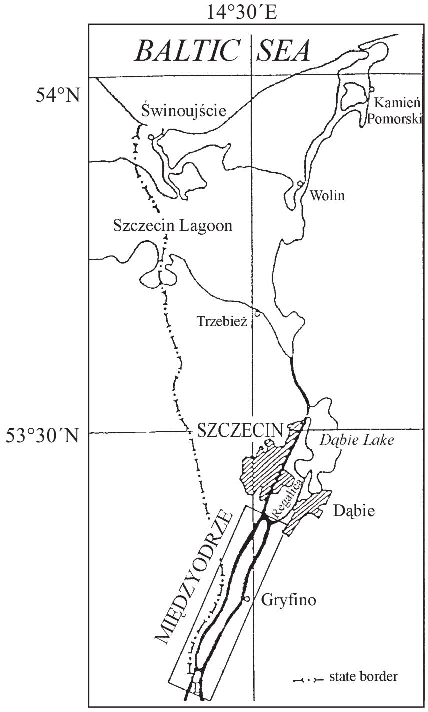

Fig. 1. Map showing location of Międzyodrze.

any information regarding the natural biology and ecology of this species is very valuable. To date, very few publications regarding asp in the western Pomerania region have been published. The works of Łukowski (1977) and Hryczyńska and Piasecki (2001) address asp parasites in Lake Dąbie and the Szczecin and Kamieński lagoons. Trzebiatowski and Leszczewicz (1976) focused on the asp growth rate and feeding patterns in the Szczecin Lagoon. All of these works describe asp which inhabits basins adjacent to and connected with the Międzyodrze. Only two publications to date have focused on the asp from Międzyodrze waters, namely those of Kompowski and Neja (2002a, b), both of which discuss the morphological characters of this species.

The aim of this work was to investigate the growth rate and condition of asp from Międzyodrze waters.

MATERIALS AND METHODS

Eighty-nine asp fry specimens in the standard length (SL) range of 23 to 83 mm were caught in Międzyodrze canals in 1996-2001 using a fine-mesh fry seine with a wingspan of 10 m, 10 mm wing mesh size and 5 mm codend mesh size. Immediately following capture, the fry were preserved in 4% formaldehyde solution. Fry length (SL) was measured to the nearest 1 mm under a binocular microscope. Scales were collected from directly above the lateral line, under the front edge of the dorsal fin and placed between two glass microscope slides which were then fastened with sticky tape. Scales were collected from a total of 85 juvenile asp specimens.

A total of 225 asp specimens measuring from 16.9 to 64.3 cm in length (SL) were collected from commercial catches conducted by the Regalica Fishing Co-operative in Gryfino in 1995-2003. The catches were made with deep-water fyke nets (4 m wing height; 15 mm codend mesh size). The fish samples were packed in ice and transported to the laboratory where they were measured to the nearest 0.5 cm and weighed to the nearest 1 g. Scales were collected from the same body location as on the fry. Following this, the body cavity was opened, the sex was determined, the fish were gutted and then weighed again. Table 1 summarizes data on the abundance of the collected materials.

The scales were viewed with a microfilm reader at a magnification of 18×. The scales were measured along the caudal radius. The pictures of the scales that were cast on the

Table 1. Summary of the materials collected

Date	Number of fish examined	Range of standard length (mm)
Exploratory catches		
6.05.1996	10	35,5 - 44
23.07.1996	20	38 - 48
25.07.1996	10	34 – 42.5
6.08.1996	4	38 – 48
5.09.1996	4	43 – 55
26.06.1997	16	23 – 31
3.07.1997	10	29.5 - 36
2.09.1997	3	60.5 - 83
13.06.2000	4	28 – 32.5
4.10.2000	7	44 – 67
30.07.2001	1	39
Total	89	23 – 83

Date	Number of fish examined	Range of standard length (mm)
Commercial catches		
17.08.1995	3	416 – 495
16.04.2002	31	366 – 560
27.05.2002	25	242 – 604
8.06.2002	13	169 – 330
24.09.2002	32	375 – 643
15.10.2002	33	362 – 582
28.11.2002	11	393 – 585
20.03.2003	17	373 – 586
27.03.2003	22	340 – 545
14.04.2003	38	343 – 592
Total	225	169 – 643

microfilm reader table were measured to the nearest mm. The sclerites in the first growth zone were also counted along the caudal radius.

The parameters of the von Bertalanffy growth equation were obtained using the method described by Beverton and Holt (1957).

The Fulton (K_1) and Clark (K_2) condition coefficients were determined using the following formulae:

$$K_1 = W_1 \cdot 100/\mathrm{SL}^3 \quad [1]$$
$$K_2 = W_2 \cdot 100/\mathrm{SL}^3 \quad [2]$$

where:
W_1 = fish total weight (g),
W_2 = weight of gutted fish (g),
SL = standard length (cm).

RESULTS

Scale growth in the first year of life

Asp fry (0 age group) ranging from 23 to 83 mm in length (SL) were used to trace the growth of scales in the first year of life and to observe the gradual increase in the number of sclerites as fish length increased. The smallest asp with scales was 25 mm long and was caught on 26 June 1997. There were only two sclerites on its scales. Fish 28 mm in length had four or five sclerites on their scales. The largest specimens, measuring 81 and 83 mm, were caught on 2 September 1997 and had 19 or 20 sclerites on their scales. The gradual increase in the number of sclerites on the scales as body length increased are presented

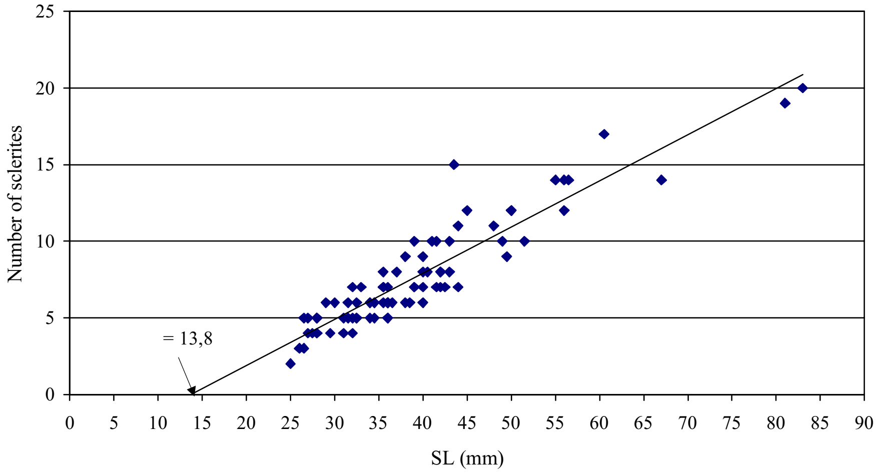

Fig. 2. Dependence between the number of sclerites on scales and standard length (SL).

in Figure 2. This dependence can be expressed using the following linear equation ($r = 0.925$):

$$y = 0.302x - 4.1715 \qquad [3]$$

where:
y – number of sclerites,
x – fry body length (SL) in mm.

The intersection of the line with the X axis may be regarded as the fish length at which scales begin to appear, in this case, the length was 13.81 mm.

Figure 3 presents the distribution of the number of sclerites in the first growth zone (from the center to the first annual ring). These numbers vary from 14 to 35 sclerites, with a modal value of 20. This corresponds with the number of sclerites on the scales of a specimen 83 mm long caught in the fall.

Figure 4 presents the dependence of the scale radius length on fry body length. This dependence is described well by the linear equation ($r = 0.974$):

$$V = 0.2968\ \mathrm{SL} - 4.003 \qquad [4]$$

where:
V – length of the caudal radius scale magnified 18× (mm);
SL – standard length (mm).

It can be also applied to evaluate the fish length at which scales begin to appear. This length is 13.49 mm and is almost identical with the value obtained using the dependence between the number of sclerites and body length.

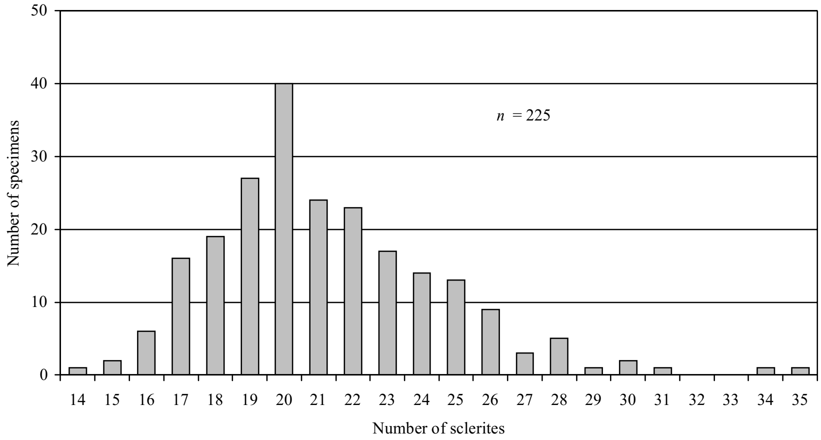

Fig. 3. Distribution of the number of sclerites in the first growth zone of scales from asp in Międzyodrze waters.

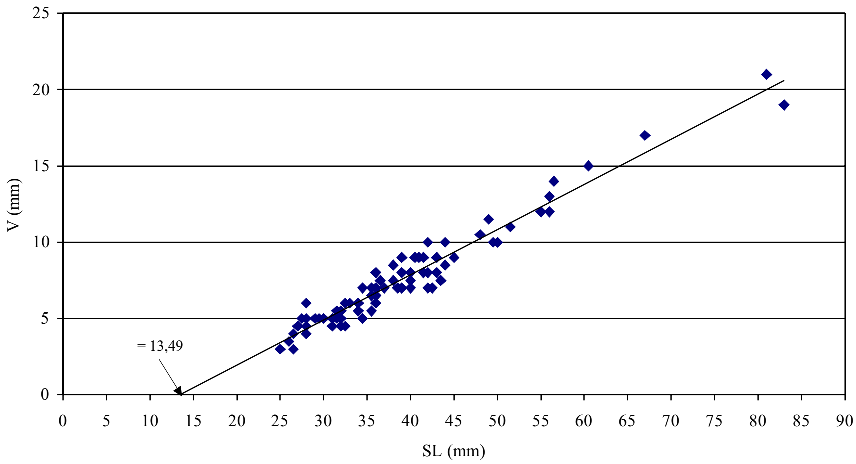

Fig. 4. Dependence of scale radius length (*V*) on standard length (SL) of asp fry.

Growth rate

The dependence between standard asp length and the length of the caudal radius on the scale is curvilinear (Figure 5) and is relatively easy to estimate ($r = 0.991$) using the following formula:

$$V = -12.578 + 7.45\ \mathrm{SL}^{0.736} \qquad [5]$$

where:
V – length of the caudal radius of the scale, magnified 18× (mm);
SL – standard length of fish (cm).

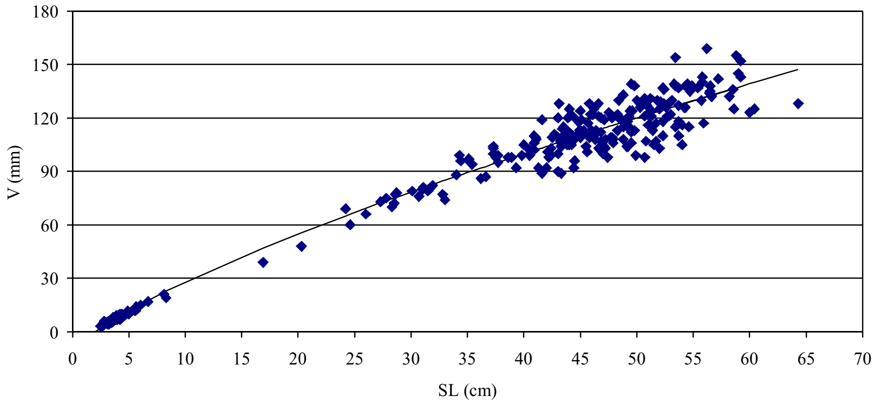

Fig. 5. Dependence of scale radius length (*V*) on standard length (SL) of asp from Międzyodrze waters.

The growth rate of the each of the 225 asp specimens was individually reconstructed using measurements of the caudal radii in the scale growth zones and the above formula.

Table 2 presents average asp lengths in subsequent years of life reconstructed with back-calculations from scales. The data in the table are based on the reconstruction of growth for 89 males, 91 females and 45 specimens of undeterminable sex due to weak gonad development (stage I on the Maier scale). The length ranges of asp in particular age groups were fairly large which was especially visible in the first year of life when the upper length limit (17.84 cm) was over three times that of the lower limit (5.08 cm).

The average female lengths were slightly longer than those noted for the males of the same age groups (Table 3). However, these differences were statistically insignificant at a confidence level of 0.01 (Student's t-test) in all age groups.

The estimation of the von Bertalanffy growth rate equation parameters yielded very good fit with the empirical data; this is confirmed by the high correlation coefficient (r) which is close to one. The correlation coefficient r for L_∞ was 0.998. An identical coefficient r value was obtained for the estimation of k and t_0. The following parameters were obtained: $L_\infty = 75.24$ cm; $k = 0.165$; $t_0 = 0.224$ year.

The dependence between asp length and its total weight in the Międzyodrze can be presented as the following power law equation:

$$W = 0.0075\ L^{3.1964} \qquad [6]$$

where:
W – total body weight in g,
L – standard fish length in cm.

The high value of correlation coefficient $r = 0.990$ indicates that there is good agreement between the empirical data and the model. If the previous value of $L_\infty = 75.24$ is used in place of L in equation [6], then $W_\infty = 7{,}463$ g is obtained.

Table 2. Growth rate of asp in Międzyodrze waters

Age [years]	*n*	Param–eter	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}
2	3	*a*	8.46 ± 0.35	19.09 ±2.28	–	–	–	–	–	–	–	–
		b	8.07-8.74	16.90-21.45	–	–	–	–	–	–	–	–
3	12	*a*	8.47 ±1.58	18.28 ±1.95	27.72 ±1.76	–	–	–	–	–	–	–
		b	6.11-11.14	14.82-21.92	24.60-30.91	–	–	–	–	–	–	–
4	18	*a*	8.80 ±0.90	18.81 ±2.72	27.34 ±2.97	33.59 ±3.03	–	–	–	–	–	–
		b	7.24-10.55	12.32-23.07	19.88-31.28	26.00-38.96	–	–	–	–	–	–
5	63	*a*	8.76 ±1.70	17.71 ±3.62	26.47 ±4.49	33.92 ±4.54	40.37 ±4.51	–	–	–	–	–
		b	6.55-17.84	11.51-28.33	20.00-39.98	26.89-44.44	32.40-50.09	–	–	–	–	–
6	64	*a*	8.47 ±1.55	18.23 ±3.46	27.84 ±4.04	36.12 ±4.03	42.06 ±3.90	47.19 ±3.62	–	–	–	–
		b	5.08-14.01	11.29-26.33	19.42-38.92	27.39-46.55	32.25-50.54	37.30-54.70	–	–	–	–
7	44	*a*	8.47 ±1.74	17.96 ±3.30	27.24 ±3.22	35.63 ±3.63	42.13 ±3.66	47.26 ±3.54	51.19 ±3.53	–	–	–
		b	5.64-14.67	13.18-30.35	21.23-36.01	28.25-44.27	36.20-51.25	41.44-53.87	43.00-59.33	–	–	–
8	18	*a*	8.63 ±1.62	17.99 ±2.44	27.14 ±2.13	35.13 ±2.88	41.68 ±2.26	47.35 ±2.81	51.47 ±2.74	54.81 ±2.65	–	–
		b	6.70-11.58	14.50-22.46	22.73-31.67	31.62-40.37	37.08-45.42	40.46-52.62	44.80-56.14	48.80-59.20	–	–
9	2	*a*	11.02 ±0.89	21.91 ±3.50	30.13 ±3.45	38.16 ±5.23	43.39 ±3.17	48.61 ±2.02	52.50 ±2.11	55.15 ±2.43	56.75 ±2.62	–
		b	10.39-11.65	19.43-24.38	27.69-32.56	34.46-41.86	41.15-45.63	47.18-50.05	51.00-53.99	53.43-56.86	54.90-58.60	–
10	1	*a*	12.33	22.71	31.98	37.17	43.11	47.57	50.99	53.30	55.64	60.40
Total	225	*a*	8.63 ±1.60	18.13 ±3.27	27.27 ±3.74	35.08 ±4.05	41.50 ±3.98	47.26 ±3.43	51.30 ±3.24	54.77 ±2.53	56.38 ±1.96	60.40
		b	5.08-17.84	11.29-30.35	19.42-39.98	26.00-46.55	32.25-51.25	37.30-54.70	43.00-59.33	48.80-59.20	54.90-58.60	–
		n	225	225	222	210	192	129	65	21	3	1

a – average length (SL cm) ± standard deviation; *b* – length range; *n* – numbers

Table 3. Comparison of the growth rate of male and female asp in Międzyodrze waters (SL, cm)

Parameter	Age [years]									
	1	2	3	4	5	6	7	8	9	10
	Males									
Average length	8.46	18.00	27.46	35.59	41.79	46.92	50.00	53.48	–	–
±SD	1.73	3.54	3.84	4.27	4.19	3.42	3.68	3.52	–	–
Numbers	89	89	89	88	84	61	24	5	–	–
	Females									
Average length	8.87	18.65	27.78	35.69	42.18	48.07	52.30	55.17	56.38	60.4
±SD	1.68	3.09	3.67	3.6	3.51	3.23	2.53	2.11	1.96	–
Numbers	91	91	91	91	85	60	39	16	3	1

Condition

The Fulton and Clark condition coefficients in different months are presented in Table 4. They are grouped by sex and immature specimens are presented separately. The high Fulton coefficient values for males and females in March were due to the greatest gonad development in this month. The values of this coefficient decreased later in connection with spawning (April) and the post-spawning period (May). Following this period, the Fulton coefficient values increased again markedly which can be explained by intense feeding and renewed gonad development. The highest values of the Clark coefficient were observed in September at the close of the intense feeding period. From this period onward gonad development continues by utilizing the stored fat supply, thus the coefficient values decreased.

Table 4. Condition coefficients of asp in Międzyodrze waters

Month	*n*	Fulton coefficient			Clark coefficient		
		range	average	±SD	range	average	±SD
Females							
March	20	1.517-1.951	1.711	0.127	1.258-1.604	1.458	0.085
April	24	1.369-1.809	1.537	0.119	1.290-1.673	1.437	0.099
May	8	1.168-1.638	1.516	0.153	1.123-1.551	1.428	0.135
June	1	–	1.490	–	–	1.428	–
September	12	1.497-1.844	1.675	0.136	1.369-1.634	1.528	0.093
October	6	1.606-1.883	1.759	0.112	1.374-1.593	1.490	0.093
Males							
March	19	1.459-1.812	1.621	0.112	1.390-1.685	1.533	0.095
April	36	1.338-1.770	1.543	0.107	1.266-1.644	1.459	0.096
May	9	1.426-1.611	1.523	0.058	1.367-1.523	1.441	0.049
August	3	1.318-1.487	1.428	0.096	1.243-1.417	1.350	0.093
September	12	1.394-2.085	1.721	0.195	1.320-1.928	1.616	0.172
October	2	1.384-1.703	1.543	0.226	1.324-1.599	1.461	0.195
Immature							
March	1	–	1.553	–	–	1.461	–
April	9	1.358-1.681	1.541	0.091	1.313-1.565	1.461	0.074
May	8	1.397-1.622	1.497	0.075	1.351-1.529	1.421	0.067
June	12/9	1.247-1.511	1.407	0.076	1.267-1.438	1.349	0.061
September	9	1.520-1.836	1.696	0.096	1.436-1.713	1.592	0.088
October	3	1.568-1.689	1.634	0.061	1.481-1.567	1.538	0.049

There was a clear difference between the condition coefficients for males and females. Prior to spawning in spring, the Fulton coefficient values were higher in females than males. This is because the developed ovaries constitute a greater percentage of body weight than do the testes. Conversely, the Clark coefficient values were lower for females in spring. In summer and fall these differences were less pronounced. The Student's t-test (assuming normal distribution) showed that the above differences were statistically insignificant; this is most likely due to high individual variability and the small sample size.

Among immature specimens (Table 4), in which the gonads constituted a very small fraction of the body weight, the lowest values of the Fulton and Clark coefficients were observed in spring and the highest in fall. The rapid decrease in the values of both coefficients in June might be explained by the small average length of the immature asp specimens in the sample. To illustrate this argument Table 5 presents the average values of the Clark coefficient of immature asp specimens with an SL length below 30 cm, between 30-40 cm and over 40 cm. It is clear that the larger specimens have higher Clark coefficient values. This phenomenon spurred the investigation of the general dependence between condition and asp length. The small sample size required the authors to combine all the males, females and immature specimens caught in various seasons, and this resulted in significant variations. An attempt to fit the linear equation showed that the Fulton coefficient for asp specimens 16.7-65 cm in length is very loosely correlated with fish length (r = 0.385). Even weaker correlation (r = 0.158) was obtained for the Clark coefficient.

Table 5. Dependence of the Clark condition coefficient on length (SL, cm) in immature asp specimens

Length range (cm)	Average length	±SD	Clark coefficient	±SD	*n*
<30	25.56	3.86	1.354	0.052	8
30 - 40	34.26	3.29	1.474	0.131	14
>40	43.87	2.11	1.513	0.095	21

DISCUSSION

Studies which estimate the average body length of asp at which scales begin to appear are very rare. One such study was done by Trzebiatowski and Leszczewicz (1976) on asp from the Szczecin Lagoon. The length, as the point where the linear regression curve for the scale radius vs. body length intersects with the X axis, was 15.5 mm. Martyniak and Heese (1994) cited Koblicka (1981) who reported that the first asp scales are formed at a length of about 20 mm. The results of the current study, which vary from 13.5 to 13.8 mm depending on the method applied, are very similar to those obtained by Trzebiatowski and Leszczewicz (1976).

The methods applied in studies of growth rate can influence the results significantly, especially in the case of back-calculations (Francis 1990). It must be kept in mind that the dependence between the length of the otolith or scale radius and body length can vary among different stocks of the same species (Shentyakova 1969). Martyniak and Heese (1994) found that this dependence for asp from the Pierzchały Reservoir on the Pasłęka

Table 6. Growth rate of asp specimens in different bodies of water, SL (cm)

Basin	Param-eter	Age [years]													Source and methodology
		1	2	3	4	5	6	7	8	9	10	11	12	13	
Pierzchalski Reservoir on the Pasłęka River	SL	13.5	20.8	27.5	34.1	40.2	44.8	48.7	52.2	55.2	58.3	61.2	64.1	–	Martyniak and Heese 1994, Back-calculation
	±SD	1.6	2.2	2.6	3.3	2.9	2.4	2.2	1.8	2.7	2.5	–	–	–	
	n	218	218	213	186	148	111	68	32	15	5	–	–	–	
Kurskij Zaliv	SL	–	19.0	26.9	31.0	39.4	43.9	48.4	52.5	56.1	57.6	63.5	–	–	Gaigalas 1977, Average length in age groups
	n	–	3	15	33	46	14	11	9	5	6	2	–	–	
Dnieper catchment basin	SL	8.6	17.2	25.2	31.5	39.1	–	–	–	–	–	–	–	–	Zhukov 1965, Back-calculation
	n	68	53	19	14	2	–	–	–	–	–	–	–	–	
Niemen River	SL	7.5	15.2	22.5	29.2	35.6	40.7	44.7	–	–	–	–	–	–	Zhukov 1965, Back-calculation
	n	25	25	23	18	17	13	7	–	–	–	–	–	–	
Kamski Reservoir	SL[a]	6.7	12.0	19.4	26.2	31.8	37.2	40.8	42.4	44.2	–	–	–	–	Pushkin 1968, Back-calculation
	SL[b]	7.1	13.2	20.5	26.8	32.5	37.3	40.9	41.8	43.3	–	–	–	–	
Szczecin Lagoon	SL	8.9	17.6	26.9	34.5	40.5	45.9	49.9	54.4	57.3	59.2	61.1	62.3	64.3	Trzebiatowski and Leszczewicz 1976, Back-calculation
Vistula River	SL	8.5	14.8	23.3	29.0	36.3	42.4	46.6	51.0	56.3	–	–	–	–	Backiel 1964, Back-calculation
	±SD	–	2.98	2.77	2.81	4.23	4.92	5.14	5.35	5.06	–	–	–	–	
	n	1	23	68	90	93	76	36	25	17	–	–	–	–	
Międzyodrze	SL	8.6	18.1	27.3	35.1	41.5	47.3	51.3	54.8	56.4	60.4	–	–	–	Current study, Back-calculation
	±SD	1.60	3.27	3.74	4.05	3.98	3.43	3.24	2.53	1.96	–	–	–	–	
	n	225	225	222	210	192	129	65	21	3	1	–	–	–	
Volga River delta	SL	15.8	27.7	35.5	39.8	46.0	50.0	53.2	56.0	–	–	–	–	–	Fortunatova and Popova 1973, Average length in age groups
Seddin See[c]	SL	9.3	17.8	33.0	41.5	47.4	53.3	55.0	–	–	–	–	–	–	Bauch 1963

[a] Vovk method
[b] Lea method
[c] TL from the original work was recalculated to SL

River may be best described using a third order polynomial. Trzebiatowski and Leszczewicz (1976) proved that this dependence is linear for asp from the Szczecin Lagoon. The linearity of this dependence was also confirmed by Pushkin (1968) (Kamski Reservoir). Backiel (1964) also applied simple proportionality for the back calculations of asp growth in the Vistula River. Pushkin (1968) obtained different back calculation results using the Vovk and Lea methods. Heese (1992) demonstrated how the back-calculated lengths of asp specimens in particular years in the Pierzchały Reservoir might differ depending on the method applied.

Bearing these reservations in mind, the growth rates of asp specimens in different reservoirs can be compared (Table 6). Asp specimens from the Seddin-See (Bauch 1963) and theVolga River delta (Fortunatova and Popova 1973) were the fastest growing. The slowest growth was observed for asp specimens in the Kamski Reservoir (Pushkin 1968). The growth rates of asp from the remaining bodies of water in Table 6 are similar to those of the asp from Międzyodrze, especially in the first year of life.

Some authors (Backiel 1964, Pushkin 1968, Gaigalas 1977) reported different growth rates for asp males and females. However, if there were any differences in the growth rates between the two sexes, they were not statistically significant. This is indicated by the current study and was also reported by Backiel (1964).

The parameters of the von Bertalanffy growth equation for asp obtained by Trzebiatowski and Leszczewicz (1976) (Szczecin Lagoon – L_∞ = 72.12 cm; k = 0.1715; t_0 = 0.1674) and Martyniak and Heese (1994) (Pierzchalski Reservoir – L_∞ = 73.3 cm; k = 0.1646; t_0 = 0.18) do not vary significantly from the results presented in this study. However, the parameters of the equation obtained by Backiel (1964) (Vistula River – L_∞ = 110 cm; k = 0.080; t_0 = 0.104) vary significantly from those described above.

The value of the Fulton coefficient for asp in the Międzyodrze varied in the range of 1.247-2.085, while in the Kamski Reservoir (Pushkin 1968) the range was from 1.34 to 1.66 and it increased with fish length. According to Zhukov (1965), the Fulton coefficient for asp from the Dnieper River ranged from 1.22 to 1.76 at an average of 1.50, for specimens from the Niemen River from 1.24 to 1.67 at an average of 1.40 and for those from the western Dźwina River from 1.10 to 1.76 at an average of 1.45.

Due to the small sample size, the authors of the current study were unable to determine the variability of the condition coefficients (Fulton and Clark) with asp length. However, for some fish species these variations are very clear and the correlation between them is statistically significant (e.g. Kompowski and Rojas 1994).

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The growth rate of the six selected fish species inhabiting in the Polish part of the Vistula Lagoon

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Abstract. The growth rate of perch, razorfish and rudd in the Vistula Lagoon was linear. That of roach, ruffe and smelt was expressed using the von Bertalanffy equation. The equation coefficients for the various species were as follows:

perch:	$a = 3.05$; $b = 4.38$
razorfish:	$a = 3.04$; $b = 9.76$
rudd:	$a = 2.68$; $b = 5.68$
roach :	$L_{inf} = 44.96$; $K = 0.082$; $t_0 = -1.567$
ruffe:	$L_{inf} = 18.62$; $K = 0.206$; $t_0 = -0.897$
smelt:	$L_{inf} = 29.37$; $K = 0.301$; $t_0 = -0.086$

Key words: Vistula Lagoon, brackish water basin, *Perca fluviatilis, Rutilus rutilus, Pelecus cultratus, Osmerus eperlanus, Scardinius erythtrophtalmus, Gymnocephalus cernuus,* growth rate

INTRODUCTION

The Vistula Lagoon is a long, narrow lagoon which stretches from the southwest to the northeast and is separated from the Baltic Sea by a sandy spit. It is connected to the sea in the northeast by the Baltiysk Strait, which is 400 m wide (Anon. 1975). The water in the lagoon has varied salinity levels which fluctuate in yearly cycles from 0.1‰ to 1.6‰ in the western region and from 2.9‰ to 4.7‰ in the eastern region (Anon. 1975). These water conditions allow approximately 40 fish species to either temporarily or permanently inhabit this basin (Borowski 1996, 2000a). The waters of this lagoon are divided by the Russian-Polish border. The waters of the Polish zone are inhabited almost exclusively by freshwater flora and fauna (Żmudziński and Szarejko 1955; Żmudziński 1957). The herring which migrate to the Vistula Lagoon to spawn comprise the bulk of the catch seasonally in the Polish part of the lagoon.

In the 1991-2001 period in the Vistula Lagoon, in addition to herring, fishermen primarily caught pikeperch, eel and bream (Borowski 2000a). The by-catch was dominated by perch and roach, followed by razorfish and smelt. Half of these species were reported in the annual catch statistics. Ruffe, which occurred in the by-catch, was noted in the statistics until 1975. Later, due to a lack of consumers, this fish was discarded back into the sea despite the fact that in fyke-net catches it comprised from 25.2% to 63.7% of the mass of caught fish (Borowski and Dąbrowski 1997). Rudd was reported in the statistics along with roach. In the 1990s catches of perch and roach rose significantly.

Although the results of studies of the primary fish species are presented in numerous scientific publications, the fish which comprise the by-catch are studied sporadically. Romański (1963), who studied roach in the 1957-1959 period, described the growth rate, length and age distribution and catches of this fish. In the 1960s the growth rate and age of perch were studied by Krawczak (1965). Terlecki (1987) and Stolarski (1992, 1995) reported the results of growth studies of razorfish from lagoon waters. Descriptions of smelt, ruffe and rudd from the lagoon can be found in general monographs (Rembiszewski 1970, Anon. 1986, Borowski 2000a).

In the mid 1970s, a decline in the abundance of pikeperch was noted and attributed primarily to the destruction of the natural spawning grounds of this species by drainage projects (Borowski 2000b). The elimination of this predator, whose dietary preferences were for roach, perch, rudd and ruffe of all life stages (Antosiak, 1963), could have had an impact on changes in the life cycles, life spans and the growth rates of these species.

Significant changes have been noted in the size and structure of commercial catches since the mid 1990s. In light of this, a central issue was to confirm possible changes in the growth rate of fish which were of secondary importance in commercial catches. Since opinions regarding changes in the biotope of the studied basin are highly varied, ecological issues were not addressed.

The aim of the current work was to study the growth rates of perch, roach, razorback, smelt, rudd and ruffe from the Vistula Lagoon waters as well as to identify dependencies between the length and mass of these fish

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MATERIALS AND METHODS

The fish used in the study were collected in the 1991-2001 period from March to November, i.e., from the moment the ice broke until the basin froze. The fish were measured aboard fishing vessels directly after being removed from fyke-nets; these measurements were rounded down to the nearest cm. The numbers of fish studied are presented in Table 1. Measurements of total length were performed on all perch, roach, razorback and rudd which occurred in the catch, whereas, due to the large numbers, only 200 - 300 individuals of ruffe and smelt (the latter was only studied in March when it was most abundant) were measured.

The fish used in the ichthyological analyses were chosen at random from large scale samplings. The fish were weighed to the nearest g, and the sex and gonad maturity (according to the Maier scale) were determined. The stomach contents was evaluated on a five-

Table 1. Length distribution of the studied fish species from the waters of the Vistula Lagoon in 1991-2001

Length classes (cm)	Species					
	perch	roach	razorfish	smelt	rudd	ruffe
5				3		2
6				0		4
7	5	3		0		92
8	54	9		13		1,312
9	576	218	2	14	8	8,661
10	2,645	1,636	7	17	60	23,209
11	6,269	4,271	12	55	198	31,473
12	9,114	6,387	17	204	277	21,336
13	8,204	6,244	19	716	188	8,223
14	6,041	6,109	88	964	158	2,701
15	4,345	5,317	90	1,149	148	551
16	2,796	3,782	121	879	92	56
17	1,713	2,436	173	861	65	17
18	1,306	1,535	136	763	31	3
19	748	1,119	183	643	22	0
20	462	659	278	462	13	2
21	379	610	373	230	8	
22	240	306	387	147	4	
23	221	240	280	52	2	
24	137	162	133	8	2	
25	104	117	124	5	2	
26	69	65	196	1	1	
27	62	42	298	1	1	
28	41	19	428		1	
29	18	20	312			
30	20	12	369			
31	9	9	399			
32	3	5	633			
33	2	4	620			
34	1	3	527			
35	0	1	670			
36	1	3	478			
37		2	330			
38		1	277			
39		0	212			
40		1	143			
41			89			
42			72			
43			44			
44			28			
45			30			
46			10			
47			6			
Total	45,585	41,347	8,594	7,187	1,281	97,642

degree scale. The age of the fish was determined from scale readings performed using transmitted light.

The growth rate characteristic, depending on the correlation coefficient calculated (r), was described with the linear equation ($y = ax + b$) or the von Bertalanffy equation [Beverton and Holt, 1957] :

$$L_t = L_{\text{inf}} [1 - e^{-K(t - to)}]$$

where: L_t – total length of fish at age t;
L_{inf} – asymptote to which the growth curve approaches;
K – catabolism indicator;
e – base of the natural logarithm;
t_o – arbitrarily assumed beginning of the growth curve.

The dependence between fish body length and mass was described with the power equation $W = aL^b$, (where: W – fish mass, L – its length, a and b – equation coefficients).

RESULTS

Fyke-net catches are not selective, thus, there is a high degree of probability that the length distribution of perch, roach, razorfish, and rudd reflected the length distribution of these populations. Additionally, as all of the fish of these species which were caught in the fyke-nets were measured during the study, their abundance probably also reflects proportions which are similar to commercial catches.

The perch studied measured from 7 to 36 cm in length and were aged from 1 to 8. Specimens from 10 to 16 cm in length dominated at 84.4% of the measured perch (Table 1). The mean length in age groups was from 9.4 to 31.4 cm and it increased with age (Table 2). Annual growth was varied in the different years of life, and the greatest was noted between the fifth and sixth years of life (7.2 cm). Among the six studied species, the range of length classes in age groups was the largest among perch, which is indicated by the high values of standard deviation, especially in specimens aged from 5 to 8.

The studied roach measured from 7 to 40 cm in length and were aged from 2 to 13. The catches were dominated by fish measuring from 11 to 17 cm (83.5% abundance - Table 1). The mean length in age groups was from 11.2 to 31.0 cm, and the annual growth declined with age (Table 2).

The razorfish caught measured from 9 to 47 cm in length and were aged from 2 to 13 years. Most of the specimens originated from the 20 to 39 cm length class, at 85.2% of the abundance of the studied fish (Table 1). The mean length in age groups was from 15.5 to 47.0 cm, and the annual growth was similar to in the subsequent years of life (Table 2).

The least abundant species was rudd. They measured from 9 to 28 cm in length and were aged from 1 to 8. The majority of the specimens (75.6%) were in the 11 to 15 cm length classes (Table 1). Rudd exhibited the highest annual growth in the first year of life, while from the second to fifth years of life it ranged from 1.9 to 2.8 cm (Table 2). Since

Table 2. Mean length in subsequent age groups of perch, roach, razorfish, smelt, rudd and ruffe from the Vistula Lagoon in 1991-2001 (in cm)

Age groups	Species											
	perch		roach		razorfish		smelt		rudd		ruffe	
	mean	*δ*	*mean*	*δ*	*mean*	*δ*	*mean*	*δ*	*mean*	*δ*	*mean*	*δ*
I	9.4	0.5					8.0		9.5	0.6		
II	10.0	1.5	11.2	1.6	15.5	0.5	14.2	1.6	11.0	1.1	8.4	1.3
III	12.3	1.6	14.2	2.0	17.8	0.9	17.6	1.9	13.9	1.0	10.2	1.8
IV	15.4	1.8	16.6	2.7	22.4	0.5	20.7	1.8	15.4	1.4	11.8	1.8
V	19.2	2.5	19.1	2.4	25.6	1.3	22.7	1.9	18.1	1.3	13.3	1.5
VI	26.4	3.6	20.5	1.8	28.7	0.8	25.0	2.8	20.0	0.0	14.0	1.5
VII	29.6	2.5	22.4	1.6	31.4	1.8			26.0			
VIII	31.4	2.7	24.8	1.9	34.7	1.6			28.0			
IX			25.0	1.1	36.9	1.7						
X			27.9	1.2	40.5	2.4						
XI			29.8	1.3	41.4	2.5						
XII												
XIII			31.0		47.0							
equation	$L_t = 3.05t + 4.38$		$L_t = 44.96\times(1-e^{-0.082\times(t+1.567)})$		$L_t = 3.04t + 9.76$		$L_t = 29.37\times(1-e^{-0.301\times(t+0.086)})$		$L_t = 2.68t + 5.68$		$L_t = 18.62\times(1-e^{-0.206\times(t+0.897)})$	
r	0.992		0.997		0.997		0.999		0.985		0.998	

only one specimen from age groups 7 and 8, the mean lengths calculated are not representative.

Specimens ranging from 5 to 28 cm in length and aged from 1 to 6 were observed during measurements of smelt. The majority of them (83.1%) measured from 13 to 19 cm (Table 1). The highest annual growth in fish of this species was observed in the first two years of its life, and growth declined as the fish aged.

The ruffe which were measured ranged from 5 to 20 cm in length and were aged from 2 to 6. Individuals from the 9 to 11 cm length classes dominated (77.5%) (Table 1). No individuals from age group 1 were noted in the samples, however, annual growth was observed from the second year of life and it decreased with age (Table 2).

The growth rate of the six studied fish species was described with equations. Analyses of the length-age dependence indicated that the linear dependence equation best described that of perch, razorfish and rudd, while the von Bertalanffy equation best described that of roach, ruffe and smelt. Data which describe the length-age dependence are presented in Table 2, and the dependence curve is presented in Figure 1. Up to the fifth year of life, the highest growth rates were observed in razorfish and smelt, and up to the tenth year of life in razorfish and perch. Ruffe growth was the slowest.

The results of studies of the length-weight dependence of the six fish species are presented in Table 3 and Figure 2.

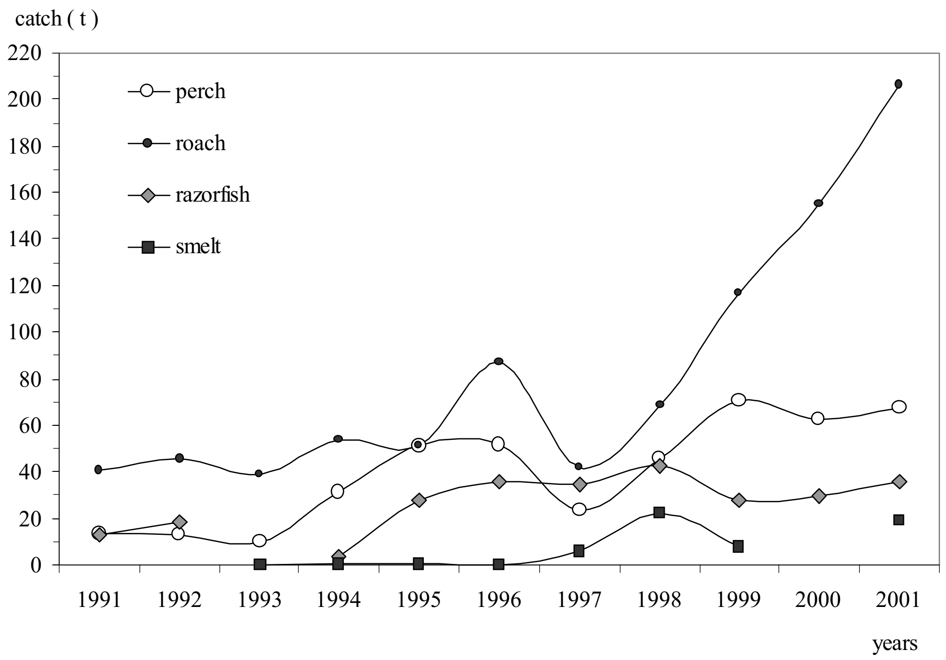

Fig. 1. Catches of perch, roach, razorfish and smelt in the Vistula Lagoon in 1991-2001 (in tons).

Table 3. Mean weight of perch, roach, razorfish, smelt, rudd and ruffe from the Vistula Lagoon in 1991-2001 (in g)

Length (cm)	mean	δ	mean	δ	mean	δ	mean	δ	mean	δ	mean	δ
5												
6											4.0	
7											4.0	0.0
8	8.0	1.0					2.0				8.5	1.8
9	11.2	1.9	7.5	0.5			4.0		9.3	1.0	11.2	1.2
10	13.5	1.4	10.2	2.2					12.2	1.2	11.5	1.8
11	17.3	1.8	14.4	1.9			8.0	1.9	15.3	1.0	18.8	3.3
12	21.8	2.2	19.4	2.8			10.8	1.9	20.6	2.6	22.8	3.0
13	28.2	1.8	24.7	3.2			15.4	2.7	27.3	5.5	26.8	2.8
14	36.7	4.2	30.0	2.5			18.2	2.9	35.2	3.9	31.5	4.1
15	41.4	5.3	39.8	4.8	18.7	1.2	22.1	3.6	44.5	4.2	42.5	3.5
16	56.3	6.6	44.2	5.5	19.3	1.2	27.2	4.7	55.7	1.5		
17	65.3	10.2	58.3	5.6	24.5	2.1	32.4	5.2	60.8	3.9	57.0	
18	79.8	11.2	68.6	5.4	28.0		39.5	5.9	72.3	5.5		
19	85.8	10.6	76.0	7.7	36.0		45.0	5.7	82.0			
20	102.7	6.6	96.2	6.4			51.7	7.7	108.5	7.1		
21	112.7	8.8	115.0	13.4			62.9	9.1				
22	140.8	21.3	119.3	11.8	60.0	2.0	72.8	12.3				
23	163.2	16.8	144.7	13.8	73.3	4.2	81.6	8.7				
24	205.0		161.3	17.2	83.0	1.4	96.2	10.3				
25	205.0		194.6	12.4	91.7	11.9	118.7	11.0				
26	273.3	30.6	205.7	27.5	112.0	3.5	154.0	19.8	272.0			
27	302.5	3.5	262.7	25.2	121.4	10.3	153.0					
28	341.0	29.6	335.3	56.4	133.5	9.0			308.0			
29	356.5	33.9	340.0	36.1	153.8	14.4						
30	412.0	13.8	400.0	14.1	158.6	14.8						
31	417.8	25.4	477.0	38.2	173.9	10.7						
32	427.5	31.8			202.1	17.4						
33	570.0	43.6			238.7	28.7						
34	545.0	63.6			267.1	28.1						
35	520.0				288.6	29.7						
36	640.0				308.0	26.6						
37	950.0				348.6	31.3						
38					377.0	38.4						
39	850.0				392.9	27.8						
40					446.4	29.4						
41					465.5	30.8						
42					513.7	42.2						
43					620.0							
44					638.7	61.2						
45					729.0							
46												
47					680.0	0.0						
	$W = 0.011L^{3.07}$		$W = 0.0066L^{3.19}$		$W = 0.0020L^{3.33}$		$W = 0.0053L^{3.08}$		$W = 0.0083L^{3.16}$		$W = 0.0320L^{2.63}$	
r	0.990		0.993		0.991		0.964		0.992		0.966	

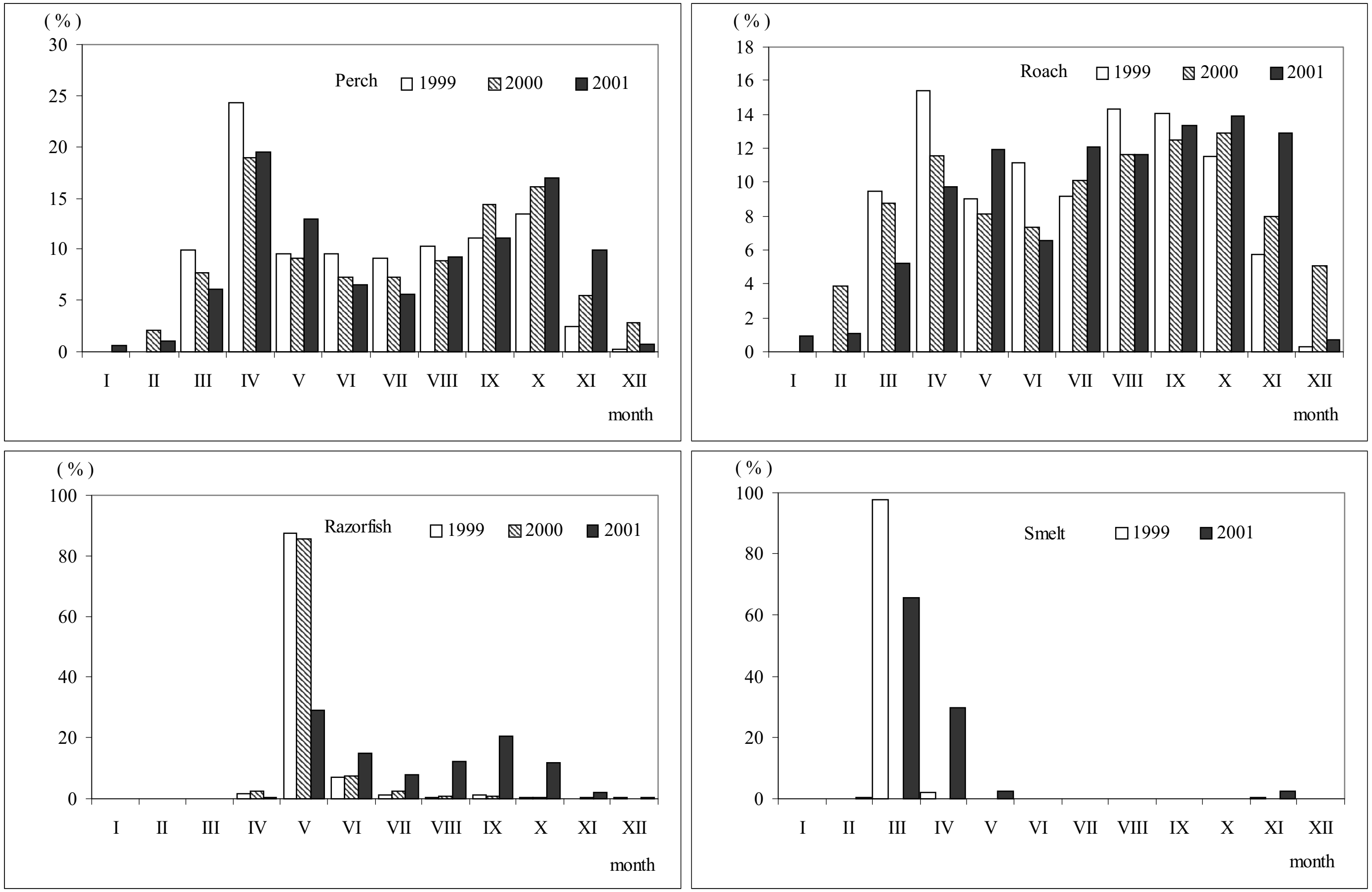

Fig. 2. Size of monthly catches of perch, roach, razorfish and smelt in the Vistula Lagoon in 1991-2001(in %).

DISCUSSION

Knowledge of the age and growth rates of fish has universal significance as this information enables answering virtually all questions pertaining to fish life cycles (Pliszka 1965). Determining the growth rate permits distinguishing between slow and quick growing species, and allows for estimating the productivity of a basin. In addition to permanent genetic characteristics, environmental conditions also impact the growth rate. Pilszka (1965) reported that the most well-understood factors which have an impact on growth rate are temperature, oxygen, light and dissolved salts in the water and food. A systematic decline in the abundance of pikeperch in the lagoon was observed from the mid 1970s. This significant qualitative change might have an impact on the growth rate of its potential prey - perch, roach, rudd and ruffe.

Studies have indicated that the growth rate of perch in the 1991-2001 period was similar to that described by Krawczak (1965) in the 1960s. Certain differences which were observed in the older age groups (Fig. 3) are connected with environmental conditions (Anon. 1996). Żuromska (1961) reported that the factors are too numerous to be able to pinpoint which ones have a decisive impact. One of them could be the transitional moment

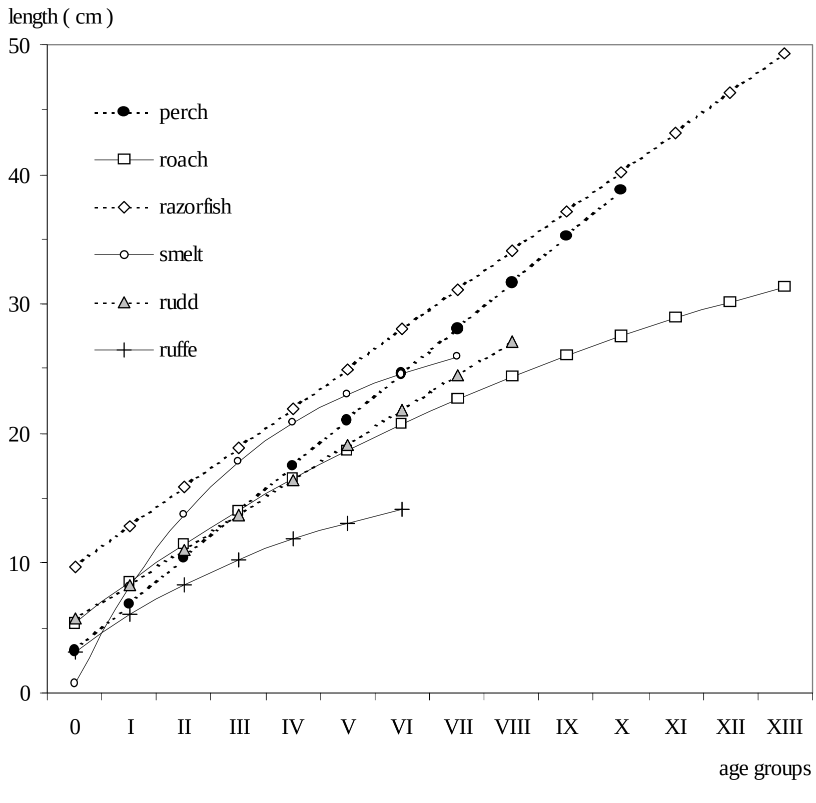

Fig. 3. Growth rate of perch, roach, razorfish, smelt, rudd and ruffe in the Vistula Lagoon in 1991-2001.

when perch adopts a predatory life strategy. Confirmation of this can be found in the studies of Filuk and Żmudziński (1965), who contended that perch in the waters of the lagoon feed exclusively on fish (primarily stickleback) after they have attained a length of 20 cm; this is in contrast with smaller specimens whose diet was dominated by *Neomysis vulgaris*.

The roach growth rate in the 1950s which was described by Romański (1963) is similar to that obtained by authors from the 1990s (Fig. 3). One can assume that the growth rate of roach did not change over a period of nearly 40 years.

In this author's opinion, the disappearance of pike from lagoon waters did not have a visible impact on the growth rates of either perch or roach, both of which are primary dietary components of this species.

The author compared his own observations of the razorfish growth rate with the results of studies by Terlecki (1987) and Stolarski (1995); he concluded that they declined in the 1991-2001 period. Variable environmental conditions might have also caused this decline. The results of studies performed by the Russian researchers Keida and Golubkova (2001) confirm these observations. These authors describe a series of anomalies which occur when estimating the razorfish biomass in subsequent years and which are related to the interaction of the razorfish and pikeperch populations. According to them, in the 1980s, when the average temperature was low, adult razorfish preyed on pikeperch fry. This pres-

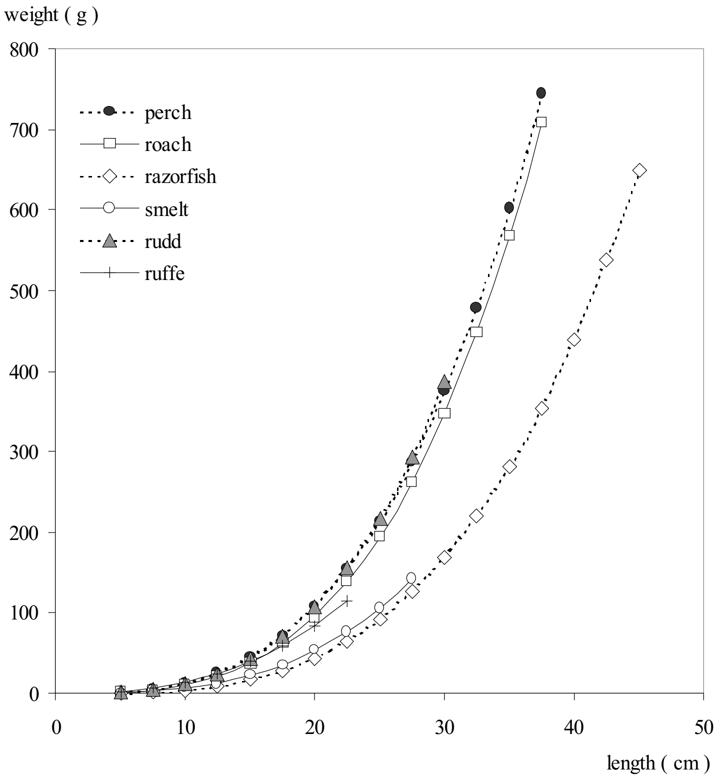

Fig. 4. Dependence curve of length-individual weight of perch, roach, razorfish, smelt, rudd and ruffe in the Vistula Lagoon in 1991-2001.

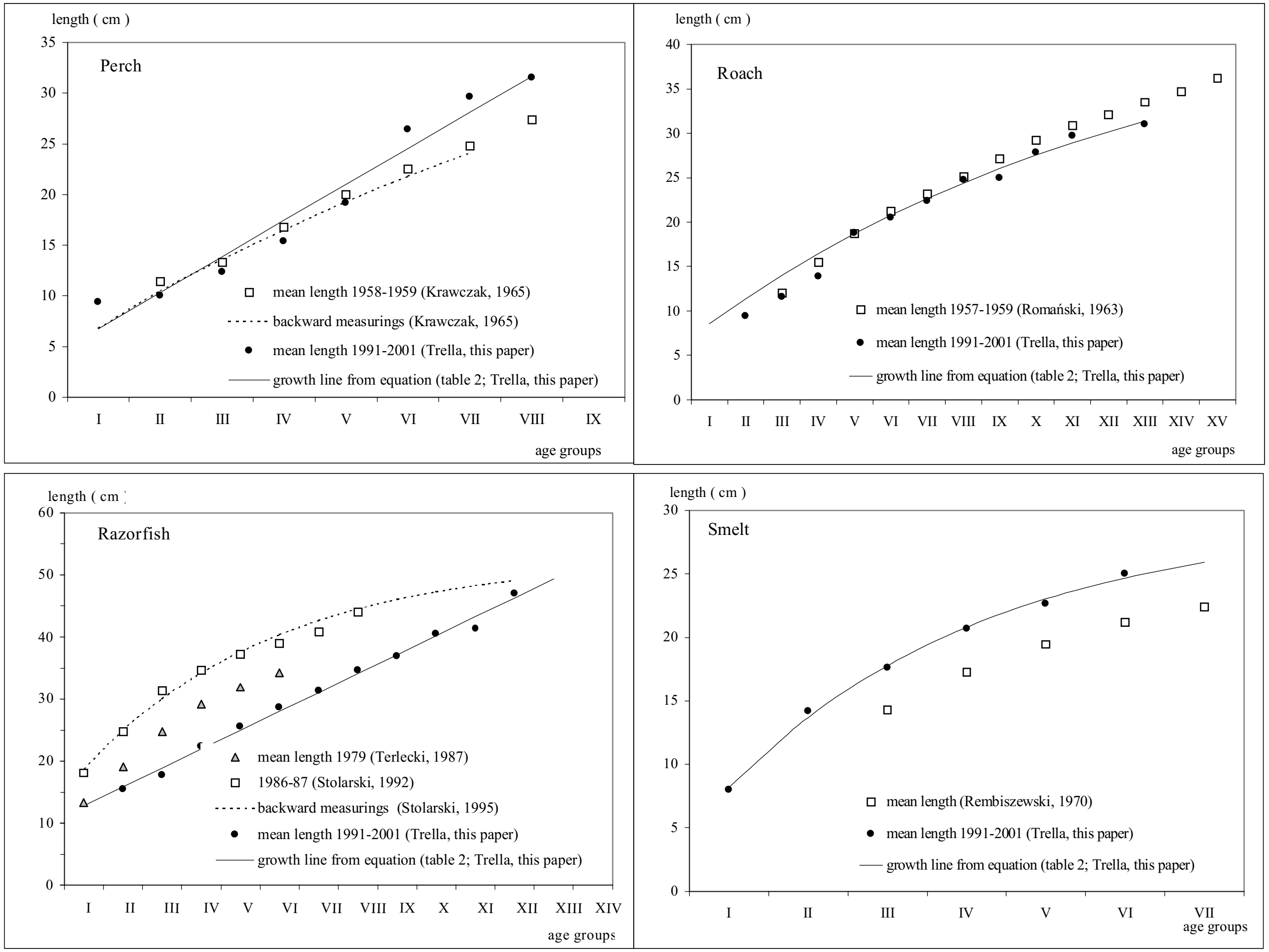

Fig. 5. Growth rate of perch, roach, razorfish and smelt in comparison with results from other authors.

sure was increased by the low abundance of zooplankton, the principle food of the razorfish. However, in the 1990s, when the temperature was higher, pikeperch fry grew faster and fairly quickly adopted a predatory life strategy, and one of its primary food components was razorfish fry. During this period, adult razorfish fed primarily on zooplankton, which meant that their growth rate was lower than in years when it fed on juvenile pikeperch.

Smelt form dense spawning concentrations in the lagoon in early spring (Horbowa 2001). These fish have a short life span, and their natural mortality increases quickly from the third year of life onwards (Rembiszewski 1970). According to this same author, the smelt population in the lagoon waters has a high growth rate and an unusual (in comparison with populations in other basins) degree of longevity. Studies conducted by the author indicate that in the 1991-2001 period the growth rate of smelt increased in comparison to the results of analogous studies conducted in the late 1960s (Rembiszewski 1970 – Fig. 3).

Ruffe, which has a short life cycle, reaches modest sizes in inland basins (Zawisza 1953). This fish attains larger sizes in coastal lagoons, e.g., the oldest studied ruffe specimen (ten years) from the Szczecin Lagoon measured 18.9 cm (Pęczalska 1971). Similar observations were made by this author in the 1991-2001 period during studies of ruffe in the Vistula Lagoon. The oldest studied specimen was 6 years old and the longest measured 20 cm.

No information regarding the growth rate of rudd in the Vistula Lagoon was found in the ichthyological literature. Comparisons of the results of the current study and those conducted in inland basins (Zawisza 1953, Stroński 1961) indicated that the growth rate in the Vistula Lagoon was higher in subsequent years of life although the life span was similar. Rudd lives for eight years in both lakes and the lagoon.

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5. Tekst. Objętość maszynopisu prac kategorii 1 nie powinna przekraczać 40 stron, a kategorii 2 – 15 stron. W pracach kategorii 1 i 2 stosuje się tradycyjny podział: 1) wstęp, 2) materiał i metoda badań, 3) wyniki badań, 4) dyskusja, 5) bibliografia. Wyniki pomiarów należy podawać w jednostkach miar przyjętych w systemie metrycznym, a ich skróty – zgodnie z Międzynarodowym Układem Jednostek Miar (SI).

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