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Contents

Scientific papers

WŁODZIMIERZ GRYGIEL and MIROSŁAW WYSZYŃSKI
Temporal (1980-2001) and geographic variation in the sexual maturity at age and length of herring and sprat inhabiting the southern Baltic 3

JAN HORBOWY, MAGDALENA PODOLSKA and KRZYSZTOF RADTKE
The distribution, stock size and year-class strength of cod in the southern Baltic in 1981-2001 based on Polish groundfish surveys 35

DOROTA NAPIERSKA and MAGDALENA PODOLSKA
Preliminary results of AChE and GST measurements in flounder *Platichthys flesus* from the southern Baltic Sea 51

ALEXEI M. TOKRANOV and ALEXEI M. ORLOV
On the distribution and biology of roughscale sole *Clidoderma asperrimum* (Temminck et Schlegel, 1846) in the Pacific waters off the northern Kuril Islands and southeastern Kamchatka 67

Short communications

IWONA PSUTY-LIPSKA
Preliminary results regarding the impact of perch-roach gillnets on pikeperch resources in the Vistula Lagoon 81

Varia

JACEK KOSZAŁKA and ALEKSANDER BIELECKI
A new record of *Piscicola borowieci* Bielecki, 1997 (Hirudinea, Piscicolidae) in Poland 91

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Temporal (1980-2001) and geographic variation in the sexual maturity at age and length of herring and sprat inhabiting the southern Baltic

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Abstract. The percentage of sexually mature males and females of herring from the southern coast spring spawning population and sprat at age groups and length classes were investigated according to aggregated years and the Bornholm and Gdańsk basins. The temporal (1980-2001) changes in the proportion of mature clupeoids at age groups in ICES sub-divisions 24 and 25 were also analyzed. Moreover, the length of herring and sprat at first sexual maturity for particular year classes was calculated, and logistic curves of maturity ogives were elaborated. The possible influence of stock size, mean weight and length, body condition and sea-water and air temperatures on the maturing of clupeoids in the southern Baltic is discussed. The results of the investigations indicated that there was a larger numerical share of mature herring and sprat in younger age groups than the one assumed by ICES working groups. In the 1990s the mean percentage of herring from age group 2, which begins spawning for the first time, decreased from 80 to 75% in the Bornholm Basin and from 92 to 82% in the Gdańsk Basin. In these decades the fraction of sprat from age group 1, which begins spawning for the first time, increased in comparison with the 1980s from 26 to 38% in the Bornholm Basin and from 14 to 18% in the Gdańsk Basin.

Key words: herring, sprat, first sexual maturity, maturity ogive, southern Baltic basins

INTRODUCTION

The age structure of fish spawning stocks undergoes changes due to, among other factors, different rates of obtaining sexual maturation by specimens from the same species (when specimens become mature earlier the average age and upper range of their life is lower).

As a consequence of changes in seawater temperature, salinity and food resources, the percentage of maturing herring and sprat from different year classes can change in separate populations, but also in relation to sex in the same population (Koshelev 1971, Polivajko 1982, Szypuła 1992). Mild winters may have modified the maturation of fish – spawning started earlier and more fish spawned earlier than normal, for example as in 1990 with herring in the northern Baltic (Rajasilta *et al.* 1996). The influence of the season in which the first spawning in the life cycle of a given population of fishes take place is usually retained in their "memories" in the following years of life, e.g. in Baltic herring for 3-4 years (Anokhina 1969). In herring from northern seas, e.g. those from the White Sea, a loss of separateness of spawning seasons often takes place (Cheprakova 1971).

The timing of spawning in herring from the northern Baltic and the Vistula Lagoon was largely regulated by environmental factors, i.e. seawater temperature and ice conditions prior to spawning, and consequently the reproductive success of the species may be vulnerable to climatic changes (Rajasilta *et al.* 1996, Krasovskaya 2002). The gonado-somatic index of herring from the southwest part of the Baltic (within the Polish EEZ) attains high values in the period from January to May (from 12 to over 15%), and in June it suddenly decreases to values below 2% (Szypuła 1992). According to the results of investigations conducted by Shirokov (1990) and Kraus and Köster (2001), the peak of sprat spawning in the central parts of the Baltic in some years occurs in June (usually in May), as it did in 1999. After a review of the relevant literature, and on the basis of our own investigations, the periods from January to April and from February to May were designated in this paper as representative of the pre-spawning and spawning seasons for herring and sprat in the southern Baltic, respectively.

According to some authors, the process of fish sexual maturation is connected with the following:

– growth rate of fish length and weight, but not their age (Lapin and Jurovitskij 1959);

– minimum weight and age and geographical location of spawning grounds, e.g. in reference to plaice from the North Sea – this process is susceptible to annual changes (Bromley 2000);

– age, rather than length, e.g. in reference to cod from the Irish Sea (Armstrong *et al.* 2001).

The simple relationship between fish maturity and age group is characteristic for a population and not for specimens of a given species (Lapin and Jurovitskij 1959).

At the end of the 1990s, scientists from most Baltic countries undertook joint investigations of herring and sprat (separately for female and male) maturity ogives as well as the sex ratio in exploited stocks with regard to the age and length structure of fish. In 1999 the ICES Study Group on Baltic Herring and Sprat Maturity (SGBHSM) and the ICES Working Group on Baltic Fisheries Assessment (WGBFAS) initiated these investigations (Anon. 1998, 1999, 2001a, 2001b). Similar international investigations of Baltic cod were begun a few years earlier (Anon. 1994, 1999, Tomkiewicz et al. 1997). The lack of detailed data for fish stock size assessment mathematical models (e.g. VPA) does not permit more accurate estimations of spawning stock size to be made and can result in erroneous calculations (Tomkiewicz *et al.* 1997).

There are a few papers in the literature from the last 25 years which report results of investigations on Baltic herring and sprat sexual maturation versus age and length (Shirokov 1990, Wyszyński 1997, Feldman *et al.* 2000, Reglero and Mosegaard 2001, Grygiel and Wyszyński 2002, Kaljuste and Raid 2002).

One of the reasons the authors undertook the present investigations was the fact that over the 1974-1999 period the ICES working groups estimated the Baltic herring (with the exception of ICES sub-divisions 30 and 31) and sprat stock sizes using constant, fixed and combined sex maturity ogive values at age groups and ICES sub-divisions. This parameter was not verified until 2000.

The goal of this paper is to present the temporal (1980-2001) and geographic (within the Polish EEZ) variation in maturity at age and length, according to the sex of herring from the southern coast spring spawning population and sprat inhabiting the Bornholm and Gdańsk basins. The possible relationships between clupeoid stocks size, mean weight and length, body condition coefficient and seawater and air temperatures versus the percentage of mature fish were also analyzed.

MATERIALS AND METHODS

The investigative materials were sampled by the authors over the 1980-2001 period, mostly during research surveys organized by the Sea Fisheries Institute in Gdynia and, to a lesser degree, directly from the catches and landings of the Polish commercial fishing fleet. Bromley (2000), Armstrong *et al*. (2001), Kraus and Köster (2001), Reglero and Mosegaard (2001), Kaljuste and Raid (2002) have applied the same system of fish sampling for investigations of maturity ogives.

A P20/25 herring bottom trawl with a 6-mm bar length in the codend was used in the survey catches. Most of the data from April and May came from commercial small mesh size trawl catches, which were not sorted into size groups. Treschov and Shevtsov (1978) and Shevtsov (1982), who conducted investigations of the selectivity of commercial sprat trawls, indicated that trawls with the popular 20 mm mesh size in the codend are characterized by relatively low selectivity (76.8% of young specimens were retained, on average).

At least two random samples per month in the pre-spawning and at the beginning of spawning seasons and ICES Sub-division, with no preference to fishing location, were examined. The geographical distribution of herring and sprat sampling over the 1980-2001 period is presented in Figure 1. In some years, the number of fish (especially sprat)

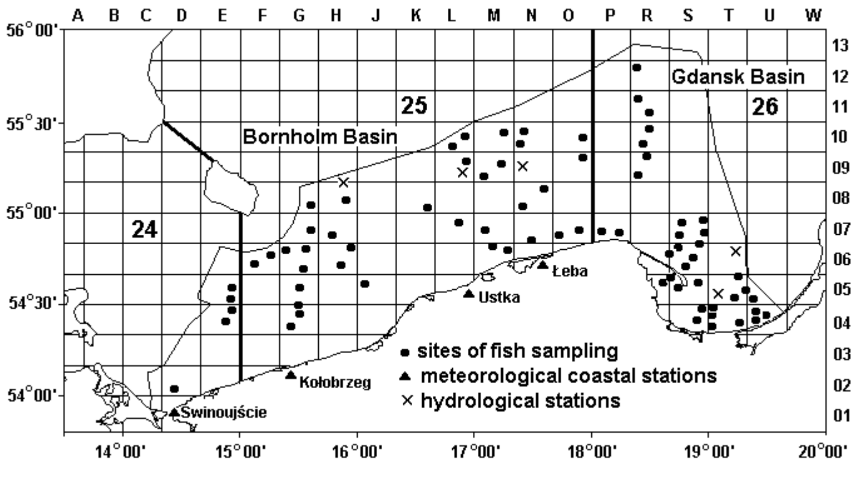


Fig. 1. Geographical distribution of herring and sprat sampling in the southern Baltic (within the Polish EEZ) in 1980-2001 and locations of hydrological and meteorological stations.

collected for biological analysis was not numerous and, equally importantly, the share of young specimens was low. Thus, for example, the sprat data from the Bornholm Basin in 1994 are not representative, those from 1984-1985 are not so numerous and in 1987 and 1999 the fraction of young sprat was relatively small.

Length (*longitudo totalis*) measurements of 104,072 herring and 61,176 sprat from the 1980-2001 period and the ichthyological analyses of 13,915 herring and 12,067 sprat specimens formed the basis for the calculations presented in this article (Tables 1 and 2). The fish were grouped into 0.5-cm length classes. The analyzed fish were weighed to within 0.1 gram, and their age was determined by examining the otolith macrostructure. The fish were sexed during standard ichthyological analyses, and the eight-degree Maier scale (Maier 1906) was used to describe the maturity stages of the Baltic herring and sprat specimens. The gonad developmental stage was determined by visual, macroscopic identification.

The length distribution and age composition were determined (separately for males and females) for the southern coast spring spawning herring population and sprat caught in the pre-spawning and at the beginning of spawning seasons (1980-2001) in the Polish EEZ. Herring from this population mature, spawn and usually dominated in Polish commercial catches. Clupeoid age composition, determined on the basis of biological analyses, was weighted by the length distribution according to sex.

The collection of materials was grouped according to the geographical locations of the Bornholm Basin (ICES sub-divisions 24+25) and the Gdańsk Basin (Sub-division 26; Fig. 1) and year groups selected according to the results of optical analysis of the mean weight at age fluctuation and clupeoid fish stocks size changes (see the Results section). The long-term (1980-2001) changes in the proportion (number %) of mature clupeoids at age groups in the Bornholm Basin were also analyzed.

Clupeoids with gonads in maturity stages III and IV on the Maier scale (in the seasons from January to April – herring, February to May – sprat) were classified as the sexually mature fraction which were potentially ready for spawning in a given season. In the final stages of constructing the fish database, the authors' data on herring and sprat gonad maturity were converted to the five-degree ICES scale recommended by ICES BIFSWG and SGBHSM (Anon. 1999, 2000a). The scheme of this transformation is given below:

ICES (BIFSWG) scale	I	II	III	IV	V	immature (I+V)	mature (II+III+IV)
Maier scale	I	III-V	VI-VII	VIII	II		

A simple statistical model of herring and sprat maturity ogives versus length classes was formulated during the final stage of the work. A modified logistic curve (non-linear regression; Rickey 1995) was applied for plotting the fish maturity ogive, well-fitted according to the following formula:

$$Y = \left(\frac{1}{1 + \mathrm{e}^{(a+bX)}} \right) \cdot 100 \qquad [1]$$

where: Y – percentage of the number of mature specimens, X – length class, e – base of the natural logarithm, and a and b – constant coefficients of the equation initially calculated from linear regression ($y = a + bx$).

Table 1. Number of herring for which total length was measured (A) and age determined (B) over the 1980-2001 period, grouped by years and basins of the southern Baltic

A)	Groups of years										
	1980-1984		1985-1989		1993-1999		2000-2001		Total		
Region \ Sex	males	females	males	females	males	females	males	females	males	females	combined
Bornholm Basin	6,059	6,802	4,198	5,142	4,141	4,127	3,309	3,753	17,707	19,824	37,531
Gdańsk Basin	6,959	7,385	6,421	7,082	19,436	19,257	–	–	32,816	33,725	66,541

B)	Years	Age groups									
		1	2	3	4	5	6	7	8	9	Total
Bornholm Basin	1980-1984	591	366	697	403	97	41	6	0	2	2,203
	1985-1989	207	406	397	237	156	87	29	9	1	1,529
	1993-1999	372	177	101	95	74	54	16	7	6	902
	2000-2001	244	164	88	63	29	38	14	2	1	643
	total	1,414	1,113	1,283	798	356	220	65	18	10	5,277
Gdańsk Basin	1980-1984	586	920	568	204	54	11	5	0	0	2,348
	1985-1989	569	561	407	181	149	30	8	4	0	1,909
	1993-1999	1,341	1,206	624	481	388	213	79	35	14	4,381
	total	2,496	2,687	1,599	866	591	254	92	39	14	8,638

Table 2. Number of sprat for which total length was measured (A) and age determined (B) over the 1980-2001 period, grouped by years and basins of the southern Baltic

A)	Groups of years												
	1980-1981		1991-1992		1996-1997		1980-1990		1991-2001		total		
Region \ Sex	males	females	males	females	males	females	males	females	males	females	males	females	combined
Bornholm Basin	962	912	1,975	3,247	1,178	1,703	6,645	6,245	7,353	8,935	13,998	15,180	29,178
Gdańsk Basin	1,303	1,793	3,759	2,885	1,566	1,832	6,962	7,039	8,532	9,465	1,5494	16,504	31,998

B)	Years	Age groups											total
		1	2	3	4	5	6	7	8	9	10	11	
Bornholm Basin	1980-1981	46	62	32	28	28	7	2	0	0	0	0	205
	1991-1992	85	289	347	139	77	45	22	13	4	0	0	1,021
	1996-1997	131	283	150	114	108	72	31	10	1	0	0	900
	1980-1990	384	379	330	347	279	211	66	12	4	1	1	2,014
	1991-2001	609	1070	976	765	468	302	121	40	18	2	0	4,371
	total	993	1449	1306	1112	747	513	187	52	22	3	1	6,385
Gdańsk Basin	1980-1981	103	132	59	45	57	13	8	1	0	0	0	418
	1991-1992	161	246	171	85	51	27	10	4	0	1	0	756
	1996-1997	58	190	147	141	101	53	13	10	1	0	0	714
	1980-1990	704	696	563	423	272	94	48	13	6	0	0	2,819
	1991-2000	414	725	700	504	303	149	47	18	2	1	0	2,863
	total	1,118	1,421	1,263	927	575	243	95	31	8	1	0	5,682

In the regression analysis used, the value of the natural logarithm from the reverses of the dependent variable was provided instead of variable Y according to the following formula:

$$Y' = \ln\left(\frac{1}{Y-1}\right) \quad [2]$$

The length at which 50% of the fish population achieved first sexual maturity was calculated according to following formula (Seber 1982):

$$L_{50\%} = \frac{-a}{b} \quad [3]$$

where: L – length (cm), a and b – the coefficients of regression analysis cited above.

Linear regression analysis was also performed on the variable percentage of mature specimens from all age groups versus length classes of herring and sprat caught in the Bornholm and Gdańsk basins in the 1980-1999 period. This type of analysis was also applied to the variable percentage of mature herring from age group 2 and sprat from age groups 1 and 2 caught in the Bornholm Basin (1980-2001) versus their mean weight, length, body condition coefficient (K), stock size (abundance) as well as mean air and seawater temperatures.

Data relating to mean weight, mean length and the coefficient of catabolism ($K = W \cdot 100/L^3$; where: W – weight (g), L – length (cm)) of herring were from the first and second quarters of the 1980-2001 period, and those for sprat were from the first quarter of the same period. ICES data for herring stock abundance refer to ICES sub-divisions 25-27 and two spring spawning populations, and for sprat they refer to the entire Baltic Sea (ICES sub-divisions 22-32; Anon. 2001a). It should be emphasized that the results of fish stock assessments (including the abundance of particular year-classes) are always more or less uncertain, and they are strongly dependent on the input data, which often includes various assumptions. Data of the mean air temperature come from measurements taken at coastal stations located in Łeba, Ustka, Kołobrzeg and Świnoujście (Fig. 1). The seawater temperature measurements at the 30-70 m depth stratum come from the Bornholm Deep (stations IBY5 – 55°14´N, 15°59´E), the Słupsk Furrow (stations RS2 – 55°14´N, 17°20´E and B2 – 55°12´N, 17°00´E), the Gdańsk Deep (station G2 – 54°50´N, 19°20´E) and partly from the Gulf of Gdańsk (station 2GD – 54°36´N, 19°06´E) in the second half of the previous year and in the first quarter of the given year (Fig. 1).

Most of water and air temperature data were obtained courtesy of the Institute of Meteorology and Water Management, Maritime Branch in Gdynia. These parameters were also measured during research surveys organized by the Sea Fisheries Institute in Gdynia.

RESULTS

Basis of grouping investigation results by years and regions

In order to create groups from the investigation results of maturity ogive changes in relation to the 1980s and 1990s, two factors were designated – stock size (biomass and abundance) and the mean weight at age groups. The total biomass and stock abundance of herring from ICES sub-divisions 25-27 has decreased dramatically over the last 22 years (Fig. 2.A):

– biomass decreased from 1,544.6 thousand t. in 1981 to 392.3 thousand t. in 1999 (↓ 75%);

– abundance decreased from 24.395 billion in 1982 to 13.740 billion in 2001 (↓ 44%).

In contrast to herring, the biomass and abundance of the sprat spawning stock (sub-divisions 22-32) increased considerably in the 1981-1997 period (Fig. 2.A):

– biomass grew from 158.3 to 1,690.4 thousand t. (↑ 968%);

– abundance grew from 15.9 to 278.7 billion (↑ 1,653%); both biomass and abundance began to decline gradually in the following years.

The herring biomass of the 1980s was higher in relation to the long-term mean, while that in the 1990s was lower. During this same period, changes in sprat stock biomass were inverse (Fig. 2.B). The lesser decline in herring stock abundance in comparison with biomass was caused by the decrease in the mean weight at age. The high numbers of the few recruiting year-classes and the decrease of the mean weight in age groups 2-4 caused a smaller increase in sprat stock biomass in comparison with its abundance.

The average values of the increase (1981) and decrease (1998 – herring, 1997 – sprat) in the mean weight of clupeoids in all the examined age groups (Fig. 3) in relation to the long-term (1980-2001) mean are listed below:

– increases of 49 and 14% in herring and sprat, respectively – from the Bornholm Basin and of 35 and 30% in the same species, respectively – from the Gdańsk Basin;

– decreases of 29 and 23% in herring and sprat, respectively – from the Bornholm Basin and of 28 and 20% in the same species, respectively – from the Gdańsk Basin.

The analysis of data from the 1980-2001 period indicates various trends in herring stock biomass and abundance in comparison with the sprat stock. Herring exhibits a decreasing tendency, while with sprat it is increasing, but similar changes are evident with regards to the mean weight at age in that the value is smaller than the long-term mean (Figs. 2 and 3).

Based on the optical analysis of the mean weight at age and stock size changes, the three following year groups for herring were determined:

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

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

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

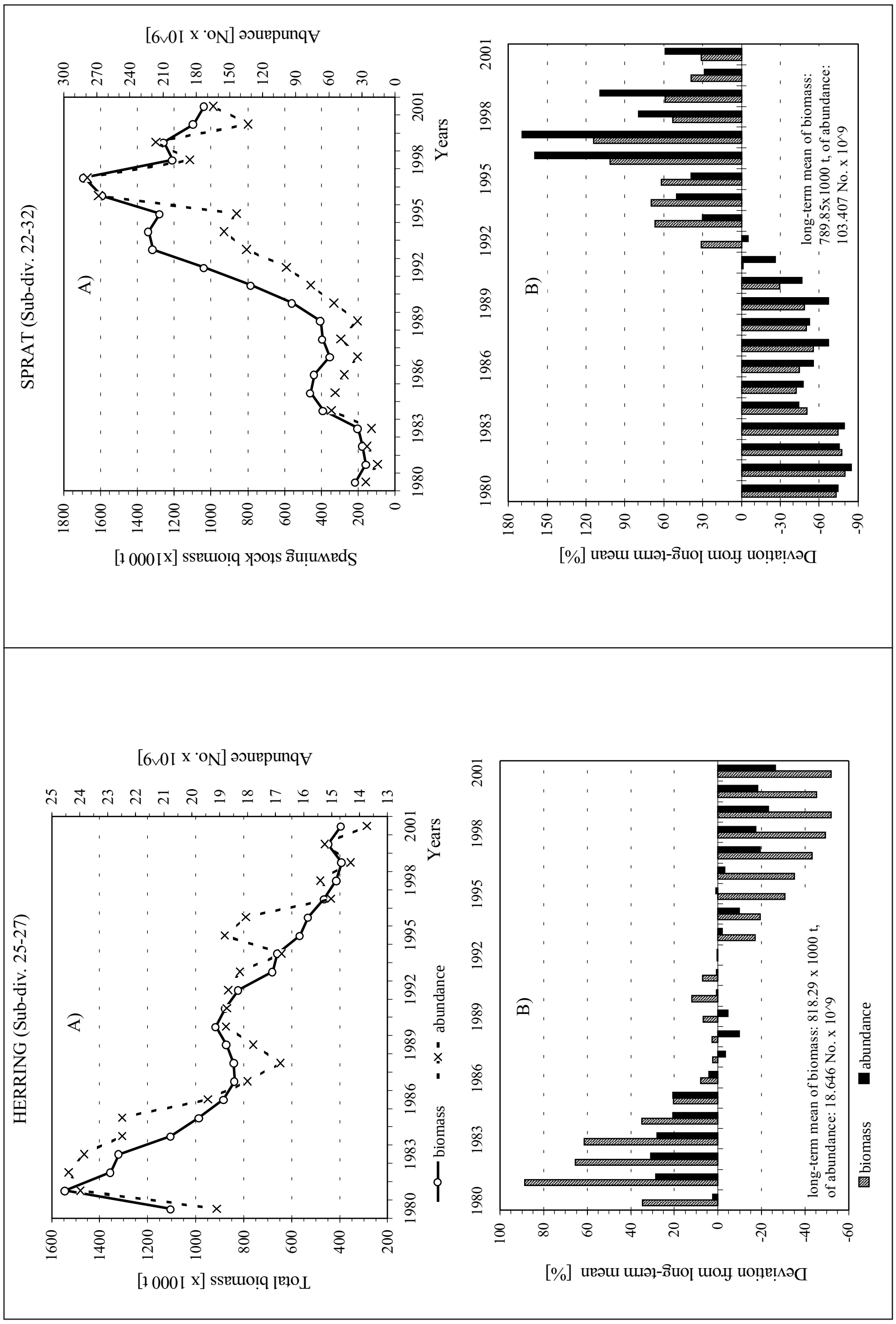
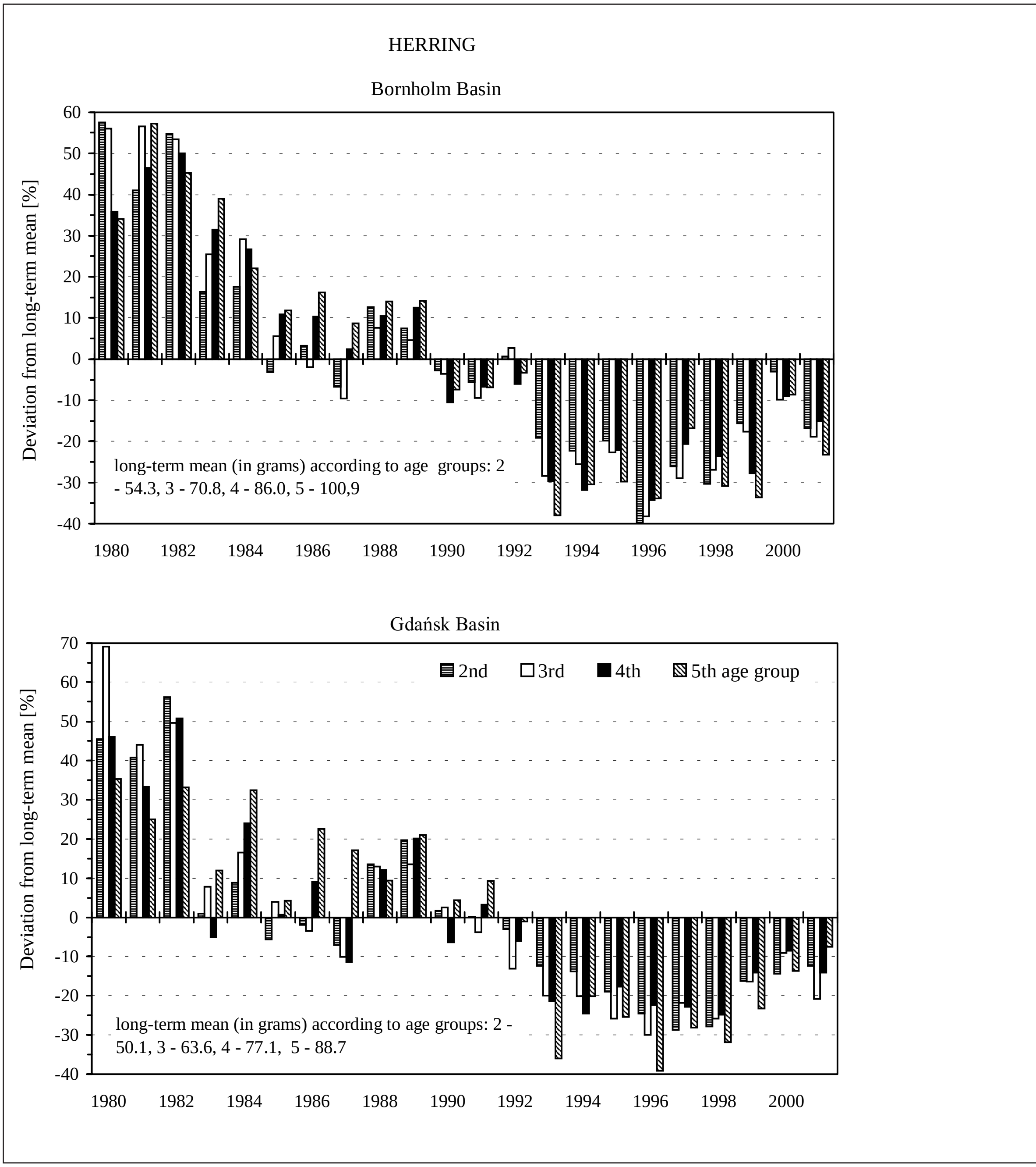


Fig. 2. Changes in herring and sprat stocks size (biomass and abundance) in 1980-2001 (part A) and deviation of variables from long-term mean values (part B); based on ICES-BFASWG data (Anon. 2001a; data for 2001 are only prognostic).


HERRING
Bornholm Basin
Deviation from long-term mean [%]
long-term mean (in grams) according to age groups: 2 - 54.3, 3 - 70.8, 4 - 86.0, 5 - 100,9
60
50
40
30
20
10
0
-10
-20
-30
-40
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
Gdańsk Basin
2nd
3rd
4th
5th age group
Deviation from long-term mean [%]
long-term mean (in grams) according to age groups: 2 - 50.1, 3 - 63.6, 4 - 77.1, 5 - 88.7
70
60
50
40
30
20
10
0
-10
-20
-30
-40
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000

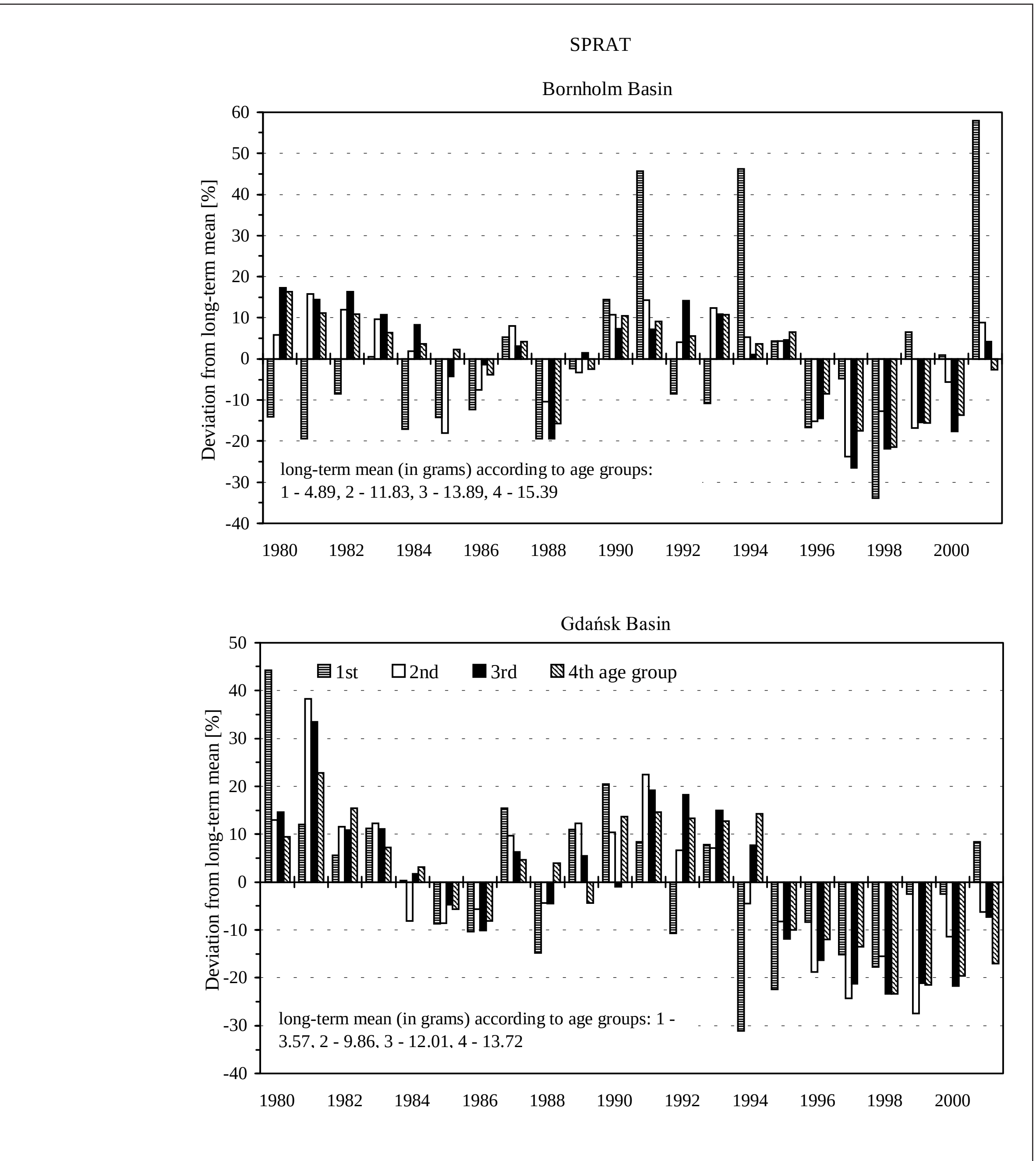


Fig. 3. Deviation of mean weight at age of herring and sprat from the long-term (1980-2001) mean; based on sampling results – herring in the second half of the year, sprat in the first quarter; data for age group 1 of sprat from the Bornholm Basin caught in 1990 and 1994 are not fully representative.

The five following groups of years were determined for sprat:

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

2) 1991-1992 – with high values of mean weight at age and stock biomass similar to the long-term (1980-2001) mean;

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

4) 1980-1990 – with spawning stock biomass and abundance below the level of the long-term mean;

5) 1991-2000 – with spawning stock biomass and abundance above the level of the long-term mean.

The second criterion for aggregating investigative materials was the geographical location of the main basins in the southern Baltic (the Bornholm Basin and the Gdańsk Basin), which, to a large degree, corresponds with ecological differentiation and with the dissimilarity of the clupeoid fish stocks inhabiting these regions.

Considering the background of the changes described above, variations could also be expected in the maturation processes of herring and sprat affected by population density as well as by mean weight at age variation in selected years.

Sexual maturity at age groups

The distributions of the fraction of mature herring (from the southern coast spring spawning population) and sprat in particular age groups (from 1 to 9) by sex, grouped by years from the 1980-2001 period and the Bornholm and Gdańsk basins are presented in Tables 3 and 4.

As the herring growth rate in weight decreased in 1980-1999, the mean percentage of mature males and females (combined) from age group 2 acceding to first spawning decreased from 79.5 to 74.8 in the Bornholm Basin and from 91.8 to 82.2 in the Gdańsk Basin (Table 3). The mean value of this variable decreased from 88.1 to 80.3% in all the investigated areas. The proportion of mature males and females of herring from age group 2 was about 7-19% higher, on average, in the Gdańsk Basin (in the examined groups of years) in comparison to the Bornholm Basin. Moreover, a slightly higher percentage (1-5) of mature males versus mature females was noted in all year groups (except for 1993-1999 in the Bornholm Basin). The proportion of mature herring in older age groups (3-9) ranged from 97.6 to 100.0%. In contrast, the fraction of young mature herring from age group 1 was generally equal to zero.

In comparison to the 1980s, the mean percentage of sprat males and females (combined) from age group 1 acceding to first spawning increased in the 1990s from 25.8 to 38.4 in the Bornholm Basin, while a lower range (from 14.5 to 18.2) was noted in the Gdańsk Basin. The mean value of this variable increased from 18.7 to 27.8% in all the investigated areas. More detailed analysis of the yearly data (1980-2001) for herring from age group 2 and sprat from age group 1 caught in the Bornholm Basin (Fig. 7) indicates that the change in the fraction of mature fish was not linear, but was approximately sinusoidal in shape with a marked growth tendency, e.g. in sprat from 1982-1984, 1991-1992 and especially after 1996. A considerable decline (below 5%, on average) of the fraction of young, mature sprat in the Bornholm Basin was recorded in 1985-1988 and 1993-1995.

Table 3. Numerical percentage of mature (M) herring in particular age groups, according to sex, year groups (1980-1999) and basins of the southern Baltic; SE – standard error

Sex	Years	Para-meters	Age groups								
			1	2	3	4	5	6	7	8	9
Bornholm Basin											
Males	1980-1984	M	0.0	85.5	99.5	99.5	100.0	100.0	100.0	–	–
		SE	0.0	0.027	0.004	0.005	0.0	0.0	0.0	–	–
	1985-1989	M	0.0	75.8	100.0	98.7	100.0	100.0	100.0	100.0	100.0
		SE	0.0	0.033	0.0	0.010	0.0	0.0	0.0	0.0	0.0
	1993-1999	M	0.0	73.2	97.7	98.0	100.0	100.0	100.0	100.0	100.0
		SE	0.0	0.047	0.021	0.020	0.0	0.0	0.0	0.0	0.0
Females	1980-1984	M	0.0	74.2	99.1	99.1	100.0	100.0	100.0	–	100.0
		SE	0.0	0.031	0.005	0.006	0.0	0.0	0.0	–	0.0
	1985-1989	M	0.0	75.5	100.0	100.0	98.9	100.0	100.0	100.0	–
		SE	0.0	0.028	0.0	0.0	0.010	0.0	0.0	0.0	–
	1993-1999	M	0.0	76.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		SE	0.0	0.046	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Combined	1980-1984	M	0.0	79.5	99.3	99.3	100.0	100.0	100.0	–	100.0
		SE	0.0	0.021	0.003	0.004	0.0	0.0	0.0	–	0.0
	1985-1989	M	0.0	75.6	100.0	99.3	99.3	100.0	100.0	100.0	100.0
		SE	0.0	0.021	0.0	0.005	0.007	0.0	0.0	0.0	0.0
	1993-1999	M	0.0	74.8	98.8	99.0	100.0	100.0	100.0	100.0	100.0
		SE	0.0	0.033	0.011	0.010	0.0	0.0	0.0	0.0	0.0
Gdańsk Basin											
Males	1980-1984	M	0.0	93.1	100.0	100.0	100.0	100.0	100.0	–	–
		SE	0.0	0.012	0.0	0.0	0.0	0.0	0.0	–	–
	1985-1989	M	0.0	89.6	99.2	100.0	100.0	100.0	100.0	100.0	–
		SE	0.0	0.019	0.006	0.0	0.0	0.0	0.0	0.0	–
	1993-1999	M	0.0	84.5	99.2	100.0	100.0	100.0	100.0	100.0	100.0
		SE	0.0	0.015	0.005	0.0	0.0	0.0	0.0	0.0	0.0
Females	1980-1984	M	0.0	90.4	99.3	100.0	95.9	100.0	100.0	–	–
		SE	0.0	0.014	0.005	0.0	0.035	0.0	0.0	–	–
	1985-1989	M	0.0	88.1	100.0	100.0	100.0	100.0	100.0	100.0	–
		SE	0.0	0.018	0.0	0.0	0.0	0.0	0.0	0.0	–
	1993-1999	M	0.0	80.0	99.0	100.0	100.0	100.0	100.0	100.0	100.0
		SE	0.0	0.016	0.006	0.0	0.0	0.0	0.0	0.0	0.0
Combined	1980-1984	M	0.0	91.8	99.6	100.0	97.6	100.0	100.0	–	–
		SE	0.0	0.009	0.003	0.0	0.021	0.0	0.0	–	–
	1985-1989	M	0.0	88.8	99.6	100.0	100.0	100.0	100.0	–	–
		SE	0.0	0.018	0.003	0.0	0.0	0.0	0.0	–	–
	1993-1999	M	0.0	82.2	99.1	100.0	100.0	100.0	100.0	100.0	100.0
		SE	0.0	0.011	0.004	0.0	0.0	0.0	0.0	0.0	0.0

Table 4. Numerical percentage of mature (M) sprat in particular age groups, according to sex, year groups (1980-2000) and basins of the southern Baltic; SE - standard error; non representative values are given in the brackets

Sex	Years	Para-meters	Age groups 1	2	3	4	5	6	7	8	9	10	11
Bornholm Basin													
Males	1980-1981	M	25.4	100.0	100.0	100.0	100.0	100.0	100.0	–	–	–	–
		SE	0.081	0.0	0.0	0.0	0.0	0.0	0.0	–	–	–	–
	1991-1992	M	60.0	99.6	100.0	100.0	100.0	100.0	100.0	100.0	–	–	–
		SE	0.077	0.006	0.0	0.0	0.0	0.0	0.0	0.0	–	–	–
	1996-1997	M	57.3	98.6	100.0	100.0	100.0	100.0	100.0	100.0	–	–	–
		SE	0.062	0.010	0.0	0.0	0.0	0.0	0.0	0.0	–	–	–
	1980-1990	M	39.5	98.5	100.0	100.0	100.0	100.0	100.0	100.0	–	100.0	–
		SE	0.036	0.008	0.0	0.0	0.0	0.0	0.0	0.0	–	0.0	–
	1991-2000	M	57.1	98.6	100.0	100.0	100.0	100.0	100.0	100.0	–	–	–
		SE	0.031	0.006	0.0	0.0	0.0	0.0	0.0	0.0	–	–	–
Females	1980-1981	M	4.6	99.5	100.0	100.0	100.0	100.0	100.0	–	–	–	–
		SE	0.051	0.014	0.0	0.0	0.0	0.0	0.0	–	–	–	–
	1991-1992	M	16.3	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	–	–
		SE	0.055	0.004	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	–
	1996-1997	M	20.7	90.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	–	–
		SE	0.049	0.024	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	–
	1980-1990	M	12.5	98.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	–	100.0
		SE	0.024	0.009	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	0.0
	1991-2000	M	22.1	94.2	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	–
		SE	0.024	0.012	0.002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–
Combined	1980-1981	M	16.8	99.8	100.0	100.0	100.0	100.0	100.0	-	–	–	–
		SE	0.055	0.006	0.0	0.0	0.0	0.0	0.0	-	–	–	–
	1991-1992	M	37.2	99.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	–	–
		SE	0.052	0.003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	–
	1996-1997	M	38.9	94.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	–	–
		SE	0.043	0.014	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	–
	1980-1990	M	25.8	98.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		SE	0.022	0.006	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1991-2000	M	38.4	96.5	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	–
		SE	0.021	0.007	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–
Gdańsk Basin													
Males	1980-1981	M	52.6	(100.0)	100.0	100.0	100.0	100.0	100.0	-	–	–	–
		SE	0.072	0.0	0.0	0.0	0.0	0.0	0.0	-	–	–	–
	1991-1992	M	14.6	96.4	100.0	100.0	100.0	100.0	100.0	-	–	100.0	–
		SE	0.039	0.015	0.0	0.0	0.0	0.0	0.0	-	–	0.0	–
	1996-1997	M	20.5	99.6	100.0	100.0	100.0	100.0	100.0	100.0	–	–	–
		SE	0.079	0.007	0.0	0.0	0.0	0.0	0.0	0.0	–	–	–
	1980-1990	M	21.1	97.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	–	–
		SE	0.022	0.008	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	–
	1991-2000	M	31.7	96.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	–
		SE	0.033	0.009	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–

table 4, continued

Sex	Years	Para-meters	Age groups 1	2	3	4	5	6	7	8	9	10	11
Gdańsk Basin (continued)													
Females	1980-1981	M	31.9	(100.0)	100.0	100.0	100.0	100.0	100.0	100.0	–	–	–
		SE	0.063	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	–	–
	1991-1992	M	0.0	79.5	100.0	100.0	100.0	100.0	100.0	100.0	–	–	–
		SE	0.0	0.044	0.0	0.0	0.0	0.0	0.0	0.0	–	–	–
	1996-1997	M	3.4	95.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	–	–
		SE	0.032	0.021	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	–
	1980-1990	M	7.6	93.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	–	–
		SE	0.014	0.014	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	–
	1991-2000	M	6.2	86.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	–
		SE	0.016	0.021	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–
Combined	1980-1981	M	40.9	(100.0)	100.0	100.0	100.0	100.0	100.0	100.0	–	–	–
		SE	0.048	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	–	–
	1991-1992	M	7.2	90.4	100.0	100.0	100.0	100.0	100.0	100.0	–	100.0	–
		SE	0.020	0.019	0.0	0.0	0.0	0.0	0.0	0.0	–	0.0	–
	1996-1997	M	10.7	97.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	–	–
		SE	0.041	0.011	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	–
	1980-1990	M	14.5	95.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	–	–
		SE	0.013	0.008	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	–
	1991-2000	M	18.1	92.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	–
		SE	0.019	0.010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–

The mean proportion of mature sprat from age group 2 caught in the Bornholm Basin ranged from 98.5 to 100.0% for males and from 90.7 to 99.8% for females in the five groups of years studied. The values of this variable for sprat from the Gdańsk Basin were slightly lower at 96.1-99.6% for males and 79.5-95.6% for females. All of the sprat individuals from older age groups were potentially ready for spawning in a given year.

The fraction of mature males from younger sprat age groups in comparison with the fraction of mature females in both the Bornholm Basin and the Gdańsk Basin was greater in every analyzed group of years (Table 4). For example, in the 1980s and 1990s, the fractions of mature males and females (from age group 1) in the two analyzed basins were as follows (in number percentages):

– 39.5 (1980s) and 57.2 (1990s) for males, and 12.5 (1980s) and 22.1 (1990s) for females from the Bornholm Basin;

– 21.1 (1980s) and 31.7 (1990s) for males, and 7.6 (1980s) and 6.2 (1990s) for females from the Gdańsk Basin.

Moreover, the proportion of mature sprat from age group 1 (except for 1980-1981) was higher in the Bornholm Basin than in the Gdańsk Basin, e. g.:

– for males about 18% in the 1980s and 26% in the 1990s, on average;

– for females about 5% in the 1980s and 16% in the 1990s, on average.

The results of the authors' investigations indicate a greater proportion of mature herring (with the exception of age group 1) and sprat in the younger age groups than was assumed by ICES working groups up to 2000 (Table 5).

Table 5. Proportion (numerical percentage) of mature herring and sprat in younger age groups, assumed by ICES working groups and calculated by the authors

	Age groups >	1	2	3	4
Herring	the authors' data	0	75-80, Bornholm Basin 82-92, Gdańsk Basin	98-100	100
	ICES data	0	70	90	100
Sprat	the authors data	26-38, Bornholm Basin 15-18, Gdańsk Basin	91-100	100	100
	ICES data	0	70	100	100

Sexual maturity in length classes – maturity ogive

Herring length in the samples ranged from 8.0 to 34.5 cm in the Bornholm Basin and from 6.5 to 32.5 cm in the Gdańsk Basin. Sprat length ranged from 6.0 to 17.0 cm and from 5.0 to 16.5 cm in the same basins, respectively.

The initial stage in the preparation of the clupeoid maturity logistic curves was regression analysis (linear model) and analysis of variance of the logarithm of the percentage of all mature herring and sprat specimens versus length classes. Calculations were performed separately according to sex, groups of years (1980-2000) and southern Baltic basins. Table 6 presents the value ranges of the indicator parameters of these analyses. The regression analysis parameters show statistically significant relationships between clupeoid length growth and the percentage of mature specimens. One of these parameters, the correlation coefficient (r) ranged from 0.78 to 0.88 for herring and from 0.64 to 0.91 for sprat. Moreover, the statistics F – ratio was higher than critical values, while the probability level and values of the p parameter (for constant coefficients a and b) were considerably below the critical level $p = 0.05$.

Three examples of logistic curves of clupeoid sexual maturation in the 1980-2000 period in relation to length classes are presented in Figures 4-6. The calculated values of the indicatory mean length at first sexual maturity ($L_{50\%}$ – a component of the protection length of a given species) of males and females are presented in Table 7. These data refer to the critical level of a 50% numerical share of mature fish in samples from the Polish EEZ which accede to first spawning in a life cycle of the very same length.

The results of the investigations show that in 1980-1999, along with the decline of herring mean weight at age, the length of first sexual maturation also decreased in both males and females (Fig. 4). In comparison to the 1980-1984 period, from 1993-1999 the indicatory length ($L_{50\%}$) of herring decreased from 19.7 to 16.7 cm in the Bornholm Basin and from 18.4 to 16.3 cm in the Gdańsk Basin. At the beginning of the 1980s, the herring growth rate, especially the mean weight at age, and the total biomass of the stock from ICES sub-divisions 25-27 was higher than it has been in the last 22 years (Figs. 2, 3 and 7). In comparison to the 1980s, the decline in sprat indicatory length ($L_{50\%}$) in the 1990s was only 0.2 cm in the Bornholm Basin and 0.3 cm in the Gdańsk Basin (Fig. 6), and was not as significant as that for herring (3.0 and 2.1 cm, on average, by basin).

Table 6. Value ranges of indicator parameters of regression analysis (linear model) and analysis of variance of the logarithm of the percentage of all mature herring and sprat specimens (data from 1980-2000) versus length classes

		Bornholm Basin			Gdańsk Basin		
		coefficient R^2 [%]	probability level	F – ratio	coefficient R^2 [%]	probability level	F – ratio
Herring	males	81.6 - 85.4	1.60E-19 - 1.20E-16	181.48 -242.61	85.1 - 87.4	5.00E-21 - 1.40E-19	259.86 - 292.54
	females	77.5 - 85.1	1.10E-20 - 1.40E-17	145.00 -263.57	83.6 - 86.4	1.20E-21 - 8.90E-20	259.93 -273.32
	combined	83.6 - 85.9	1.30E-21 - 6.60E-19	224.90 -285.89	83.6 - 87.6	1.10E-21 - 1.75E-20	260.52 - 295.97
Sprat	males	64.3 - 86.1	4.00E-9 - 1.90E-4	25.23 - 111.36	68.4 - 90.7	1.00E-10 - 4.00E-5	34.16 - 166.22
	females	66.4 - 84.4	2.00E-9 - 7.00E-5	29.63 - 107.98	73.8 - 89.7	3.00E-11 - 5.00E-6	44.95 - 164.87
	combined	68.7 - 85.1	4.00E-10 - 3.00E-5	34.26 - 118.88	72.8 - 89.0	1.00E-11 - 7.00E-6	42.78 - 177.63

In 1980-1999, the 50% level of mature herring in the samples from the Gdańsk Basin as compared to those from the Bornholm Basin was achieved at an indicatory length that was smaller by about 0.75 cm, on average (Fig. 4). A similar tendency was observed with sprat (except in 1991-1992). In 1980-1981, differences in the indicatory length ($L_{50\%}$) of sprat from the two Baltic basins was 1.22 cm for males and 1.66 cm for females, but in 1996-1997 these differences were smaller at 0.55 cm (males) and 0.83 cm (females).

In comparison with sprat females, males always achieved the 50% level of mature specimens at a smaller indicatory mean length (Figs. 5 and 6, Table 7) in the two studied Baltic basins and year groups, although this tendency was weaker in young herring. The indicatory mean length ($L_{50\%}$) of sprat males ranged from 7.84 to 9.73 cm in the Bornholm Basin and from 8.25 to 9.89 cm in the Gdańsk Basin in the 1980-2000 period. Sprat females from the studied basins achieved first sexual maturity at a length range of 9.98 to 10.85 cm in the Bornholm Basin and from 9.19 to 10.92 cm in the Gdańsk Basin. In the 1980s, the length differences between sprat males and females at which 50% of the specimens are potentially ready for the first spawning was 0.25 cm in the Bornholm Basin and 0.52 cm in the Gdańsk Basin. These differences were slightly larger in the two basins in the 1990s at 0.96 and 0.67 cm, respectively.

The percentages of mature clupeoids successively increased in length classes that are larger than the critical length at first sexual maturation. In the 1980-1999 period almost all herring males and females above 19 and 20 cm, respectively, and sprat males and females above 9.5 and 10.5 cm, respectively, were mature. The share of females in the samples increased with herring and sprat longer than 21.5 cm and 11.5 cm, respectively.

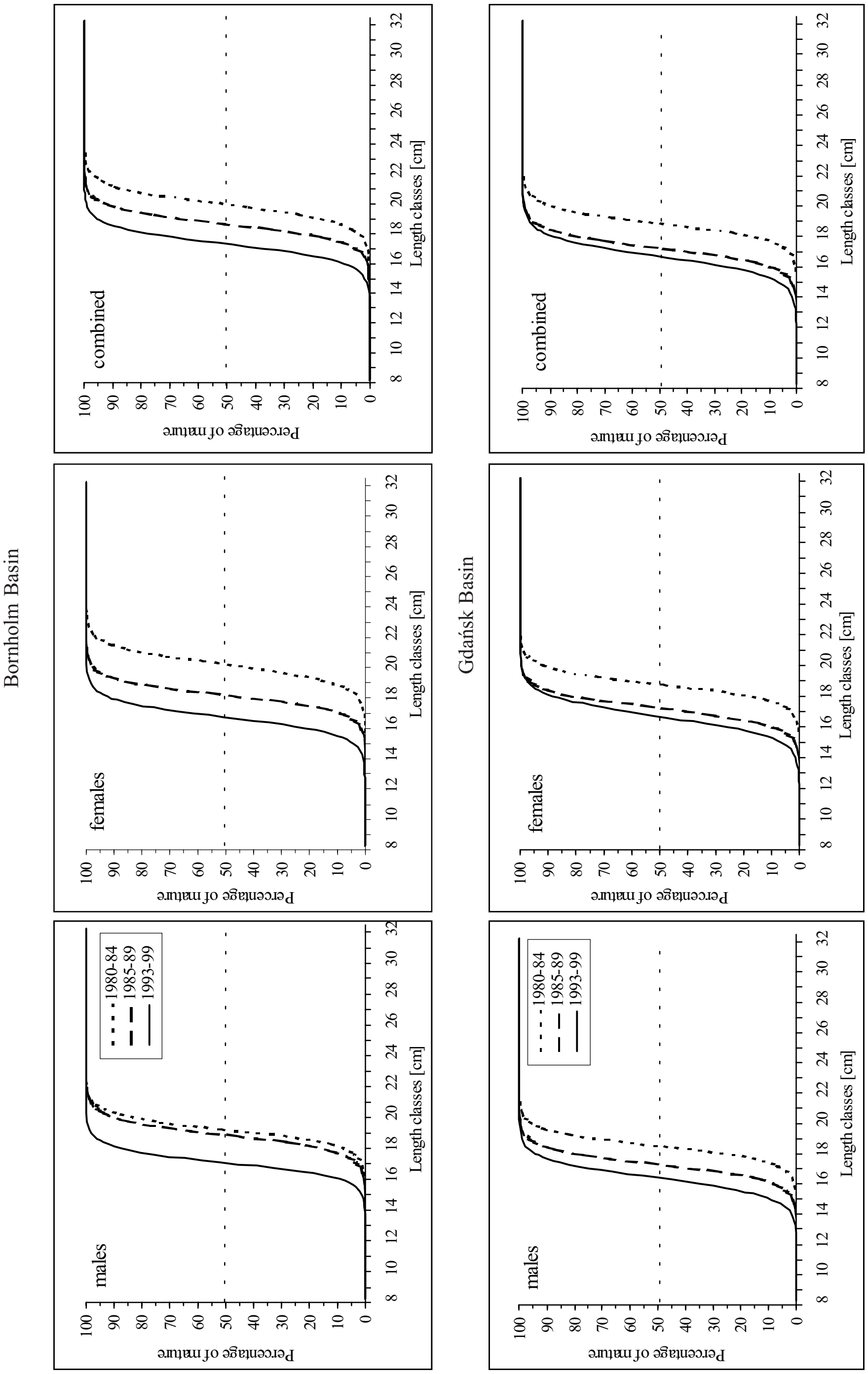


Fig. 4. Maturity ogives of herring caught in the Bornholm Basin and the Gdańsk Basin in selected groups of years vs. length classes of males and females.

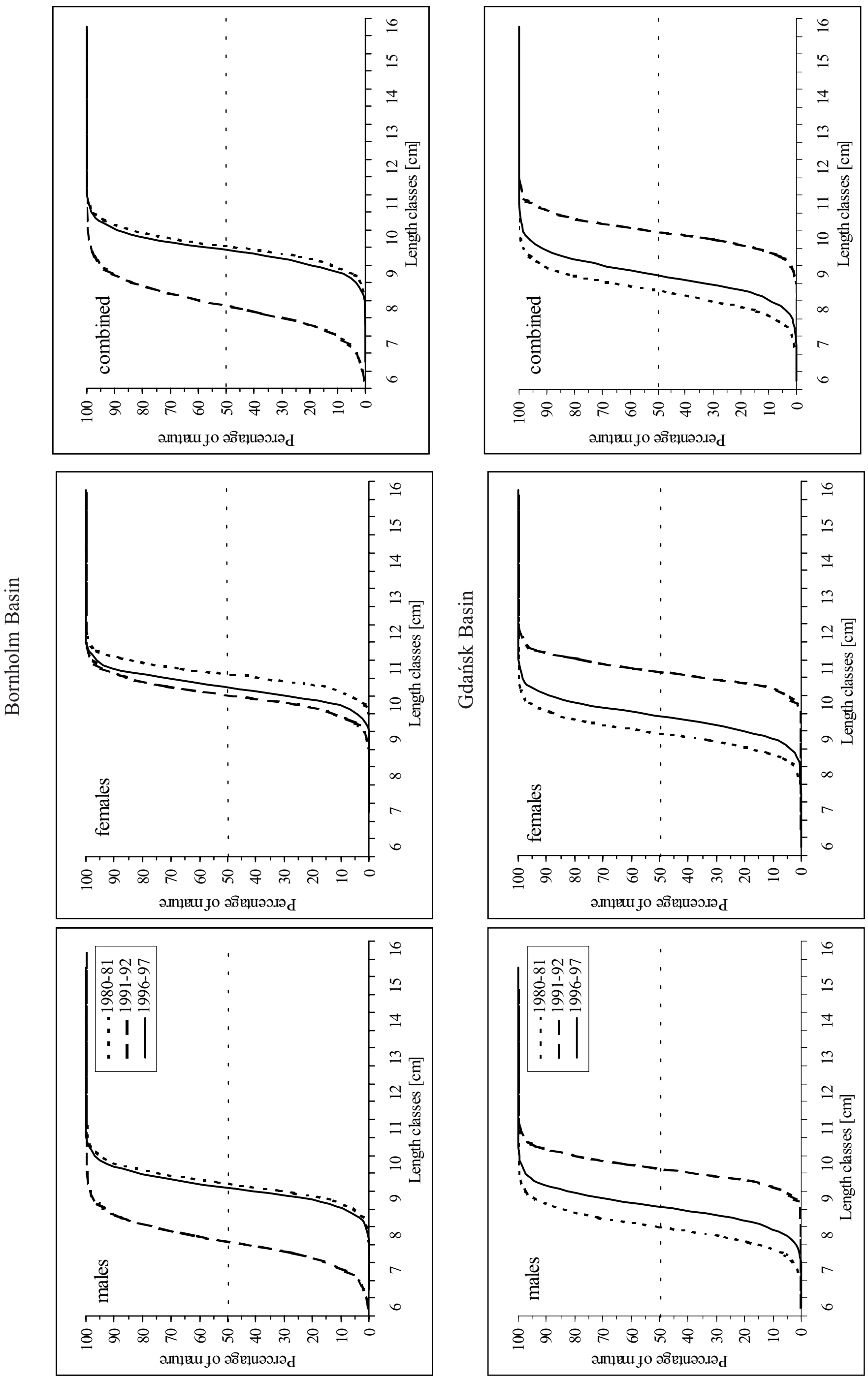


Fig. 5. Maturity ogives of sprat caught in the Bornholm Basin and the Gdańsk Basin in selected groups of years vs. length classes of males and females.

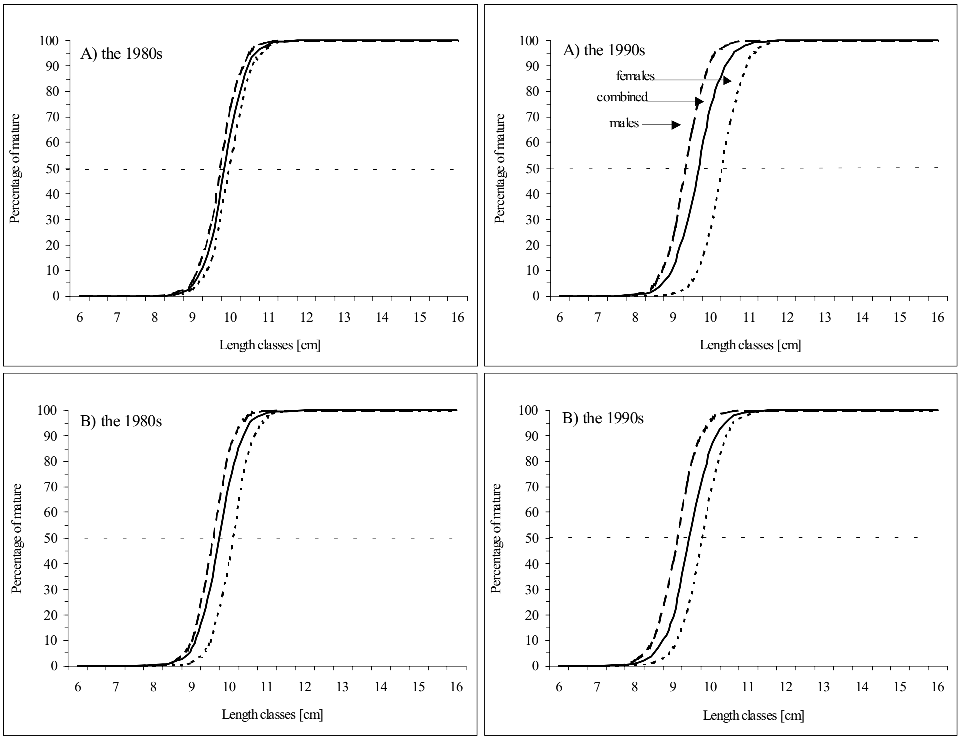


Fig. 6. Maturity ogives of the sprat males and females caught in the Bornholm Basin (A) and the Gdańsk Basin (B) in the 1980s and 1990s vs. length classes.

Table 7. Values of herring and sprat length at first sexual maturity ($L_{50\%}$), i.e. length at which 50% of specimens accede to first spawning in the life cycle

Sex	Herring			Sprat		
	Years	length – $L_{50\%}$ [cm]		Years	length – $L_{50\%}$ [cm]	
		the Bornholm Basin	the Gdańsk Basin		the Bornholm Basin	the Gdańsk Basin
Males	1980-1984	19.0	18.2	1980-1981	9.47	8.25
Females		19.9	18.5		10.85	9.19
Combined		19.7	18.4		9.78	8.54
Males	1985-1989	18.6	17.0	1991-1992	7.84	9.89
Females		18.0	17.0		10.27	10.92
Combined		18.4	17.0		8.09	10.22
Males	1993-1999	16.8	16.1	1996-1997	9.36	8.80
Females		16.5	16.4		10.49	9.66
Combined		16.7	16.3		9.66	8.99
Males	–	–	–	the 1980s	9.73	9.57
Females		–	–		9.98	10.09
Combined		–	–		9.84	9.74
Males	–	–	–	the 1990s	9.33	9.11
Females		–	–		10.29	9.78
Combined		–	–		9.66	9.45

Relationship between the percentage of mature clupeoids and biotic and abiotic factors

Yearly changes throughout the investigation period in the share of clupeoids spawning for the first time against a background of selected biotic and abiotic factors are presented in Figure 7. An attempt was made to examine the influence of the factors listed below on the fraction of mature young herring and sprat inhabiting the Bornholm Basin:

– herring and sprat stocks size (abundance) in the first, second and all age groups (separately by species and combined);

– mean weight, length and body condition coefficient at age – separately in the first quarter and in the first half of the year;

– air and seawater temperatures – separately in the first quarter of a given year and in the third and fourth quarters of the previous year plus the first quarter in a given year (15 factors in total).

In the next stage of the study regression analysis with four basic models – linear, multiplicative, exponential and reciprocal – was applied. Table 8 presents some of the basic results of these analyses, with priority given to the statistical models which best describe changes in empirical data.

The results of twenty-six simple regression analyses (the total for both herring and sprat) indicate that there was a statistically significant, positive impact (correlation) of the following factors on the percentage of fish spawning for the first time:

– increase of seawater temperature at depth layers of 30-70 m and air temperature in the first quarter (refers only to sprat);

– increase of sprat stock abundance in age group 1, but only in 1995-2001 (additional regression analysis, where: R^2 = 68.9%, F - ratio = 11.06, alpha = 0.021);

– increase of the mean length and weight in age group 2 in the first quarter (refers only to herring; Table 8).

The relationships between the percentage of mature sprat at age 1 versus three other factors, listed below, were on the border of statistical significance, i.e.:

– mean length in the first quarter;

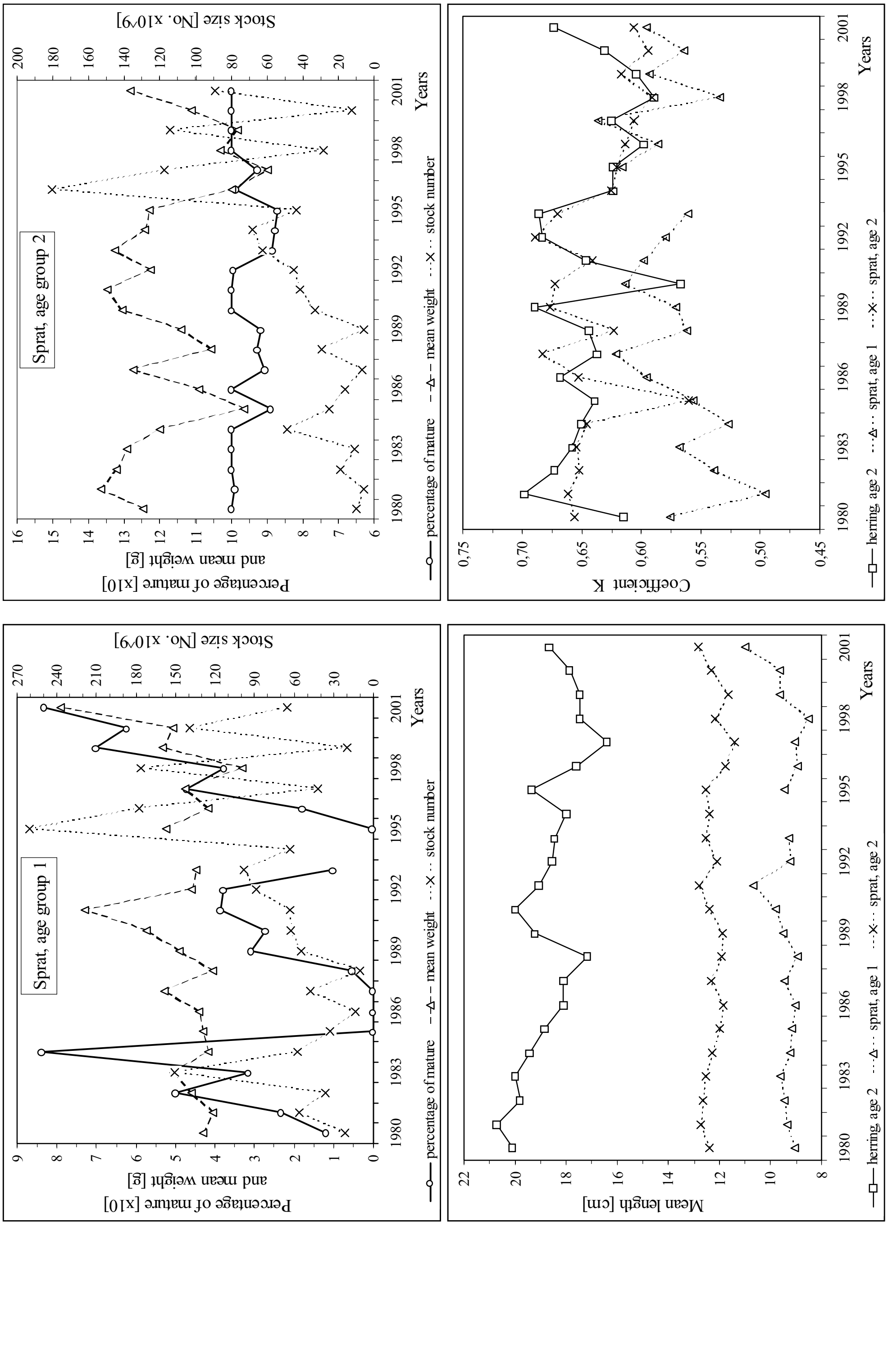
– the abundance of combined herring and sprat stocks in age groups 1 and 2;

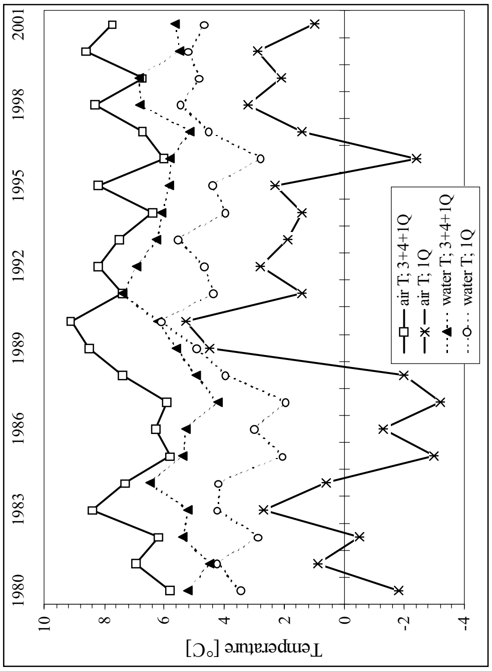
– seawater temperature in three of the examined quarters.

Statistical significance was not detected between twelve other pairs of variables; nor were any relationships found in four more analyses of herring.

DISCUSSION

The results presented in this paper indicate that there is a greater proportion of sexually mature herring (excluding age group 1) and sprat in younger age groups inhabiting the southern Baltic than was assumed by the ICES working groups up to 2000. For example, with herring from age groups 2 and 3 the differences were 5-22% and 8-10%, respectively, and with sprat from age groups 1 and 2 the differences were 15-38% and 21-30%, respectively (Tables 3-5).


Sprat, age group 1
Sprat, age group 2
Percentage of mature [x10] and mean weight [g]
Stock size [No. x10^9]
Years
percentage of mature
mean weight
stock number
Mean length [cm]
Coefficient K
herring, age 2
sprat, age 1
sprat, age 2



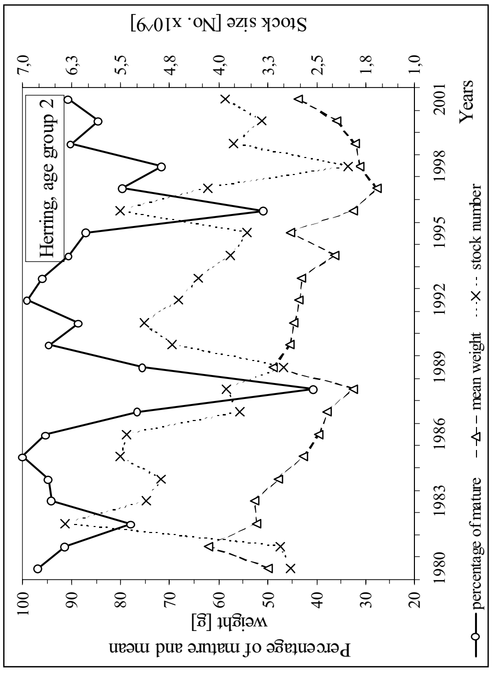


Fig. 7. Annual (1980-2001) changes of Baltic sprat and herring stocks abundance, mean weight and length, body condition coefficient, air and seawater temperatures and percentage of mature young clupeoid specimens caught in the Bornholm Basin.

Table 8. Summary of regression analysis of the percentage of mature herring and sprat (males + females) caught in the Bornholm Basin in 1980-2001 (dependent variable) vs. different biotic and abiotic factors, which potentially determine fish maturation; *) – due to negative air temperature values which occurred in the first quarter, the multiplicative model in the regression analysis was not accessible, statistically significant values of the regression between these variables are marked in bold, values on the border of statistically significance are marked in italics, the intercept in the multiplicative model is equal to Log *a*, SE – standard error, herring and sprat stocks size from SD 25-27 and SD 22-32, respectively, are included in the calculations

	Mean weight [g] in 1st Q	Mean weight [g] in 1st+2nd Q	Mean length [cm] in 1st Q	Mean length [cm] in 1st+2nd Q	Mean body condition coefficient *K* in 1st Q	Mean body condition coefficient *K* in 1st+2nd Q	Abundance of 1st age group in the stock	Abundance of 2nd age group in the stock	Abundance of total stock	Abundance of 1st and 2nd age groups in clupeoids stocks	Abundance of clupeoids total stocks	Air temperature [°C] in 3rd+4th+1st Q	Air temperature [°C] in 1st Q	Seawater temperature [°C] in 3rd+4th+1st Q	Seawater temperature [°C] in 1st Q
Herring, 2nd age group															
Type of model	Linear	Linear	Linear	Linear	Linear	lack of any correlation	–	lack of any correlation	Linear	Linear	Linear	lack of any correlation	Reciprocal	Multi-plicative	lack of any correlation
Parameter *a* and SE	49.633 15.225	50.782 18.061	–39.15 49.387	–44.29 55.867	27.336 60.744		–		60.611 19.626	90.387 6.5280	90.608 6.4331		0.0128 7.62E–4	3.8186 0.5917	
Parameter *b* and SE	0.8329 0.3543	0.7856 0.4417	6.6445 2.6439	6.8792 2.9741	89.4254 94.4644		–		1.2950 1.0387	–0.041 0.0394	–0.029 0.0277		–4.97E–4 3.05E–4	0.3453 0.3387	
Coefficient *r*	**0.465**	0.393	**0.490**	**0.459**	0.207		–		0.269	–0.228	–0.228		–0.343	0.222	
Probability level	**0.029**	0.071	**0.021**	**0.031**	0.355		–		0.227	0.307	0.307		0.118	0.320	
Sprat, 1st age group															
Type of model	Linear	–	Linear	–	Exponent–ial	–	Multi-plicative	–	Multi-plicative	Multi-plicative	Multi-plicative	Multi-plicative	Exponent-ial*)	Multi-plicative	Multi-plicative
Parameter *a* and SE	–13.09 27.037	–	–167.7 93.97	–	23.7698 23.4171	–	–8.365 6.4947	–	–15.18 9.4642	–19.95 9.9988	–18.29 11.269	–43.09 16.739	–0.587 1.1973	–31.99 15.500	–19.738 4.2944
Parameter *b* and SE	9.1693 5.3949	–	21.146 9.9386	–	–39.952 40.6021	–	2.2523 1.5684	–	3.2091 1.8866	4.3711 2.0935	3.7215 2.1858	22.200 8.4511	1.5122 0.4709	18.85 8.888	14.8569 3.0385
Coefficient *r*	0.363	–	*0.439*	–	–0.226	–	0.313	–	0.364	*0.432*	0.364	**0.516**	**0.593**	*0.438*	**0.747**
Probability level	0.106	–	*0.047*	–	0.337	–	0.167	–	0.105	*0.051*	0.105	**0.017**	**0.005**	*0.047*	**0.0001**

In the 1974-1999 period, ICES working groups accepted fixed and assumed values of Baltic sprat and herring maturity ogives for both sexes combined according to age groups and ICES sub-divisions (with the exception of ICES sub-divisions 30 and 31). For example, up to 2000 it was accepted in sprat stock assessment that specimens from age groups 0 and 1 do not accede to spawning, whereas 70% of the specimen abundance from age group 2 and 100% from older groups spawn in a given year (Anon. 2001a).

The values of the maturity ogive at age groups of sprat from the southeastern and northeastern parts of the Baltic, which were assessed by both Feldman *et al.* (2000) and Kaljuste and Raid (2002), were nearly the same as those calculated by authors of this paper. The discrepancies in these results are the effect of slightly different methods of sampling research materials and elaborating databases. The authors of this paper followed recommendations presented by ICES experts (Anon. 1994, 1999, 2000a), Morgan and Hoenig (1997) as well as the Study Group on Baltic Herring and Sprat Maturity (Anon. 2001b) about length stratified fish sampling in maturity-at-age investigations.

The proportion of mature fish in age groups, sex ratio, year-class abundance and mean weights at age have an influence on the clupeoid spawning stock biomass level. Changes in maturity ogives may have an effect on the perception of stock dynamics and management advice. Due to the improving accuracy of Baltic herring and sprat stocks size assessment, during the ICES Baltic Fisheries Assessment Working Group meetings in 2000 and 2003 (Anon. 2000b, 2003), attempts were made to evaluate the effect of changes in the maturity ogives of these species on biological reference points. The data which is both temporally and spatially limited was provided by few national laboratories (including the input data obtained by the authors of this paper) to the ICES Study Group on Baltic Herring and Sprat Maturity and differed in particular years and sub-divisions. Due to this, new maturity ogives have not yet been applied to the final clupeoid stock size assessment procedure.

The results of existing publications indicate that most sprat and herring inhabiting the southern Baltic accede to spawning for the first time in the second or third year of life (Popiel 1950, 1955, Elwertowski 1957, 1982, Birjukov 1970, 1980, Kosior and Strzyżewska 1979, Polivajko 1982, Anon. 1998). One hundred percent of the abundance of age group 3 sprat and age group 4 herring had acceded to the first spawning and created the spawning stock. Parmanne (1990) presented an example of first sexual maturation of the Bothnian Sea herring in age group 2 – approximately 50 and 16% of males and females, respectively, were mature. Kaljuste and Raid (2002) revealed that the maturation of sprat from the Estonian EEZ at age group 1 shows high variability and ranges from 6 to 60%, depending on area and year.

The period in which populations of the same fish species attain first maturity is diverse in the different regions of the Baltic Sea (Birjukov 1970, 1980, Ojaveer 1988, Wyszyński 1997, Anon. 2001b, Grygiel and Wyszyński 2002, Kaljuste and Raid 2002). According to Rannak (1960), Birjukov (1970), Ojaveer (1981, 1988), Parmanne (1990) and Wyszyński (1997), herring acceding to the first spawning of their life cycle in the following years of life:

– in the first (Gulf of Riga – however, only a small fraction of the specimens do so);

– in the second (Rügen Island, the Pomeranian Bay, the southern Baltic – the Polish EEZ, the Vistula Lagoon, the Gulf of Riga, the Gulf of Finland as well as the Bothnian Sea – but only a portion of the specimens);

– in the third (the northern Baltic, southwestern Norwegian waters);
– in the fourth (northeastern Norwegian waters);
– in the fifth (Faroe Islands waters).

Early maturation and the small length of maturing fish are thus typical of herring in the inner parts of Baltic Sea gulfs; the differences in Baltic herring maturation between areas support the view that the fish do not mix completely between the areas (Parmanne 1990). In comparison with herring that inhabit oceans, Baltic herring have had to adapt to water with low salinity (optimum is 5 PSU), and this has caused, among others factors, earlier sexual maturation – in age groups 2-3 (Popiel 1955) and at lengths of 11-12 cm (Anokhina 1969). Higher seawater temperatures in spring can induce earlier spawning so that the new-born year class has a longer growth period in the first summer of life and grater potential to reach sexual maturity at the age of 1 (Ojaveer *et al.* 1985). Furthermore, after a mild winter the fish has more energy left for the development of gonads, which is especially important in the first years of life (Kaljuste and Raid 2002). Rajasilta *et al.* (1996) and Wieland *et al.* (2000) also concluded that seawater temperature during the period of gonad maturation is one of the significant factors governing the timing of the spawning of Baltic spring spawning herring population and cod.

The Baltic herring and sprat specimens with larger otolith size and those that grow faster and mature earlier in a given spawning season contribute earlier to the fishery (Popiel 1955, Anokhina 1969, Rajasilta *et al.* 1996, Reglero and Mosegaard 2001). These authors also concluded that specimens with smaller otolith size at the same time contribute in larger amounts to both spawning stocks and fishery later when they are at age 2.

The investigations conducted by the authors of the present paper indicate that in comparison to the 1980s, the proportion of sprat from age group 1 acceding to first spawning in the 1990s increased by approximately 13% in the Bornholm Basin and by 4% in the Gdańsk Basin (Table 4). In contrast, the proportion of sexually mature herring from age group 2 decreased by about 5% in the Bornholm Basin and by 10% in the Gdańsk Basin. Moreover, the proportion of mature, young clupeoids was about 7-19% higher, on average, for herring and about 5-26% lower, on average, for sprat in the Gdańsk Basin than in the Bornholm Basin.

The northern Baltic sprat maturity ogive investigations conducted by Kaljuste and Raid (2002) also indicated that sprat matured earlier in age groups in the 1990s as compared with the 1980s. The mild winter with relatively higher air temperatures observed in the 1990s by Matthäus and Nausch (2001) can be, according to Kaljuste and Raid (2002), at least partially responsible for this phenomenon. At the same time, the mean weight at age of sprat decreased in the Baltic Sea in the 1990s by 30-50% in comparison with the 1980s (Anon. 2000b, 2001a, Grygiel and Wyszyński 2002, Kaljuste and Raid 2002).

Other authors like Armstrong *et al.* (2001) revealed that the mean age-at-maturity (MAM) of cod from the Irish Sea in 1992-2000 was lower than that recorded in the 1970s, although this could reflect differences in sampling schemes. Moreover, two-year-old males comprised 32% of the mature fish in non-spawning areas and over 90% in spawning areas. The same tendency was recorded for cod females. Frie *et al.* (2001) concluded that MAM for Northeast Atlantic harp seal females from the Barents Sea-White Sea stock increased from 5.3 years in 1962-1964 to 8.4 years in 1990-1993 concurrently with a decline in body growth rates.

Most of authors already cited in this paper (Popiel 1955, Elwertowski 1957, Birjukov 1970, 1980, Polivajko 1982, Ojaveer 1988, Parmanne 1990, Anon. 2001b, Kaljuste and Raid 2002), including the authors of the present work, concluded that males of Baltic clupeoids are sexually mature earlier in the life cycle than females. According to results obtained by the authors of this paper, the fraction of mature southern Baltic sprat males in younger age groups was greater than that of mature females in every analyzed group from the 1980-2000 period (Tables 3 and 4). For example, in age group 1 the percentage of mature sprat males was 2.6 – 5.1 times higher than females. In the second sprat and in the third herring age groups these differences were very low or insignificant. Polivajko (1982) presented one example of differences between the percentage of sexually mature south-eastern Baltic sprat males and females – in age group 1 males were 7-13 times higher, but in the second and the third age groups they were only 1.3-2.0 times higher than the females.

The percentage of mature southern Baltic herring and sprat specimens is length dependent, and this percentage increases successively in length classes. The results obtained by the authors of this paper indicate that there are statistically significant relationships between these variables (best fitted according to the linear model in regression analysis applied; Table 6). Similar analyses of results for Baltic herring and sprat were not found in the literature, although results obtained by Torstensen (1998) demonstrate that the maturation of sprat from Norwegian fjords is also length dependent. The length at 50% maturity was 9.3 cm. Sprat from this region normally mature as 1-year-olds at a minimum length of 8.0-9.0 cm. They spawn during the same season as older fish, but a little later.

The decline of the southern Baltic herring mean weight at age in the 1980-1999 period was accompanied by a decrease in the length of first sexual maturation in both males and females (Fig. 4, Table 7). In comparison to the 1980-1984 period, the indicatory length ($L_{50\%}$ – 50% of specimens are mature) of herring decreased by an average of 2.55 cm from 1993-1999, i.e. from 19.7 to 16.7 cm in the Bornholm Basin and from 18.4 to 16.3 cm in the Gdańsk Basin. In comparison to the 1980s, the decline in sprat indicatory length in the 1990s was an average of 0.25 cm, i.e. from 9.84 to 9.66 cm in the Bornholm Basin and from 9.74 to 9.45 cm in the Gdańsk Basin (Fig. 6, Table 7). In 1980-1981, the differences in the indicatory length of sprat from the two Baltic basins were 1.22 cm for males and 1.66 cm for females, but in 1996-1997 these differences were smaller by 0.55 cm (males) and 0.83 cm (females). Nearly 100% of the herring males larger than 19.0 cm and females larger than 20.0 cm and sprat males $\geq$ 10.0 cm and females $\geq$ 11.0 cm were mature.

Earlier investigations conducted by Wyszyński (1997) with a somewhat different method than that described above showed that in two selected years, 1989 and 1996, the 50% level of mature herring specimens was achieved at an indicatory length which decreased from 18.0 to 16.8 cm in the Bornholm Basin and from 16.2 to 15.4 cm in the Gdańsk Basin. A tendency of herring growth rate decrease was noted in the years compared. The foregoing differentiation described over lengths ($L_{50\%}$) is the result, among other factors, of the variability in the growth rate of clupeoids versus geographical location; the decreasing trend is observed from west to east and to the north in the Baltic Sea (Grygiel 1987).

The gonad maturation process of both Baltic and Black Sea sprat begins in the seventh to eighth month of life, and most of specimens from age group 1 in the southern Baltic accede to the first spawning after reaching 9-10 cm (Elwertowski 1957). Polivajko (1982) published an almost identical opinion to that of the authors of this paper, namely that in the Gdańsk Basin the gonad maturation process begins in 60% of age group 1 sprat males at lengths of 7.0-9.5 cm and in 50% of the females at lengths of 8.0-9.5 cm. Most young sprat from age group 1 accede to spawning after they have reached 9.0-9.5 cm in length.

According to Anokhina (1969), herring females from the coastal spring spawning population which inhabit the southeastern part of the Baltic can accede to first spawning when they are 8.5 cm and one year old. Investigations conducted by Parmanne (1990) indicated that herring from the northern Baltic are already sexually mature by the time they reach 14-15 cm in length. Spring and autumn herring populations in the Gulf of Gdańsk achieve first sexual maturity at lengths of 13.2 cm and 16.0 cm, respectively (Strzyżewska 1960). According to results obtained by Kändler and Dutt (1958), spring and autumn herring populations from the western Baltic accede to first spawning when they reach 19.3 cm and 20.0 cm, respectively.

The percentage of young herring (age group 2) and sprat (age group 1) which spawned for the first time in the Bornholm Basin in the 1980-2001 period was dependent on some biotic and abiotic factors (Table 8). The results of regression analysis indicate that the percentage of mature young sprat was statistically significantly dependent on seawater and air temperatures (in the first quarter) and on sprat stock year-class (1995-2001) abundance in age group 1. The same was also found between the percentage of young herring from the spring spawning population which were spawning for the first time and the mean length and weight of fish (in the first quarter).

Physical factors such as the duration of ice cover, seawater temperature and light levels in the sea can also affect fish feeding conditions during winter in the pre-spawning season (Rajasilta *et al.* 1996, Krasovskaya 2002). These factors are strongly correlated, thus it is difficult to analyze their role separately from the collected data (Rajasilta *et al.* 1996). According to Szypuła (1992), feeding intensity, gonad maturity and condition coefficient (K) and gonado-somatic index (q) of herring from the southwestern part of the Baltic were statistically significantly correlated ($r = -0.863$ and -0.854, respectively), while condition and feeding intensity were the least correlated ($r = 0.219$). Inter-annual variations in the proportion of mature male cod from the Irish Sea and in mean length-at-age were significantly negatively correlated with year class strength (Armstrong *et al.* 2001). This suggests that there may be density-dependent variations in both growth and maturity, even if the proportion of mature specimens does not vary with length within an age group in any year.

In summary, it can be concluded that differentiation in the sexual maturation of herring and sprat in relation to the age and length structure of the exploited stocks, sex, year groups and regions is mostly due to variation in ecological conditions, to selected biotic and abiotic parameters and the specificity of species inhabiting the western and eastern parts of the southern Baltic Sea. In comparison with the 1980s, the mean percentage of sprat from age group 1 which began spawning for the first time increased in the 1990s from 26 to 38% in the Bornholm Basin and from 14 to 18% in the Gdańsk Basin. During these two decades, the fraction of herring from age group 2, which began spawning for the first time, decreased from 80 to 75% in the Bornholm Basin and from 92 to 82% in the Gdańsk Basin. These results differed from the data used by ICES working groups in 1974-2000.

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The distribution, stock size and year-class strength of cod in the southern Baltic in 1981-2001 based on Polish groundfish surveys

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Abstract. Polish groundfish survey data were analyzed using generalized linear models (GLM) to investigate fish distribution, year-class strength and stock size. Negative binomial errors were assumed for the analysis of young fish numbers (age 1 and 2), while gamma error distribution was applied for the analysis of adult fish biomass. The abundance of young fish was significantly dependent on year of birth, depth, area (longitude, latitude), quarter and gear used in the survey. The highest numbers were caught in the area demarcated by 15°50´E-16°10´E while the lowest catches were made in the area demarcated by 17°00´E-17°30´E. The maximal abundance was observed in the 50-70 m depth range. Cod at age 2 were more susceptible to survey gear catches than age group 1. The year-class strength indices correlate relatively well with recruitment estimates from analytical models ($R^2 = 0.6$).

The survey biomass of adult cod was significantly dependent on year, depth, longitude and gear. The highest biomass concentration was in an area demarcated by 15°50´E-16°50´E at a depth of 70-100 m. The indices determined for adult stock size correlate relatively well with the spawning stock biomass from analytical models ($R^2 = 0.57$).

Key words: cod, groundfish survey, GLM, Baltic Sea

INTRODUCTION

The Baltic cod (*Gadus morhua callarias* L.) is widely distributed and one of the most important commercial species in the Baltic. At present, the eastern Baltic cod spawning stock biomass (SSB) is approximately five times lower than its highest ever recorded value observed in the mid 1980s. The poor state of the stock has lead to a decrease of total allowable catch (TAC) set by the International Baltic Sea Fishery Commission (IBSFC), especially in the 1990s. The cod TAC has been restrictive since the early 1990s, and this has led to the under-reporting of cod catches. Erroneous catch statistics, in turn, affect the reliability of cod stock assessment. Under these circumstances, information on the state of the stock obtained from research surveys is very important. Survey data can be used both for fishery-independent estimations of stock dynamics as well as for the calibration of standard assessment models and projections of catch and stock development.

Polish groundfish (demersal trawl) surveys are part of an international survey conducted annually in the Baltic. They provide indices of recruiting year-class and stock size as well as essential information on the biology and distribution of a wide range of species. Polish demersal trawl surveys have been carried out annually in the Bay of Gdańsk since 1962. Since 1981, the survey has been extended and more systematic. Estimating the abundance and distribution of juvenile cod against the background hydrological factors (temperature, salinity and dissolved oxygen) has been the main goal of the investigations. However, adult fish are also sampled and abundance is recorded.

Extensive statistical analysis of Polish and other survey data was conducted by Sparholt *et al.* (1991). Since this publication, new data have been collected and new procedures for statistical analyses have become available. Generalized linear models (GLM) allow for the assumption of the error structure from the exponential family of distributions, not only from normal distribution, as is assumed in general linear models. In 1999 new, more effective standard gear was introduced in the Polish bottom survey. This has necessitated determining conversion factors so that data collected with the old and new gear can be compared.

Catch data from Polish groundfish surveys will be used in the present study to:

– investigate the spatial and temporal distribution of cod in the southern Baltic Sea;

– obtain statistical estimates of indices of year-class strength and adult stock size.

MATERIAL AND METHODS

Data

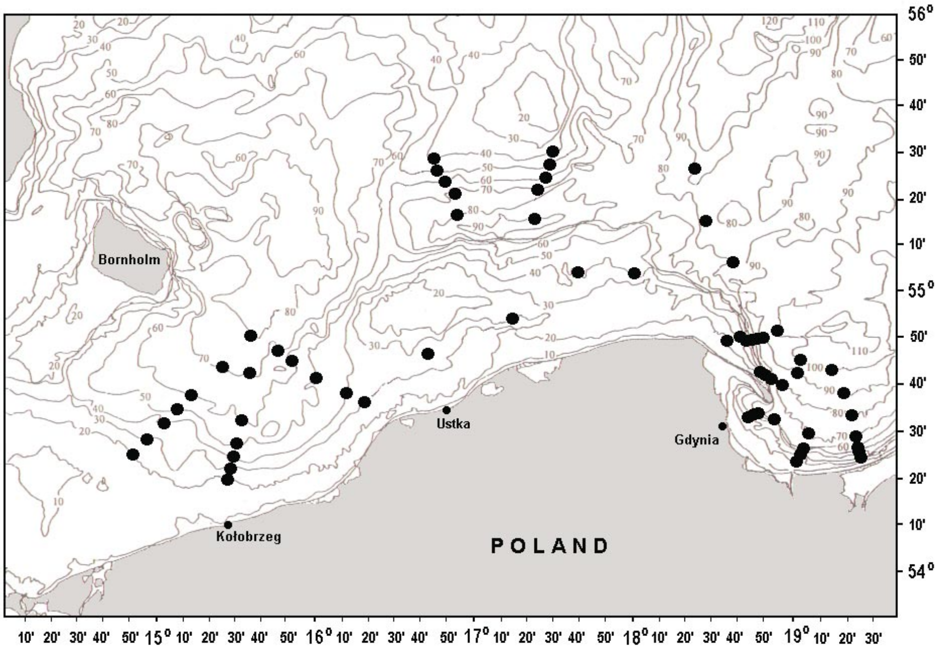
Data for the present study were collected during surveys conducted in the first and fourth quarters from 1981 to 2001. The Polish fishing zone, which is part of ICES sub-divisions 24, 25 and 26, was covered. Sampling strategy was based on a fixed stations grid, arranged as depth cross-sections (transects) (Fig. 1). The hauls were carried out at a depth interval of 10 m along the respective isobaths starting from 20 m. In some years the time and area of the planned surveys were shortened. Therefore, the materials are unevenly distributed between quarters and sub-divisions; they prevail in the 1st quarter in Sub-division 26, while the data series for sub-divisions 24 and 25 is much shorter. The number of hauls by year, quarter and sub-division is presented in Table 1. The best coverage is in Sub-division 26, the time series for Sub-division 25 is much shorter, while the data from Sub-division 24 are very scarce.

The gaps in the data occurred mainly in 1981-1992 when surveys were conducted by chartered cutters with similar technical characteristics. Since 1993, the surveys have been conducted from aboard the research vessel BALTICA. Fishing operations in 1981-2000 were carried out using the same standard trawl (the mesh in the cod-end was 6 mm from knot to knot). A new TV3 trawl was introduced in 1999, and some comparative trawling with the P 20/25 gear was conducted. The effective fishing time at each depth interval was 30 minutes at a trawling speed of about 3 knots. Trawling was carried out only during daylight hours to avoid day/night variations in fish distribution.

Table 1. Number of hauls by year and sub-division

Year	Sub-divison			Total
	24	25	26	
1981			84	84
1982			116	116
1983			62	62
1984			122	122
1985			60	60
1987			86	86
1988			136	136
1989		2	132	134
1990			142	142
1991			138	138
1992		22	128	150
1993		26	128	154
1994		28	218	246
1995		24	64	88
1996		38	136	174
1997	8	104	156	268
1998	6	88	146	240
1999	6	74	116	196
2000	2	60	66	128
2001		62	80	142
Total	22	528	2,316	2,866

Fig. 1. Sampling locations of bottom trawls in Polish surveys in the Baltic Sea.



The species were identified and the catch weight was estimated for each haul. Cod samples were taken mainly to determine the length and age distribution. Cod measurements were rounded down to the nearest cm.

Statistical analysis

Generalized linear models (GLM) were used in the analysis (McCullagh and Nelder 1986). Two models were applied – one for young cod i.e. ages 1 and 2 (model 1a) and one for adult fish comprising cod at age 3 and older (model 1b):

$$G(N_{tow}) = \text{yc} + \text{age} + \text{quarter} + \text{Longitude} + \text{Latitude} + \text{depth} + \text{gear} + \text{interactions} + \text{error}, \quad [1a]$$

$$G(B_{tow}) = \text{year} + \text{quarter} + \text{Longitude} + \text{Latitude} + \text{depth} + \text{gear} + \text{interactions} + \text{error}, \quad [1b]$$

where G is a link function, N_{tow} is the abundance of young fish in a tow, B_{tow} is the biomass of adult fish in a tow, and yc stands for year-class. Originally all variables were treated as factors, and finally depth was taken as a covariate. Only second order interactions were analyzed. In addition, a model without interactions was fitted to test approximate differences between the main effects if some interactions were significant but explained a relatively small amount of variance.

The error distribution was assumed to be a negative binomial for young cod, gamma for adult cod, and the logarithmic link function was used in both models. As gamma distribution is defined for positive numbers only, the 0.1 was added to tow biomasses to include "no fish" tows in the analysis. Corner point parameterization was applied, i.e. factor effects for level one were assumed as zero for all factors. Thus, the factor effects for other levels may be regarded as the differences between the effect at given level and the effect at level one. The significance of factors, covariates and interactions were tested and only significant terms were left in the final model. Similarly, factor levels that did not produce a significantly different response were grouped into new factor levels. The tests were performed by deletion, i.e. only those terms whose deletion did not result in a significant increase in deviance (i.e. the GLM measure of discrepancy between modeled and observed values) were left in the final model. The significance of the effects and factor levels was tested by the χ^2 test in case of negative binomial errors and by the F-test when gamma errors were assumed.

In case of the negative binomial distribution the variance, var, is related to the mean, m, by

$$\text{var(m)} = \text{m} + \text{m}^2/\text{k}, \quad [2]$$

where k is an aggregation parameter. This relation was fitted to the data to obtain an initial verification of the assumption of the negative binomial error distribution. Next, U-statistic was used to verify if var(m) differs significantly from the observed variance (Evans 1953, O'Brien *et al.* 2000).

If variable shows the gamma distribution its variance is proportional to the square of the mean and such relation was fitted to the averages and variances of the survey data in order to verify the gamma errors assumption.

All calculations were performed with the GenStat package, version 6 (GenStat 2000).

RESULTS

The relation between variance and the mean as well as the U-statistic values supports the assumption of the negative binomial distribution of the abundance of young cod. Figure 2a, b shows the distribution of the young cod catch and the quadratic relation (equation 2) between variance and the mean of the cod abundance in the Gdańsk Basin (longitude range

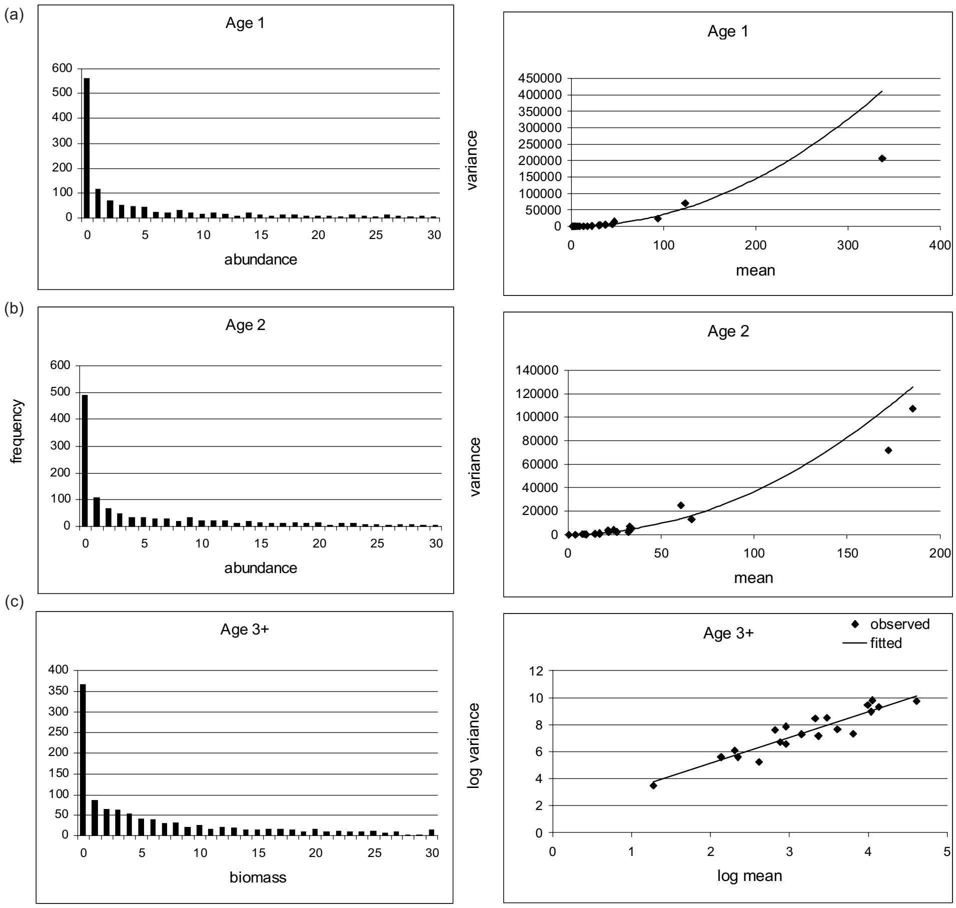


Fig. 2. (a) and (b) – The distribution of numbers and the relationship between variance and mean numbers for young cod (age 1 and 2), (c) – The distribution of biomass and the relationship between variance and mean biomass for adult cod (age 3+).

18°10′-19°30′) in the first quarters of 1982 to 2001. In most cases, the U-statistic did not reveal significant differences between the observed variance of abundance and that estimated by formula (2). Of 40 comparisons (20 for age 1 and 20 for age 2), only three were significant at the 5% level.

Similarly, the assumption of the gamma distribution of the biomass of adult cod is supported. The distribution is highly skewed, the log variance is approximately linearly related to the log-mean and the regression coefficient (point estimate equals 1.91) is not significantly different from 2 (Fig. 2c).

A. Analysis for young fish (age 1 and age 2)

First, the model was fitted with longitude and latitude levels at 10′ intervals. However, the number of factor levels for both longitude and latitude was too large in relation to the number of data points (23 longitude and 7 latitude levels). An attempt was made to merge responses which were not significantly different into new levels. This was relatively easy with latitude as the effects for it south of 55°00′ and north of 55°00′ were not significantly different. Thus, only two levels of latitude (54°20′-55°00′ and 55°10′-55°20′), which had significantly different responses, were finally selected. With longitude it was not possible to select effects that were statistically insignificant and referred to compact areas. Thus merging longitude intervals into larger units was based on both the homogeneity of the effects and the desire to have compact areas. Five longitude ranges (14°50′-15°40′, 15°50′-16°10′, 16°40′-16°50′, 17°00′-17°30′, and 18°10′-19°30′) were selected for further analysis.

Half of interaction terms were significant. Due to gaps in the data some of them could not be fully evaluated or fully included in the model, and they were aliased with other parameters. Significant interactions explained about 10% of the total deviance. The most important was the interaction of year-class with age, contributing 50% to the portion of deviance explained by the interactions. The other significant interactions contributed less than 1% to the total deviance. Of these, the most important interactions were year-class*latitude, year-class*longitude and year-class*quarter, which suggests that the distribution of year-class undergoes slight, but significant, spatial and temporal changes.

Year-class, age, quarter, longitude, latitude, depth and gear were significant in the model without interactions. The depth effects could be well described by a quadratic relationship, so the depth factor was replaced by depth as a covariate with the terms depth + depth^2. The model explained 30% of the deviance. The longitude effects of 14°50′-15°40′ and 18°10′-19°30′ were not significantly different and could be merged (Fig. 3). The effects of the neighbouring areas of 14°50′-15°40′ and 15°50′-16°10′ were also not significantly different, but after merging 14°50′-15°40′ and 18°10′-19°30′ the combined area was different at 2% level from longitude 15°50′-16°10′. The highest abundance of young cod was in the longitude range 15°50′-16°10′ and the lowest was in 17°00′-17°30′. The highest abundance of young cod by depth was at 50-70 m, the density of fish increased almost linearly up to this depth range and decreased in deeper areas (Fig. 3).

Table 2. Analysis of deviance for model of year-class abundance without interactions (model 1a)

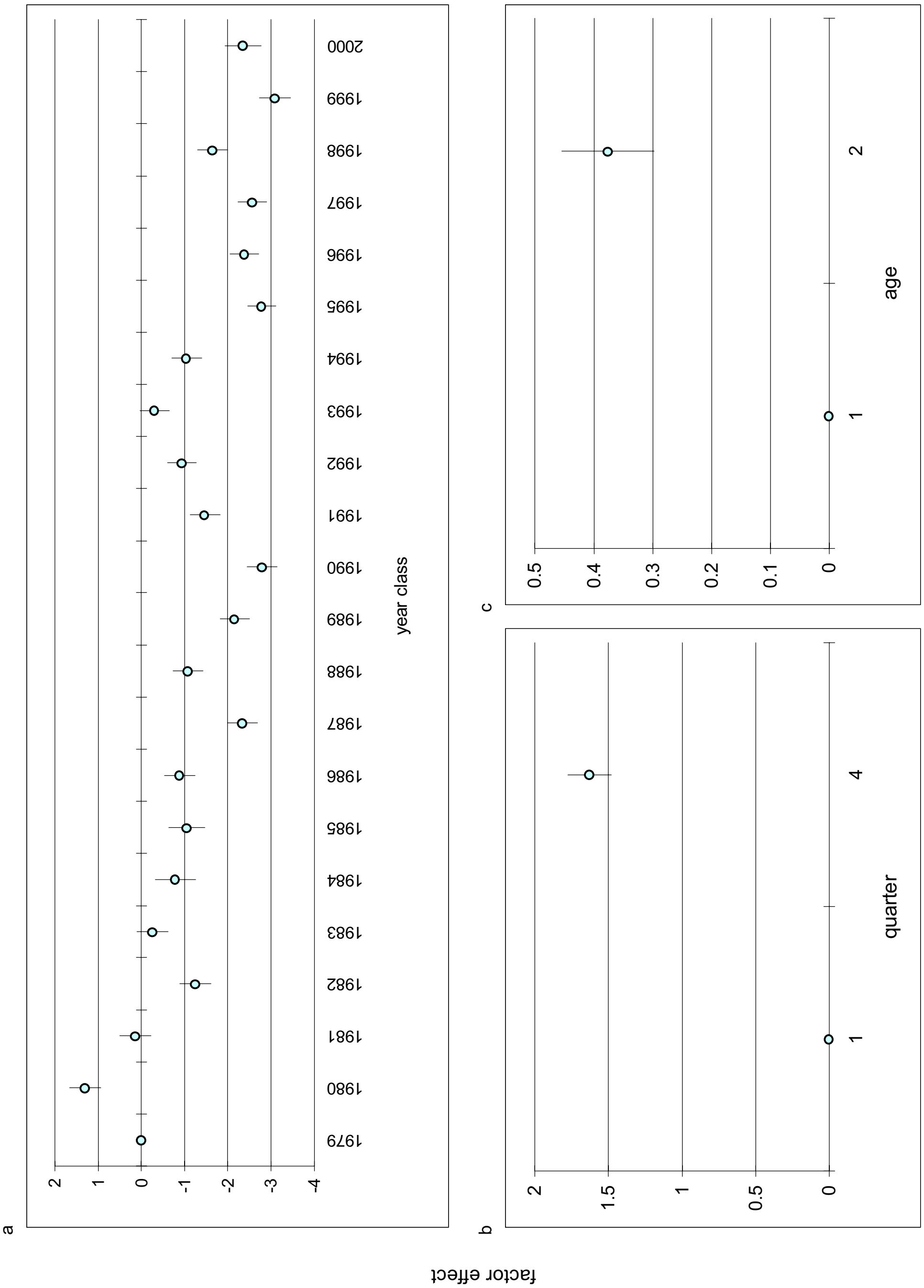
Source	df	Deviance	p	R^2
Model	31	1,347	<.001	0.30
Error	2,834	3,140		
Longitude	4	58	<.001	
Latitude	1	25	0.005	
Year-class	21	673	<.001	
Quarter	1	114	<.001	
Gear	1	31	<.001	
Depth+depth^2	2	425	<.001	
Age	1	21	<.001	

The quarter effect shows significantly higher survey catches in the 4th quarter than in the 1st quarter (Fig. 3). The estimate of the age effect is 0.38, which indicates higher survey catches of the same year-class at age 2 than at age 1 and suggests the higher catchability of age 2 cod in comparison with age 1 cod. The higher effect of 4th quarter compared to 1st quarter is consistent with the finding that growing young cod is more vulnerable to the survey gear. The decline of year-class abundance resulting from natural mortality did not compensate for this effect.

The gear effect was significant and the catchability (effect anti-logged) of the new TV3 gear was almost three times higher than that of the previously used trawl gear.

Table 2 presents the contribution of factors and variables to the explained amount of deviance in the final model. Most of the deviance is explained by year-class (55%) and depth (30%). The effect of quarter, which explains almost 10% of the deviance, is less important. The other factors, although significant, explain only 1-2% of the deviance.

The year-class effects (Fig. 3) were not merged into homogenous groups because one of the basic goals of the analysis was to provide indices of year-class strength. Strong year-classes are evident in the early 1980s and weak generations were noted in the second half of the 1980s and in the 1990s. The relatively high effects of the 1992-94 year-classes were not confirmed by later estimates from the XSA analytical model (Shepherd 1999, ICES 2002a). The year-class effects (anti-logged) were regressed against the XSA estimates of year-class abundance (Fig. 4). Linear regression explains 56% of the variance of the year-class effect. When the survey data is subjected to GLM analysis separately for ages 1 and 2, then the estimated year-class effects correlate markedly worse with the XSA estimates of year- class strength than when analysis is done with both age 1 and 2 abundances and the age effect (model 1a). The averaged year-class effects for age 1 and 2 from separate analyses produce indices of year-class strength which are better correlated with XSA estimates of recruitment than the effects based on age 1 or 2 data only. However, such estimates are still worse than those obtained from model 1a, where both ages 1 and 2 were analyzed simultaneously.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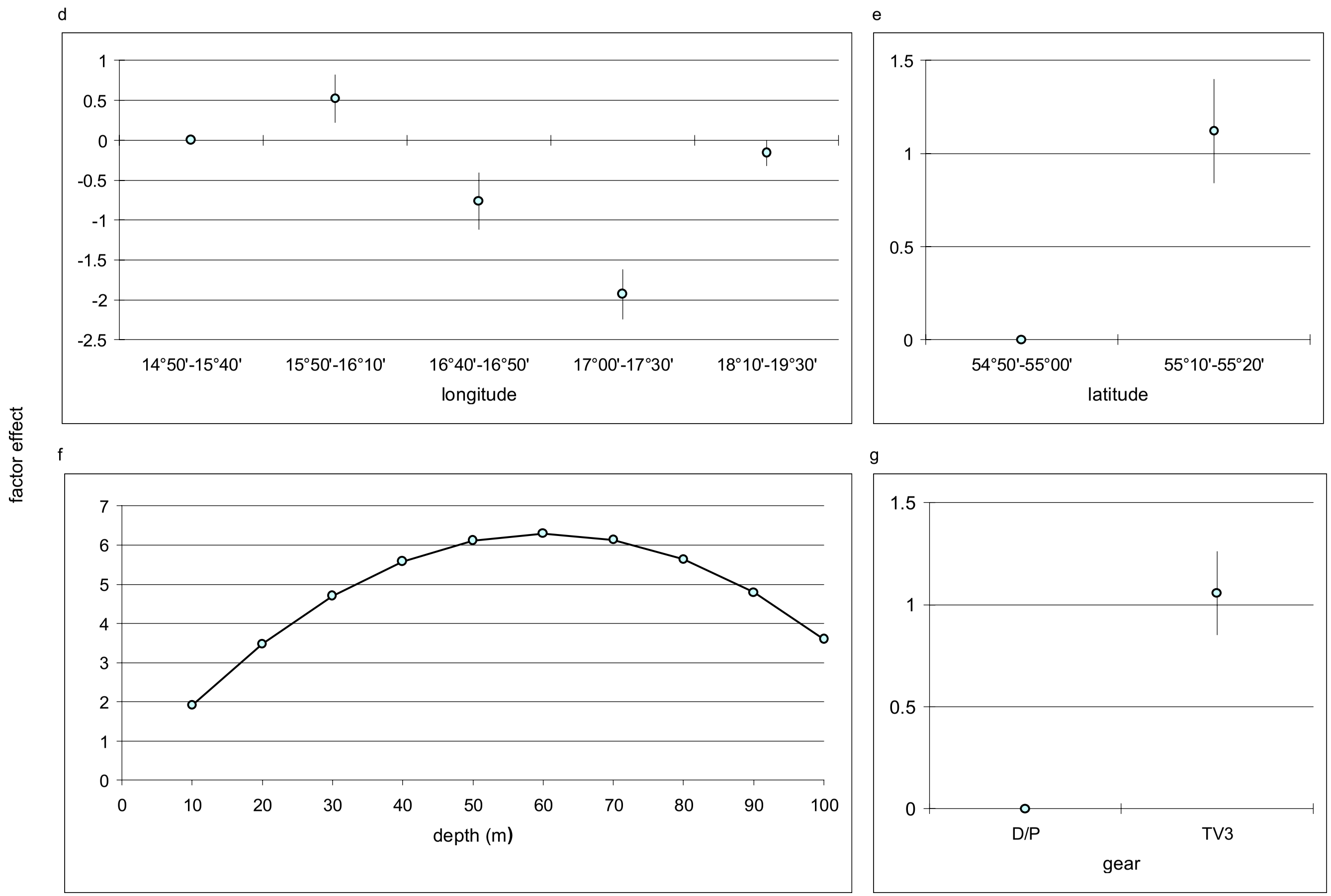


Fig. 3. Effects of year-class (a), quarter (b), age (c), longitude (d), latitude (e), depth (f) and gear (e) with standard errors for the model of young fish numbers (model 1a) without interactions.

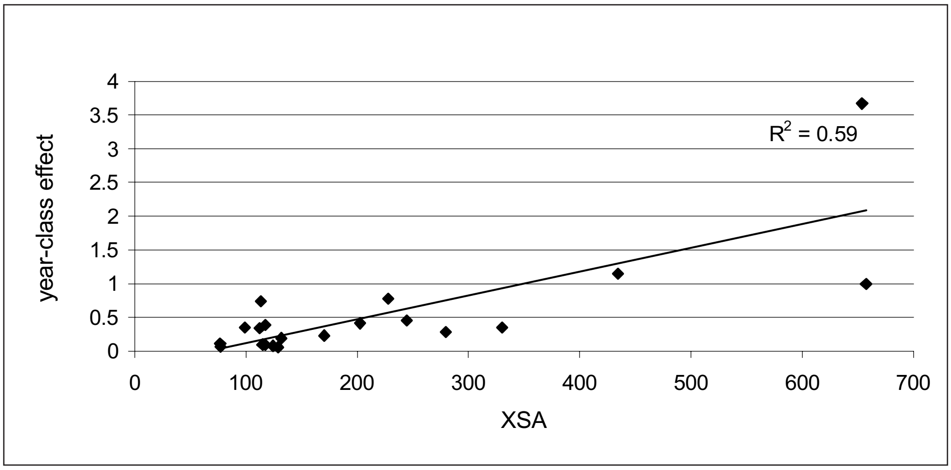


Fig. 4. Year-class effects estimated by model 1a plotted against the XSA estimates of year-class strength (millions).

B. Analysis for adult fish (age 3 and older)

The latitude and quarter effects were insignificant, while year, longitude, depth and gear were highly significant. As was the case with young cod the depth factor was replaced by depth as a covariate with the terms depth + depth^2. Homogenous longitude intervals were selected similarly to those accepted for young cod. The only difference was that the longitude range of 15°50′ – 16°50′ was treated as one interval; this differs from the analysis of young cod in which it was treated as two intervals (15°50′–16°10′ and 16°40′–16°50′). Adult cod seems to be relatively uniformly distributed by area, and only at longitude interval 15°50′ –16°50′ was there a significantly higher biomass concentration (Fig. 5).

The effects of depth attain maximum values at 70-100 m. As was the case with young cod, the gear effect indicated that the new TV3 trawl was almost three-fold more efficient than the former P 20/25 trawl (Fig. 5).

The year*depth and year*gear interactions were significant. However, the second interaction could not be fully included in the model as the two gears were in parallel use only for two years of the survey. The interaction year*depth increased the explained deviance by 16% and showed that optimal depth (defined as the peak of fitted parabolas) ranged from 70 to 90 m, with the 70-80 m depth dominating.

The final model without interactions explained 35% of the deviance and the largest contributors to it were depth and year (57 and 37% of the explained deviance, respectively, Table 3).

Table 3. Analysis of deviance for model of year-class abundance without interactions (model 1a)

Source	df	Deviance	*p*	R^2
Model	25	1,888	<.001	0.35
Error	1,392	3,555		
Depth+depth^2	2	1,087	<.001	
Year	19	699	<.001	
Longitude	3	72	<.001	
Gear	1	30	<.001	

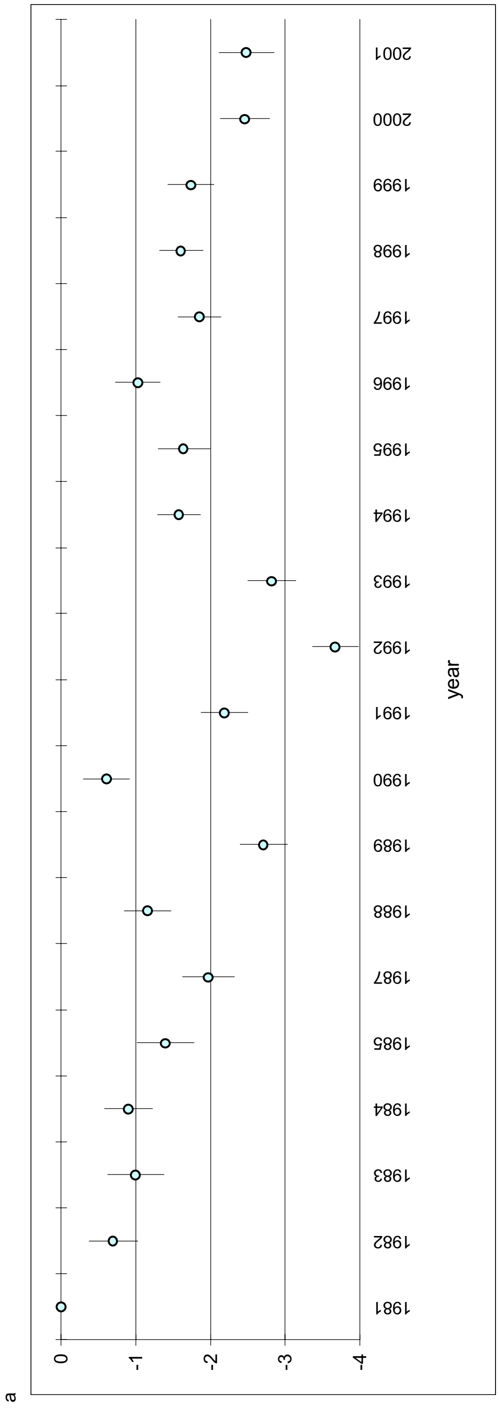
The year effects for adult fish (Fig. 5) were not merged into homogenous groups as one of the goals of the analysis was to provide indices of the adult stock size. The effects show similar trends as the stock size estimates obtained from the XSA (ICES 2002a). However, they indicate higher biomass increase in the mid 1990s than that estimated by the XSA. The effects (anti-logged) were regressed against the XSA estimates of the stock biomass (Fig. 6). Linear regression explains almost 60% of the variance of the year effect.

DISCUSSION

Conclusions drawn from statistical analyses very often depend heavily on the degree to which the necessary assumptions are fulfilled. The framework of the GLM (McCullagh and Nelder 1986) allows for the distribution of a dependent variable from the exponential family and provides a modern tool for data analysis. Power and Moser (1999) showed that, for simulated data, the use of GLM with a negative binomial distribution of catches was more effective than the t-test in the analysis of net catch data. Other examples of the application of negative binomial distribution in the analysis of catch data can be found in Welch and Ishida (1992) and O'Brien *et al.* (2000).

Surveys often include many empty tows, and this creates some problems in the analysis. Some authors apply two stage distribution models. Stefanson (1996) first applies the binomial model for empty/not-empty tows and then gamma distribution for not-empty tows. O'Brien *et al.* (2000) use an approach where numbers have Poisson distribution with the mean itself gamma distributed. This composition leads to negative binomial distribution (O'Brien *et al.* 2000). Penington (1983) applies delta distribution; in this approach lognormal distribution is assumed for positive values while zero tows are treated separately.

An extensive analysis of cod survey data for the Baltic was performed by Sparholt *et al.* (1991). The analysis comprised data from the surveys of six countries conducted from 1982 to 1989 in sub-divisions 25, 26, and 28, in the first, second and fourth quarters. The authors used the general linear model on log-transformed data, assuming normally distributed error. The results of the present analysis are in some respects similar to those of Sparholt *et al.* (1991). The amount of explained deviance is similar in both approaches (around 30% for young cod and over 40% for adult fish). The cod density in Sub-division 26 (our longitude interval 18°10'-19°30') is lower than in Sub-division 25. Both analyses show similar optimal depth for young cod, but, according to Sparholt *et al.* (1991) analysis, adult cod prefer 60-70 m depths as compared to the 80-100 m depths obtained in our analysis. The main difference between the results of Sparholt *et al.* (1991) and the current analysis lies in quarter effects. The effect of the 4th quarter on young cod is higher than that of the 1st quarter in our analysis, while in Sparholt *et al.* (1991) the opposite was shown. With adult fish, the quarter effect is insignificant in the present study, but it is significant in the Sparholt *et al.* study.



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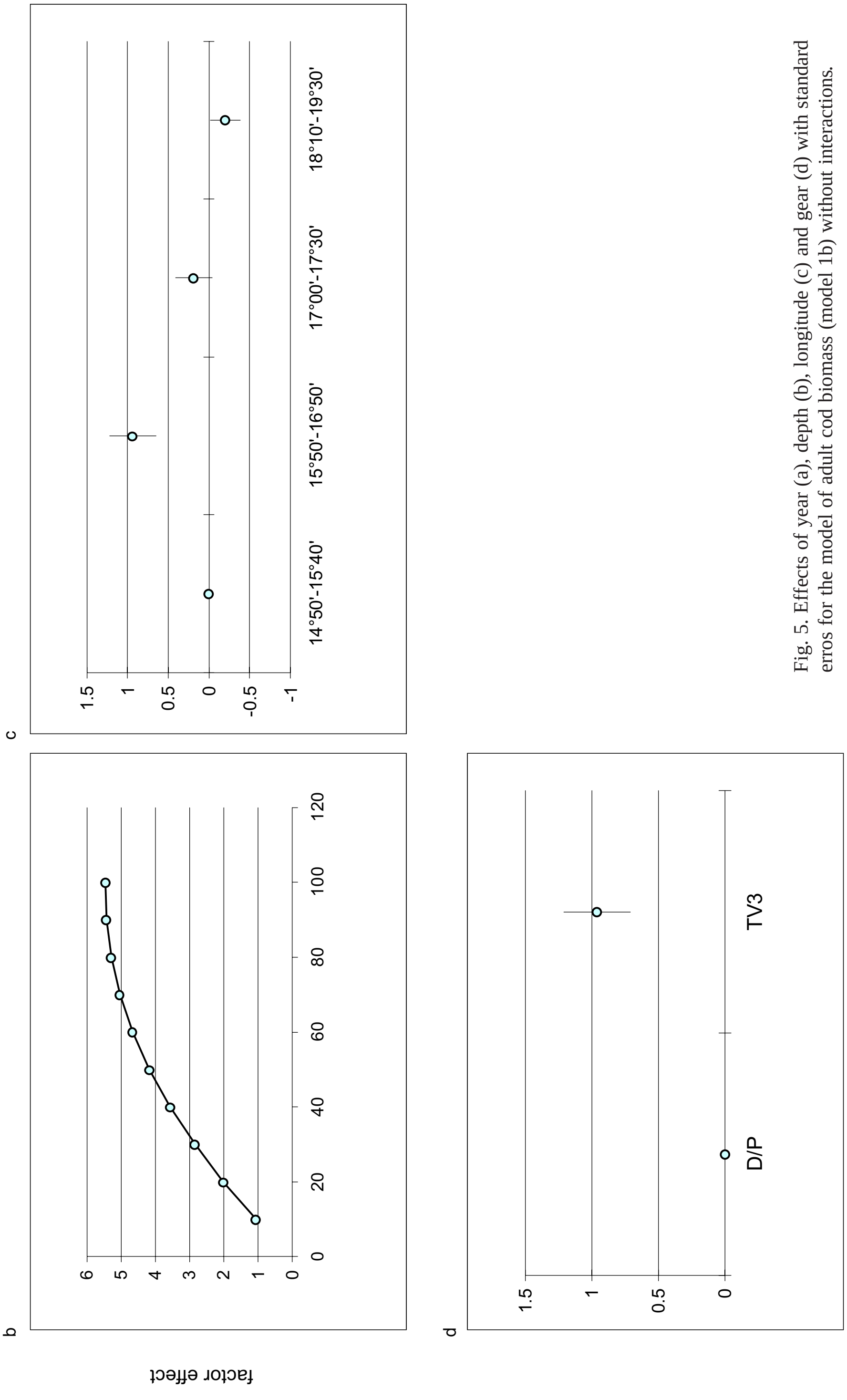

Fig. 5. Effects of year (a), depth (b), longitude (c) and gear (d) with standard erros for the model of adult cod biomass (model 1b) without interactions.

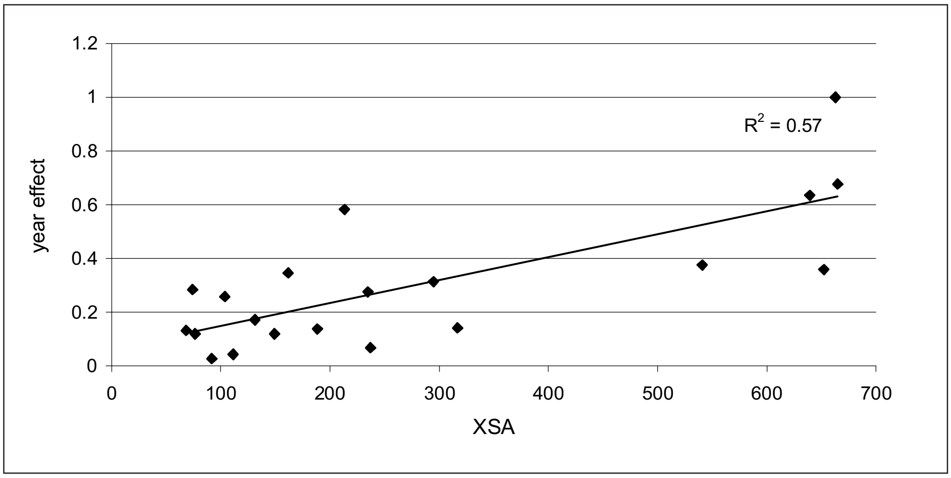

Fig. 6. The year effects estimated by model 1b plotted against the XSA estimates of adult cod biomass (age 3+, in thousands of tons).

The higher quarter effect of the 4th over the 1st quarter in the case of young cod is a puzzling result as one would expect the opposite tendency due to fish mortality. This result suggests either the higher catchability of young cod in the 4th quarter survey or immigration from other areas. The high 4th quarter effect can not be explained only by the increasing size of cod as the difference between the effects of age group 1 and 2 is much lower than the difference between quarter effects. It appears that the fraction of tows without young cod is two to three times higher in the 1st quarter than in the fourth (40% vs. 16%, on average). This observation supports the presumption of the better availability of young cod in the 4th quarter. However, the ratio of cod catches at the same localities in the first and fourth quarters is quite variable; in 33 cases catches in the 4th quarter were higher than in the 1st quarter, but in 23 cases the opposite was noted. Further analysis is necessary until a firm conclusion can be drawn.

The estimated, positive age effect is consistent with the findings of Sparholt and Tomkiewicz (2000) who state that the catchability of age 2 is higher than the catchability of age 1 cod.

The estimated gear effect shows that the catchability of the new standard trawl is higher by 2.7-2.8 in comparison with previously used gear. The higher catchability of the new trawl was anticipated since its horizontal and vertical openings are 3 and approximately 1.5 times higher, respectively, than those of the previously used gear. The comparison of the two gears at the same locations and in the same quarter shows that standard catches made with the new gear were higher that those made with the old trawl on 27 occasions, while the reverse was noted only 11 times. However, estimates of the gear effect should rather not be used for the conversion of old data into units comparable with results from the new gear. Some of the analyses provided in ICES (2002 b) suggest that the conversion factor may be much lower. In these analyses only tows performed for calibration experiments were compared and it is suggested that the order of towing impacts the results. Thus, separate analysis needs to be done so that the conversion factor can be more adequately estimated.

The advantage of the present approach is that it is possible to estimate year-class strength based on simultaneous inclusion of both young cod ages (age 1 and 2) into statistical analysis through the incorporation of age effect in the model. This procedure appears to provide a better index of year-class strength than does the separate analyses of ages 1 and 2 possibly followed by averaging the resulting indices.

Sparholt and Tomkiewicz (2000) proposed another method to determine indices of stock and year-class size based on international trawl survey data. In their approach, the fishing power of the vessels participating in the survey is first estimated, and then simple arithmetic averages over depth strata are calculated. The final indices are averages weighted by the fishing power of the participating vessels. These indices are considered by the authors to be robust, and they correlate very well with XSA estimates of stock size (almost 90% of variation explained). Obviously, indices based on trawl data from all countries participating in the survey will generally be better than the index provided by only one survey. In addition, the XSA, which is the basis for comparing survey indices of stock size, is tuned by using indices proposed by Sparholt and Tomkiewicz (2000) which positively affects correlation. The authors indicate that in their analysis national, or individual, surveys explained from 1 to 81% of the stock size variance. In this context the stock size indices from the Polish survey estimated with the present approach are relatively good as they explain almost 60% of the variance.

Acknowledgement
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Preliminary results of AChE and GST measurements in flounder *Platichthys flesus* from the southern Baltic Sea

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Abstract. High-level environmental contamination has been documented as eliciting negative effects on endocrine, reproductive and developmental events across vertebrate groups in the wild. Of particular interest and importance is whether relatively low levels of mixtures of environmental pollutants may have long-term impacts.

Muscular Acetylcholinesterase (AChE) and hepatic glutathione S-transferase (GST) activities were measured in each sampled specimen of flounder *Platichthys flesus*. Statistically significant differences in the activities of both biomarkers were observed between reference and contaminated sites. A decrease of the activity of both enzymes was noted in older fish (over 6 years). GST activity differed with gender, and females had lower activities than males. A seasonal pattern of activity was seen in the case of GST, with the lowest values in June. Flounder muscle and liver tissue were analyzed for polychlorinated biphenyls (PCB congeners: 28, 52, 101, 118, 138, 153 and 180), organochlorine pesticides (α-HCH, β-HCH, γ-HCH, HCB, p,p´-DDE, p,p´-DDD, p,p´-DDT) and trace metals (Pb, Cd, Zn, Cu, Hg, Cr). The results of this study suggest that from endogene related variables, the age of the fish has strong impact on AChE and GST activity. Location has also high influence on the activity of both biomarkers. However, it has not been investigated if the influence of location is caused by pollution or by other location-related factors.

Key words: environmental pollution, AChE, GST, flounder *Platichthys flesus*, biomarker, Baltic Sea

INTRODUCTION

Marine coastal zones and estuaries are the main recipients of almost all anthropogenic discharges of pollutants. Pollutant exposure may lead to severe consequences for populations or species inhabiting these waters. A generally accepted concept in ecotoxicology is that responses such as decreased growth rates, elevated levels of diseases and decreased reproduction rates are proceeded in time by effects at the molecular and cellular level in individual organisms.

Biomarkers are defined as sub-lethal biological measures of the response to and effects of pollutants in living organisms (Peakall 1994). These include a number of molecular, cellular and physiological parameters that, in principle, can be measured with simple and inexpensive techniques. Biomarkers have been identified as a powerful and cost-effective approach to obtain information on the state of the environment and the effects of pollution on living biological resources (McCarthy and Shugart 1990, Hugget *et al.* 1992, Wester *et al.* 1994, Depledge *et al.* 1995).

Generally, biomarkers are selected for their responses to particular classes of environmental contaminants rather than to specific individual chemicals, consequently they are sufficiently versatile to enable their use in a wide variety of field situations (Goksøyr *et al.* 1996).

Acetylcholinesterase (AChE) is present in most animals and is responsible for the rapid hydrolytic degradation of the neurotransmitter acetylcholine (ACh) into the inactive products choline and acetic acid. AChE inhibition has been used as a biomarker of the effects of organophosphate and carbamate compounds (Coppage and Braidech 1976, Nemcsok *et al.* 1985, Zinkl *et al.* 1987, Day and Scott 1990). More recently, Bocquené e*t al.* (1995) indicated high inhibitory activities of several organophosphates and carbamates on AChE extracts of marine organisms.

The function of the glutathione S-transferase (GST) enzymes has traditionally been considered to be the detoxification of electrophiles by gluthatione conjugation (Strange *et al.* 2001). A wide variety of endogenous (e. g. by-products of reactive oxygen species activity) and exogenous (e. g. polycyclic aromatic hydrocarbons) electrophilic substrates have been identified.

This paper describes the use of two important enzyme biomarkers in fish: i) muscular AChE as a marker of exposure to neurotoxins (especially organophosphate and carbamate pesticides), and ii) hepatic glutathione S-transferase (GST) as a marker of exposure to organic xenobiotics (especially PAHs - polycyclic aromatic hydrocarbons and PCBs - polychlorinated biphenyls). The results presented in this paper are based on biomarker studies with a flatfish species widely distributed in the Baltic coastal waters, the flounder *Platichthys flesus*. This fish typically prefers fine-grained to sandy sediments, where it feeds mostly on benthic invertebrates. This habitat and feeding preferences make the flounder particularly vulnerable to sediment-associated pollution. The flounder is also a rather stationary species for most of the year. Hence, it meets most criteria for selection as an indicator species.

The aim of this study was to measure two biomarkers (AChE and GST) in the tissues of flounder *Platichthys flesus* in order to characterize some subcellular effects of trace metals and organic contaminants in flounder subjected to long-term, low-level exposure situations where acute responses are not observed.

MATERIALS AND METHODS

Samples of fish

Samples of *Platichthys flesus* were collected from the southern Baltic Sea in February, March, June and September. Sampling was conducted in different seasons to characterize the natural variations in the biomarker responses depending on fish size, feeding status, gender and sexual maturation.

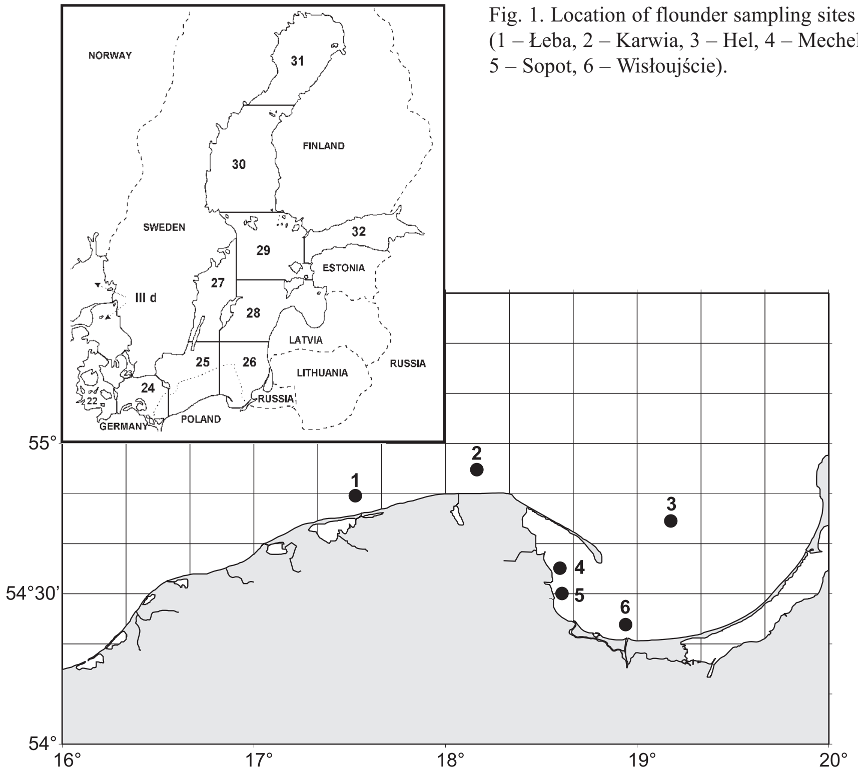


Fig. 1. Location of flounder sampling sites (1 – Łeba, 2 – Karwia, 3 – Hel, 4 – Mechelinki, 5 – Sopot, 6 – Wisłoujście).

The fish were caught in the vicinity of Łeba, Karwia, Hel, Mechelinki, Sopot and Wisłoujście (Fig. 1). Łeba, as a well-flushed coastal site with lower contaminant inputs, was treated as "a reference region". The areas of Karwia, Hel, Mechelinki, Sopot and Wisłoujście are subjected to heavy anthropogenic pressure (industrial as well as intensive agricultural effluents) and were treated as "contaminated sites". Area, season and the number of sampled fish are presented in Table 1. Only fish over 20 cm in length were taken as samples. The liver and muscle of each fish were excised and immediately frozen at –70°C for biochemical analysis. Dissection was performed within 1 hour of capture.

The total body length (cm), weight (g), age, sex and gonad developmental stage of each fish were recorded. The age was determined from otoliths, and the gonad stages were

Table 1. Number of sampled flounder by area and month

No. of site*	Area	Month	*n*
1	Łeba (reference region)	June	23
		September	30
2	Karwia	March	18
3	Hel	March	19
4	Mechelinki	September	30
5	Sopot	June	24
6	Wisłoujście	February	19
		June	30
		September	30
Total			223

* correspond to numbers presented in Fig. 1

classified according to the Maier's scale. Fulton's formula was used to determine the body condition factor, *CF*

$$CF = \frac{w}{l^3} \cdot 100$$

where "*w*" is the total weight and "*l*" is the length of the fish.

Somatic indices for liver (HSI) and gonad (GSI) were determined as follow:

$$HSI = \frac{w_l}{w_f} \cdot 100$$

and

$$GSI = \frac{w_g}{w_f} \cdot 100$$

where "w_l" is the weight of the liver, "w_g" – the weight of the gonads and "w_f" – fish weight.

Preparation of tissue homogenates

GST: a 200 mg slice of liver was homogenized with 1 ml of cold homogenizing buffer (100 mM K_2HPO_4/KH_2PO_4, 150 mM KCl, pH 7.5). The homogenates were centrifuged at 10,000 × g for 20 minutes at 4°C. An aliquot of the supernatant was then transferred to a fresh eppendorf tube and assayed after storage at –70°C.
AChE: extraction was performed on 500 mg of muscle tissue using a 0.02 M phosphate buffer (pH 7.0) containing 0.1% Triton X 100. The tissue was homogenized in 4 volumes of buffer (4 ml buffer/g tissue wet weight) and centrifuged at 10,000 × g for 20 minutes at 4°C. An aliquot of the supernatant was stored at –70°C and used in the assay.

Enzyme activity determination

AChE measurements were performed using the method described by Ellman *et al.* (1961) and adapted for use with a microplate reader (Bocquené and Galgani 1998). The enzyme kinetic was monitored with a microplate reader GENios at 412 nm. The standard reaction mixture, with a final volume 0.380 ml, contained 0.02 M phosphate buffer, pH 7.0, 0.5 mM DTNB (5,5'-Dithio-bis(2-nitrobenzoic acid)) and 2.6 mM ACTC (acetylthiocholine chloride).

GST measurements were performed using a modification of the method described in Habig *et al*. (1974). The enzyme kinetics were monitored with a spectrometer (a microplate reader GENios) at 340 nm. The standard reaction mixture, with a final volume 0.210 ml, contained 0.1 M phosphate buffer, pH 7.4, 1 mM CDNB (1-chloro-2,4-dinitrobenzene) and 1 mM GSH (glutathione, reduced form).

Protein concentration was determined as described by Bradford (1976) using BSA (bovine serum albumin) as the protein standard.

Chemical analysis

Trace metal, polychlorinated biphenyl (PCBs) and organochlorine pesticide (OCPs) concentrations in the muscle and liver samples of flounder were determined. Liver and muscle tissue was lyophilized and extracted by hexane to obtain fat with cumulated organochlorine compounds. This extract was cleaned with sulfuric acid (Muccio 1993). DDTs and PCBs were determined using the capillary gas chromatography method with electron capture detection (UNEP /United Nations Environment Programme/ 1988). Trace metals were determined by atomic absorption. The fish tissue was mineralized with nitric acid in microwave ovens. The zinc and copper concentration (over 1 mg kg^{-1}) was determined by the flame method, while the concentrations of lead, cadmium, chromium and copper (below 1 mg kg^{-1}) were determined by the flameless method in a graphite furnace. The mercury concentration was measured by the vapor generation method in a gold amalgam by a mercury analyzer (AMA 254) (UNEP 1984a and b).

Statistical analysis

Generalized linear models (GLM) were used to analyze the dependence of the activity of AChE and GST enzymes on time and area of sampling as well as the biological parameters of fish, such as age, sex, gonad maturity stage and body condition. All calculations were performed using the statistical package GenStat (GenStat for Windows 2000). First, the full model (all considered variables and factors included) was fitted

$$\ln(\text{activity}) = \text{sex} + \text{age} + \text{gon} + \text{mon} + \text{area} + CF + \text{error}$$

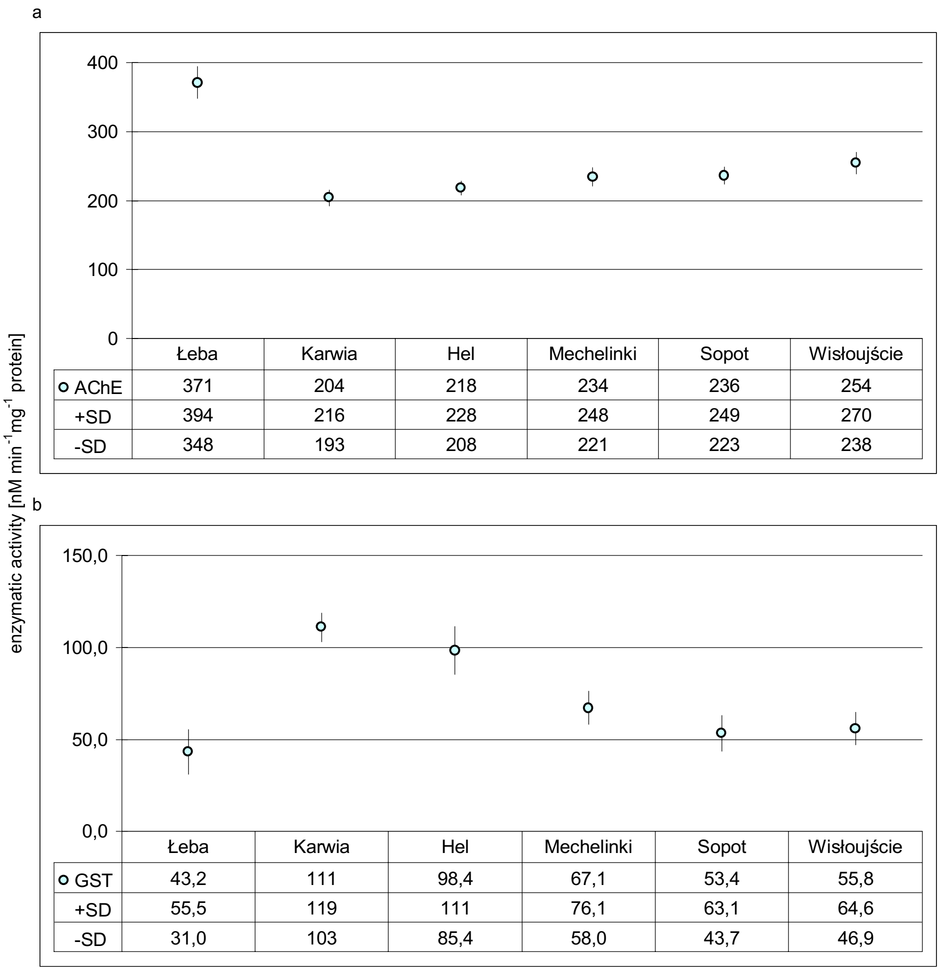
where:
ln(activity) – log transformed values of AChE (model 1) and GST (model 2) activity,
sex – the sex of fish,
age – the age group of fish,
gon – stage of gonad maturity,
mon – month of sampling,
area – area of sampling,
CF – body condition factor.

Corner point parameterization was used, i. e. factor effects for level one were assumed zero for all factors. Thus the factor effects for other levels may be regarded as differences between the effect at a given level and that at level one. Body condition factor was taken as a covariate, while sex, age, gonad stage, month and area were treated as factors in the analysis. For modeling the log transformed activity of enzymes, the error was assumed to be normal and the identity link function was used. Next, the significance of factors and the covariate were tested and only significant terms were left in the final model. Similarly, factor levels that did not produce a significantly different response of the enzymatic activity were grouped into new factor levels. The tests were performed by deletion, i.e. only those terms whose deletion did not result in a significant increase in deviance (i.e. the GLM measure of discrepancy between modeled and observed values) were left in the model. The significance of the effects and factor levels was tested by the F test. The distributions of the model residuals were analyzed to test the model assumptions and performance.

For the subset of data in which GSI and HSI were measured, models 1, 2 which also included these indices, were used for statistical analysis.

RESULTS

Mean muscular AChE and hepatic GST activities with their standard deviations, SD, are presented in Fig. 2a and b. AChE activity, with the lowest value noted in Karwia (204 nM min^{-1} mg^{-1} protein), reached the highest level of 371 nM min^{-1} mg^{-1} protein in the



	Łeba	Karwia	Hel	Mechelinki	Sopot	Wisłoujście
AChE	371	204	218	234	236	254
+SD	394	216	228	248	249	270
-SD	348	193	208	221	223	238

	Łeba	Karwia	Hel	Mechelinki	Sopot	Wisłoujście
GST	43,2	111	98,4	67,1	53,4	55,8
+SD	55,5	119	111	76,1	63,1	64,6
-SD	31,0	103	85,4	58,0	43,7	46,9

Fig. 2. Mean muscular AChE (a) and hepatic GST (b) activity in flounder from the examined areas.

reference region of Łeba. GST activity values ranged from 43.2 to 111 nM min^{-1} mg^{-1} protein. Contrary to the AChE activity, the lowest mean value of GST was noted in Łeba, and the highest in Karwia (in fish caught during the spawning season). Lower activity levels of GST and higher activity levels of AChE were evident in samples taken from the well-flushed coast (Łeba site) with lower contaminant inputs.

The results of trace metals analysis in fish muscle and liver did not indicate any substantial differences in mean tissue concentrations between samples from contaminated sites and the reference region of Łeba (data not shown). The mean concentrations of muscle and liver ΣPCB (CB28, CB52, CB101, CB118, CB 138, CB153, CB180), ΣDDT (pp´-DDE, pp´-DDD, pp´-DDT), ΣHCH (α-HCH, β-HCH, γ-HCH) and HCB are presented in Table 2. The mean concentrations of ΣPCB in muscle and liver oscillated from 98 to 316 ng g^{-1} and from 90 to 471 ng g^{-1} lipid, respectively. ΣDDT ranged from 206 to 638 ng g^{-1} lipid in muscle and from 168 to 578 ng g^{-1} lipid in liver. The mean concentrations of ΣHCH oscillated from 24 to 39 ng g^{-1} lipid in muscle and from 27 to 41 ng g^{-1} lipid in liver. HCB concentrations ranged from 3.7 to 11.4 ng g^{-1} lipid in muscle and 6.7 to 18.1 ng g^{-1} lipid in liver. The levels of ΣPCB and ΣDDT were markedly higher at contaminated sites (1.5- to 2-fold for males and 2- to 3-fold for females) when compared with the Łeba site both in muscle (Fig. 3a, b) and liver fish tissue (Fig. 4a, b). The concentration levels of ΣHCH and HCB were evidently much less different in the areas of sampling (Fig. 3c, d and Fig. 4c, d). The values in figures 3 and 4 are relative to the Łeba reference site.

Table 2. The mean concentrations of ΣPCB, ΣDDT, ΣHCH and HCB (ng*g^{-1} lipid) with their SD in the fish muscular (a) and hepatic (b) tissues

a)

Area	sex	ΣPCB	SD	ΣDDT	SD	Σ HCH	SD	HCB	SD
Łeba	males	123	98	297	231	29	3.7	7.4	1.2
	females	98	41	206	93	27	3.5	7.1	3.1
Mechelinki	males	289	11	507	97	30	5.5	5.4	0.4
	females	254	21	371	16	24	2.1	3.7	1.1
Sopot	males	197	8	448	12	32	0.4	9.0	0.4
	females	316	40	568	106	37	1.7	8.2	0.8
Wisłoujście	males	254	81	581	246	34	5.6	8.0	3.7
	females	302	152	638	234	39	31.7	11.4	4.9

b)

Area	sex	ΣPCB	SD	Σ DDT	SD	Σ HCH	SD	HCB	SD
Łeba	males	90	48	181	63	27	4.9	7.2	0.4
	females	92	40	168	74	28	4.5	6.7	2.1
Karwia	females	406	12	489	17	40	3.1	18.1	0.4
Hel	females	471	10	505	11	41	1.5	6.5	1.5
Mechelinki	males	257	6	404	7	36	1.1	8.6	0.5
	females	200	81	377	76	33	6.0	9.4	2.8
Sopot	males	232	5	414	8	35	2.5	14.3	0.6
	females	267	21	473	38	36	9.7	13.1	1.1
Wisłoujście	males	223	64	459	176	33	1.2	8.7	3.1
	females	291	102	578	192	35	5.9	11.9	7.0

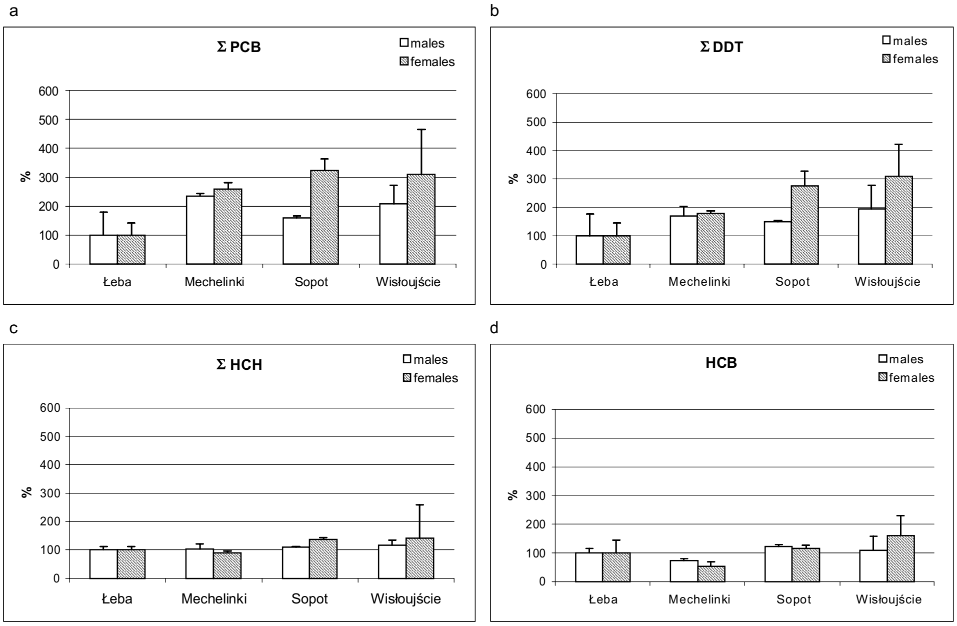


Fig. 3. Mean concentrations of ΣPCB (a), ΣDDT (b), ΣHCH (c) and HCB (d) in fish muscle tissue. The plotted values are relative to Łeba (100%).

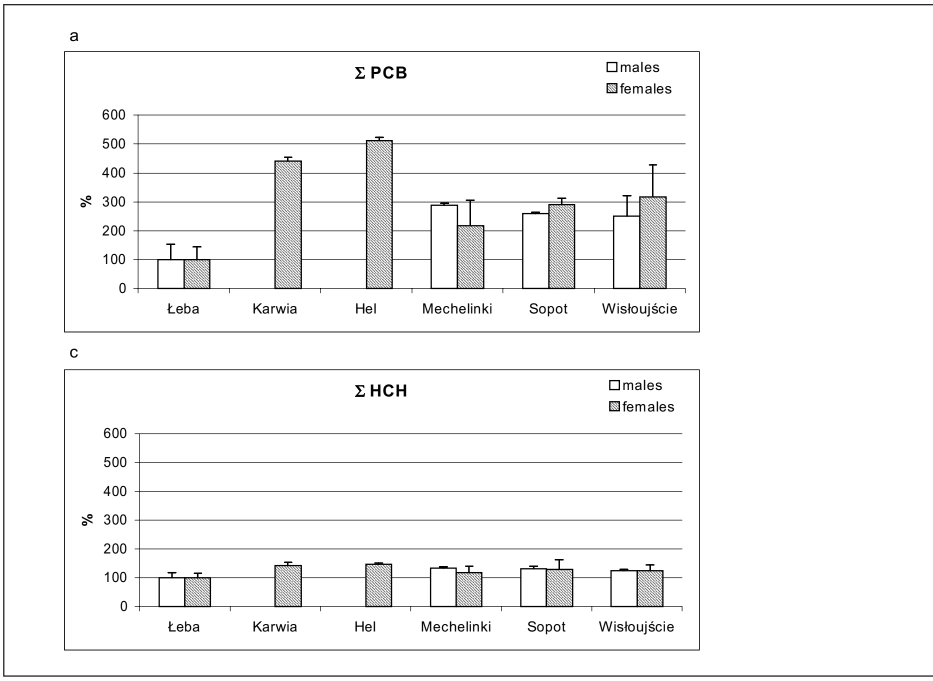


Fig. 4. Mean concentrations of ΣPCB (a), ΣDDT (b), ΣHCH (c) and HCB (d) in fish hepatic tissue.

Table. 3. The estimates of the main effects and their standard errors, s. e. for AChE activity final model in flounder

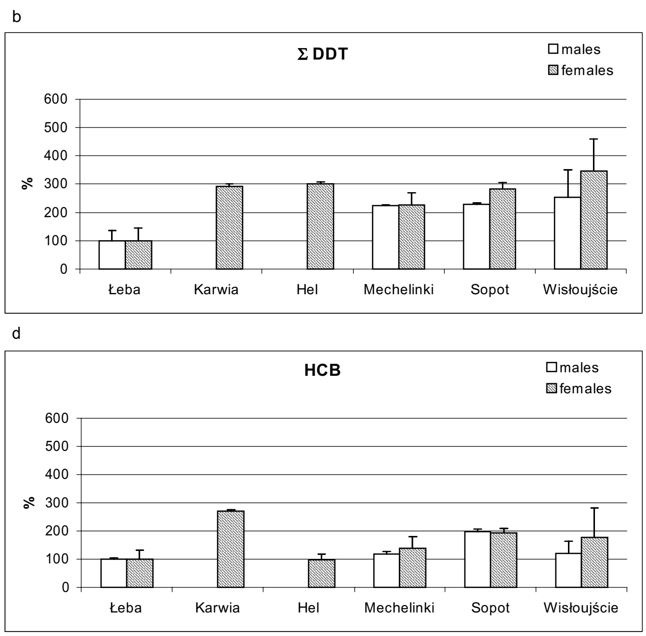
Parameter	estimate	s. e.	t pr.
Intercept	5.85	0.06	<.001
Reference area (Łeba)	0,00	aliased	
Other areas *	-0,41	0.07	<.001
Age group 3-6	0.00	aliased	
Age group 7-8	-0.57	0.11	<.001

*Karwia, Hel, Mechelinki, Sopot, Wisłoujście

AChE activity model

Only sampling area and the age of fish were significant in model 1 of AChE activity. The explanatory factors and variables explained 73% of the deviance. The factor effects for the full model are presented in Figure 5. The model fitted with factor levels with insignificantly different effects merged into new levels explains 8% less of the variance than does the model with unmerged factor levels. The parameter estimates for the final model and their standard errors are presented in Table 3. The normal probability plot of errors was approximately linear, which justifies the assumption of the normal distribution of error.

The effect of area was significantly higher ($p < 0.001$) in Łeba (reference area) than in the other sampling areas. Other areas could be grouped into a new level, as they were not



The plotted values are relative to Łeba (100%).

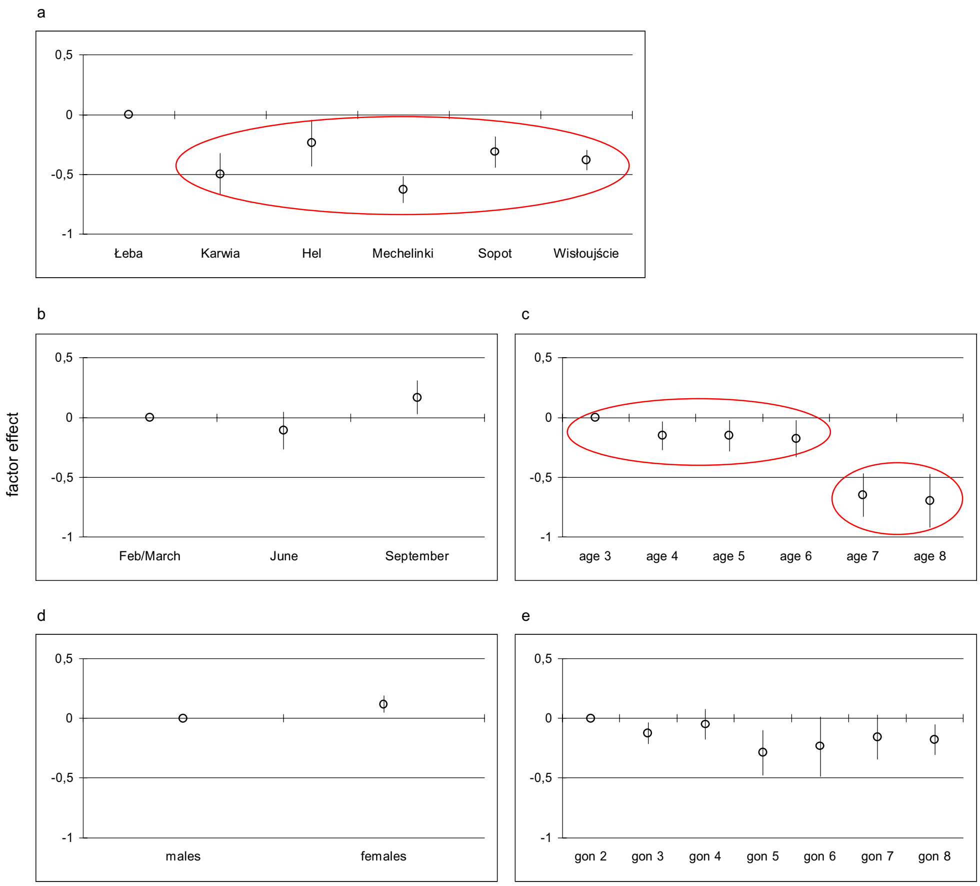


Fig. 5. Effects of area (a), month (b), age (c), sex (d) and gonad stages (e) with their standard errors estimated in the full model of AChE activity in flounder.

significantly different (Fig. 5 a). AChE activity decreased with the age of the examined fish. The factor levels of age could be merged into two new levels: one comprising ages 3-6 and one of ages 7-8. The age effect was significantly higher ($p < 0.001$) in age group 3-6 than in age group 7-8 (Fig. 5c). The effect of sex was higher for females than for males, but it was not statistically significant (Fig. 5d). The highest effect of month was observed in September, but it was not significantly different from the levels observed in other months (Fig. 5b). The gonad maturity stages were also not significant in the model (Fig. 5e).

GST activity model

The area and month of sampling as well as sex, age and the body condition factor of fish were significant in model 2 of GST activity. The model explains 49% of the deviance. The factor effects for the full model are shown in Figure 6. The model fitted with factor levels with insignificantly different effects merged into new levels explains 5% less of the variance than does the model with unmerged factor levels.

Table 4 contains estimates of the final model parameters and their standard errors. The normal probability plot of errors revealed no major deviations of error distribution from normal.

Similarly as in model 1, the area effect of Łeba was significantly different from that of other areas. The area levels could be merged into four new levels as follow: 1 – Łeba (reference), 2 – Karwia and Hel, 3 – Mechelinki and Sopot, 4 – Wisłoujście. The lowest area effect was observed in Łeba, while the highest was noted in open sea waters (Karwia and Hel) (Fig. 6a). The effect of month was statistically significant and the lowest in June ($p < 0.001$). Factor levels of other months (February, March and September) were not significantly different and could be merged into one new level (Fig. 6b). The sex effect was

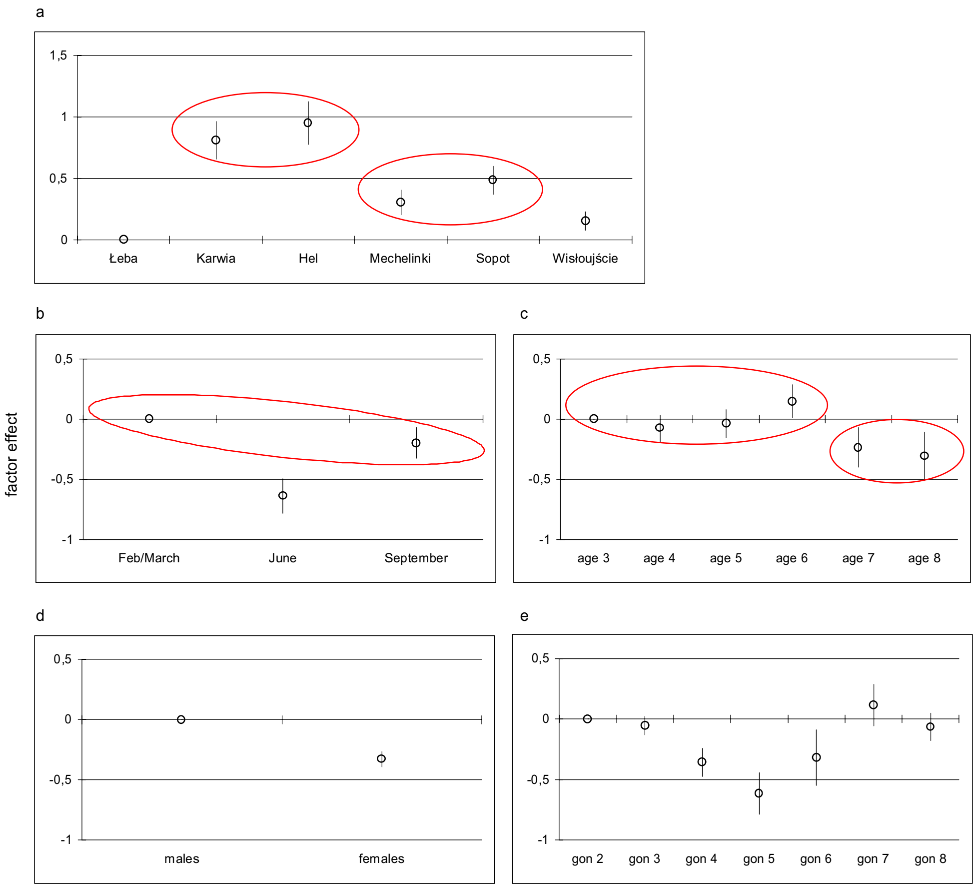


Fig. 6. The effects of area (a), month (b), age (c), sex (d) and gonad stages (e) with their standard errors estimated in the full model of GST activity in flounder.

Table. 4. The estimates of the main effects and their standard errors, s. e. for GST activity final model in flounder

Parameter	estimate	s. e.	t pr.
Intercept	4.40	0.24	<.001
Reference area (Łeba)	0.00	aliased	
Karwia and Hel	0.75	0.09	<.001
Mechelinki and Sopot	0.36	0.08	<.001
Wisłoujście	0.15	0.07	0.032
June	0.00	aliased	
Other months	0.29	0.07	<.001
Age group 3-6	0.00	aliased	
Age group 7-8	-0.25	0.10	0.016
Males	0.00	aliased	
Females	-0.32	0.06	<.001
Body condition factor	-0.52	0.20	0.011

significantly higher ($p < 0.001$) in males than females (Fig. 6d). GST activity was observed to decrease with fish age. At age 3-6 this effect was significantly higher ($p = 0.016$) than at age 7-8 (Fig. 6 c). The GST activity was negatively correlated with the body condition factor. This covariate was statistically significant in the model ($p = 0.01$). Similarly as in model 1, the gonad maturity effect was not statistically significant (Fig. 6e).

The statistical analysis did not reveal significant effects of GSI and HSI on the activity of biomarkers.

DISCUSSION

Recent studies have shown that fish populations are being exposed to an extensive mixture of contaminants at the sub-lethal level. The use of biomarkers in selected indicator species could be standardized to provide a reference database for future monitoring purposes (Goksøyr *et al.* 1996). This relies on a full characterization of the natural variations in the biomarker responses (natural limits of variability in enzyme activity) related to sex, size, feeding status and sexual maturation, as well as seawater temperature. It was suggested that the biological effects may be more severe in brackish water systems than in purely marine systems. Laboratory studies have indicated that the sensitivity of aquatic organisms to contaminants is closely related to the disruption of water and ion regulation in these animals (Seim *et al.* 1984, Mount *et al.* 1990, Cleveland *et al.* 1991, Dave *et al.* 1993).

The results of the GLM analysis of the muscular AChE activity model indicates that the area effect is significantly lower in all sampling locations in comparison to the reference area (Łeba). The studies of Kirby *et al.* (2000) also show that the muscle AChE activity in flounder from the North Sea was lower at the majority of sampling sites than in the reference region. The specific activity of AChE was also determined for the muscle of dab (*Limanda limanda*) sampled along a pollution gradient in the North Sea (Galgani *et al.*

1992). The AChE activity varied according to the contamination gradient and was the highest for "clean" waters.

The effects observed may indicate the presence of neurotoxic molecules known to be the strongest cholinesterase inhibitors. Some very limited data exist on the presence of these compounds in the southern Baltic Sea. Since the Baltic Sea area is heavily subjected to industrial as well as intensive agricultural effluents, the presence of such AChE-inhibiting xenobiotics in the Polish coast can be well expected. The existence of extremely low thresholds for the induction of inhibitory effects on AChE suggests that detection is possible after exposure to insecticide concentrations of around 0.1 to 1 $\mu g\ l^{-1}$ (Klaverkamp and Hobden 1980, Habig *et al*. 1986). However, a number of other important contaminants have been shown to have anti-AChE properties, including heavy metals (Zinkl *et al.* 1991), hydrocarbons and detergents (Payne *et al*. 1996). It seems more likely that the reactions in AChE activity observed in this study, if caused by pollution, could be attributed to the integrated effect of several classes of contaminants.

No significant difference in acetylcholinesterase activity between the genders in flounder from UK estuaries was recorded (Kirby *et al.* 2000). Schneider *et al*. (2000) observed significantly lower activity of AChE ($p < 0.02$) in female than in male cod. In model (1), AChE activity did not differ significantly with gender. According to Zinkl *et al*. (1991), AChE activity is lower in larger (older) fish than in smaller (younger) individuals. Our studies confirmed these results – in old fish (age group of 7-8), AChE activity decreased dramatically (statistically significantly) in comparison with the younger age group (3-6) (Fig. 5 c).

The result of the GLM analysis of the hepatic GST activity model indicates that the area effect is significantly higher in all sampling sites in comparison to the reference area (Łeba). In farmed mussels (*Perna perna*) held in clean and contaminated sites on Santa Catarina Island, Brazil, increased GST activity was observed in those from contaminated sites after 180 days (Bainy *et al.* 2000). Studies on the influence of dioxin and metal-contaminated sediment on GST activity in carp *Carassius auratus gibelio* showed slight, but significant, induction (1.4-fold of the control) after four weeks of exposure to contaminated sediments (Guosheng *et al*. 1998).

The literature data on the presence in the southern Baltic Sea of organic xenobiotics that can elicit the induction of hepatic GST activity are limited. Kowalewska and Konat (1997) reported the values of the sum of polynuclear aromatic hydrocarbons (ΣPAH) concentration in sediments from stations in the vicinity of Łeba and from the Gulf of Gdańsk reached about 400 and 2300 ng g^{-1}, respectively. The same authors reported that the level of (PCB in recent sediments from the Gulf of Gdańsk was up to 35 ng g^{-1} (Konat and Kowalewska 2001). Organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) were analyzed in the water of the Vistula River to investigate possible sources of contamination in the Gulf of Gdańsk (Falandysz *et al.* 1998).

The induction of GST activity may be caused by PCBs and DDTs measured in the muscle and liver of fish, however, it could also be due to other compounds not measured in this study, such as e.g. PAHs.

GST activity was significantly lower ($p < 0.001$) in females than males. The comparison of GST activity in fish has not been performed previously in relation to gender. Similar studies on glutatione S-tansferases in mammals showed that values for GST activities in young male rats were significantly higher than the corresponding values in female rats (Carrillo *et al*. 1991). GST activity was significantly lower in older specimens (age group 7-8) than in younger individuals (age group 3-6). The lowest values of CF corresponded to the highest activity of GST noted in February and March; this can be related to spawning season. In the model of AChE activity, CF was not statistically significant.

The simultaneous use of two biomarkers and the results obtained during this study provide useful information about the natural limits of variability in AChE and GST activity in the species of interest. General, but clear, patterns of AChE depression and GST induction have emerged over the dataset. The lower activities of AChE and higher activities of GST observed in the area of the Gulf of Gdańsk could be associated with heavy anthropogenic pressure (industrial as well as intensive agricultural effluents) and may suggest that flounder populations are experiencing exposure to different classes of contaminant at levels high enough to elicit sub-lethal responses.

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On the distribution and biology of roughscale sole *Clidoderma asperrimum* (Temminck et Schlegel, 1846) in the Pacific waters off the northern Kuril Islands and southeastern Kamchatka*

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Abstract. Features of spatial and vertical distribution, size and age compositions, sex ratio and feeding habits of roughscale sole *Clidoderma asperrimum* within the outer shelf and upper continental slope (depth range from 100 to 850 m) of the Pacific waters off southeastern Kamchatka and the northern Kuril Islands (47°50' N to 52°N) are considered on the basis of data obtained during 1992-2000.

Key words: northern Kuril Islands, southeastern Kamchatka, roughscale sole, *Clidoderma asperrimum*, distribution, size and age compositions, sex ratio, feeding habits

INTRODUCTION

Roughscale sole *Clidoderma asperrimum* (Temminck et Schlegel 1846) is a relatively rare mesobenthic representative of the righteyed flounder family (Pleuronectidae). This species does not support commercial fishery and is fished as by-catch during deep-water bottom trawl fishery (Fadeev 1984). Due to its delicious, fat, white flesh, roughscale sole is very popular in Japanese fish markets where its price varied from 3,000 to 8,000 JPY. This species inhabits the North Pacific from the Yellow and East China Seas (Taiwan) and the Pacific waters off Japan to California (Fadeev 1959, 1984, 1986, 1987, Clemens and Wilby 1961, Nosov 1972, Okutani 1972, Hart 1973, Eschmeyer *et al*. 1983, Anon. 1984, Lea *et al.* 1989, Gillespie 1991, Chen *et al*. 1992, Kim and Youn 1994, Amaoka *et al.* 1995, Kramer *et al.* 1995). Most of these papers comprised only descriptions of the species and common data on its geographic range, depth inhabited and occurrence. Some papers (Moiseev 1953, Mikulich 1954, Shuntov 1965, Nosov 1972, Fadeev 1984, 1986, 1987,

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Chen *et al*. 1992, Dudnik and Dolganov 1992, Orlov 1998) contain some data on the distribution and biology of this species in the North Pacific Ocean as a whole, and in Kuril Islands and Kamchatka waters in particular, though it is limited, as a rule, by catch rates, capture depths, geographic range and food items consumed.

Between 1992-2000 numerous research cruises were conducted by the staff of the Russian Federal (VNIRO, Moscow), Kamchatka (KamchatNIRO, Petropavlovsk-Kamchatsky) and Sakhalin (SakhNIRO, Yuzhno-Sakhalinsk) Research Institutes of Fisheries and Oceanography in the Pacific waters off southern Kamchatka and the northern Kuril Islands aboard the Japanese trawlers Tora-maru No. 58, Tomi-maru No. 53 and Tomi-maru No. 82. Sampling during these cruises enabled the characterization of the spatial and bathymetric distribution, size-age and sexual compositions and feeding habits of roughscale sole caught on the outer shelf and upper continental slope. The purpose of the present paper is to describe features of spatial and vertical distribution, size, weight, age and diet compositions, length-weight relationship and sex ratio of roughscale sole *Clidoderma asperrimum* within the outer shelf and upper continental slope of the Pacific waters off southeastern Kamchatka and the northern Kuril Islands, Russia (western North Pacific).

MATERIAL AND METHODS

The samples were obtained from 48 research cruises (about 8,000 bottom trawl hauls within the 100-850 m depth range) conducted during February-December from 1992 to 2000 (Fig. 1) in the Pacific waters off southeastern Kamchatka and the northern Kuril Islands

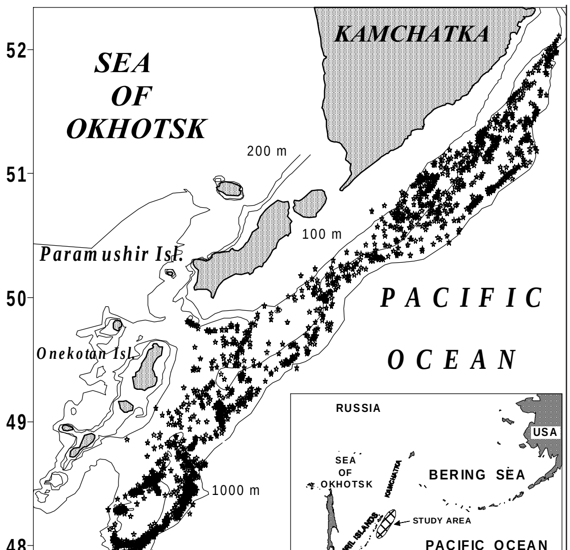

Fig. 1. Map of study area in the Pacific waters of the northern Kuril Islands and southeastern Kamchatka, 1992-2000, showing bottom trawl stations (hollow asterisks).

(47°50´-52°N). The bottom temperature was recorded on most of the cruises. Fishing was carried out around the clock using a bottom trawl with a vertical opening of about 5-6 m and a horizontal opening of 25 m and at an average towing speed of 3.6 knots. The duration of each trawl varied from 0.5 to 10 hours. All the catch rates were standardized to the number of specimens per hour of trawling. The distributions of roughscale sole relative to depth and bottom temperature were analyzed according to their frequency of occurrence (%) which was estimated as the catch rate within a depth or bottom temperature range divided by the total catch.

The analysis of the spatial and vertical distribution of various size groups of roughscale sole was based on measurements of 1670 specimens made between 1993-2000. Size-age and sex composition was based on data from 1457 fish, the length-weight relation was estimated from 656 specimens, sex was examined in 213 fish. Age estimations were based on otolith readings using the break-and-burn technique for 135 specimens. These age determinations were then extrapolated to the size composition using size-age keys.

The stomach contents of 213 roughscale sole were sampled during May-October from 1993 to 1997. The composition of the diet was expressed by the frequency of occurrence (%) (the number of stomachs that contained a particular food item divided by the total number of stomachs examined).

RESULTS

Species occurrence within the surveyed area

During the study period roughscale sole were distributed from Krusenstern's Strait to Avacha Bay (47°50´-52°N) within the depth range of 100-824 m (Fig. 2). Their catches varied from 1-2 to several tens of specimens per hour of trawling (maximum catch 65 specimens). The patterns of spatial distribution of species were relatively similar during the various seasons. Maximum catches during summer and autumn periods (over 20 specimens per hour of trawling) always occurred within the eastern slope of underwater plateau located in the southern part of study area (48°05´-48°15´N), along the Paramushir Island slope (49°45´-50°15´N) and off the southern tip of Kamchatka peninsula (50°45´-50°55´N).

Species associations

Bottom trawl catches containing roughscale sole were composed of typically deep-water benthic and bentho-pelagic fishes such as Kamchatka flounder, *Atheresthes evermanni* (frequency of occurrence 89.9%), broadbanded thornyhead, *Sebastolobus macrochir* (81.2%), darkfin sculpin, *Malacocottus zonurus* (79.6%), Greenland turbot, *Reinhardtius hippoglossoides matsuurae* (76.9%), shortraker rockfish, *Sebastes borealis* (75.4%), giant grenadier, *Albatrossia pectoralis* (61.1%), dimdisc snailfish, *Elassodiscus tremebundus* (57.2%), forktail snailfish, *Careproctus furcellus* (56.2%), popeye grenadier, *Coryphaenoides cinereus* (48.8%), Aleutian skate, *Bathyraja aleutica* (48.1%), shortspine thornyhead, *Sebastolobus alascanus* (43.9%), whitebar eelpout, *Lycodes albolineatus*

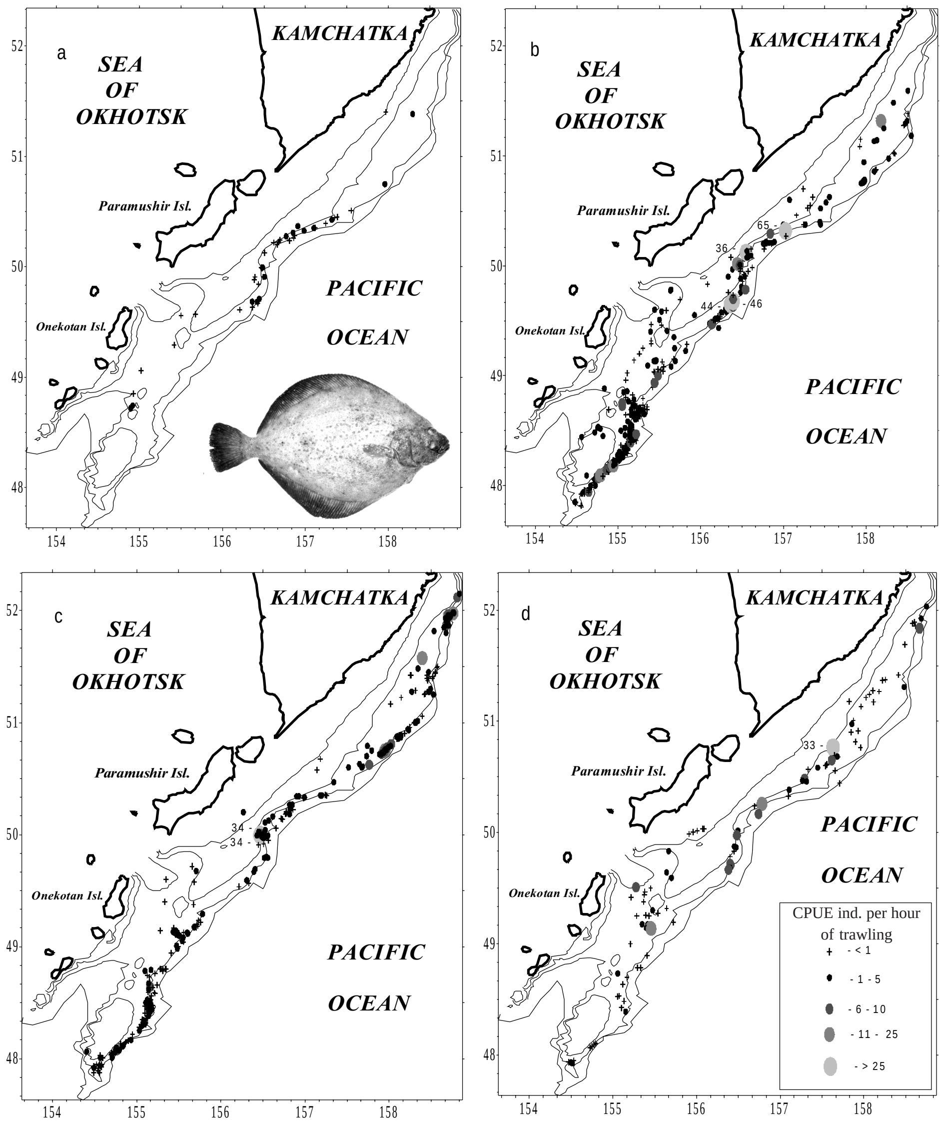

Fig. 2. Distribution and relative abundance categorized by CPUE (specimens per hour of trawling) of roughscale sole in the Pacific waters off southeastern Kamchatka and the northern Kuril Islands, 1992-2000: a – February-April, b – May-July, c – August-October, d – November-December (numbers are maximum catches, thin lines are isobaths 100, 200, 500 and 1000 m).

(41.2%), twoline eelpout, *Bothrocara brunneum* (38.2%), walleye pollock, *Theragra chalcogramma* (36.7%), whiteblotched skate, *Bathyraja maculata* (36.4%), blackfin poacher, *Bathyagonus nigripinnis* (31.9%), Pacific ocean perch, *Sebastes alutus* (29.9%), Pacific flatnose, *Antimora microlepis* (29.7%), Matsubara skate, *Bathyraja matsubarai*

(29.3%), *Elassodiscus obscurus* (29.2%), porehead sculpin, *Icelus canaliculatus* (28.3%), Pacific halibut, *Hippoglossus stenolepis* (28.3 %), and *Careproctus* cf. *cyclocephalus* (25.6%). The frequencies of occurrence of other fish were less than 25%.

Vertical distribution

Roughscale sole inhabited a broad depth range from 100 to 824 m in the study area during the period of February-December. However, throughout the year most of them (63-83%) occupied depths of 400-600 m (Fig. 3). Nevertheless, some specimens were always caught on the outer shelf.

Species distribution depending on bottom temperature

Our data allow us to characterize the temperature regime of roughscale sole in the Pacific waters off southeastern Kamchatka and the northern Kuril Islands. During the period from May to December they were present in areas with a wide range of bottom temperatures from 0.5-3.6°C (Fig. 4). However, during spring, summer and autumn (May-October), most roughscale sole (70-88%) were distributed between 2.0 and 3.5°C. In November-December the cooling of the shelf waters is accompanied by the migration of the species into deeper waters. The distribution of the fish in this period was bimodal depending on bottom temperature (Fig. 4), and the maximum relative abundance of fish (20.6 and 51.6%) occurred within the ranges of 1.0°-1.5° and 2.5°-3.0°C, respectively.

Length, weight, and age

According to our data, the size of roughscale sole in the Pacific waters off southeastern Kamchatka and the northern Kuril Islands increased with increasing depth as is shown by mean, modal and maximum sizes and also by the relative abundance of the smallest and largest specimens in various depth ranges (Fig. 5). This species has bimodal length distribution in shallow waters (200-400 m) while at greater depths (401-600 m) it is single-modal.

The size composition of roughscale sole within the whole study area was rather similar (Fig. 6). Only south of 49°N are the largest specimens caught more frequently than in the northern part of study area.

The equation of the length-weight relation (coefficient of correlation $R = 0.950$) for roughscale sole caught in the study area was fitted as follows:

$$\text{wt (kg)} = 1.054 \cdot 10^{-5}\ \text{TL (cm)}^{3.153} \text{ (Fig. 7).}$$

In bottom trawl catches taken in the Pacific waters off southeastern Kamchatka and the northern Kuril Islands during 1992-2000, roughscale sole were represented by fish which had a total length of 20 to 62 cm (mean 42.8 cm) and a body weight of 0.2 to 4.4 kg (mean 1.62 kg) and were aged 4-15 years (Fig. 8). Specimens with a total length of 36-50 cm, a body weight of 0.5-2.5 kg and aged 8-12 years were numerically dominant in the catches (79.85 and 86%, respectively). The total length of aged roughscale sole did not exceed 55 cm, therefore, taking into account their maximum known size, it is possible to suggest that the longevity of this species is no less than 18-20 years.

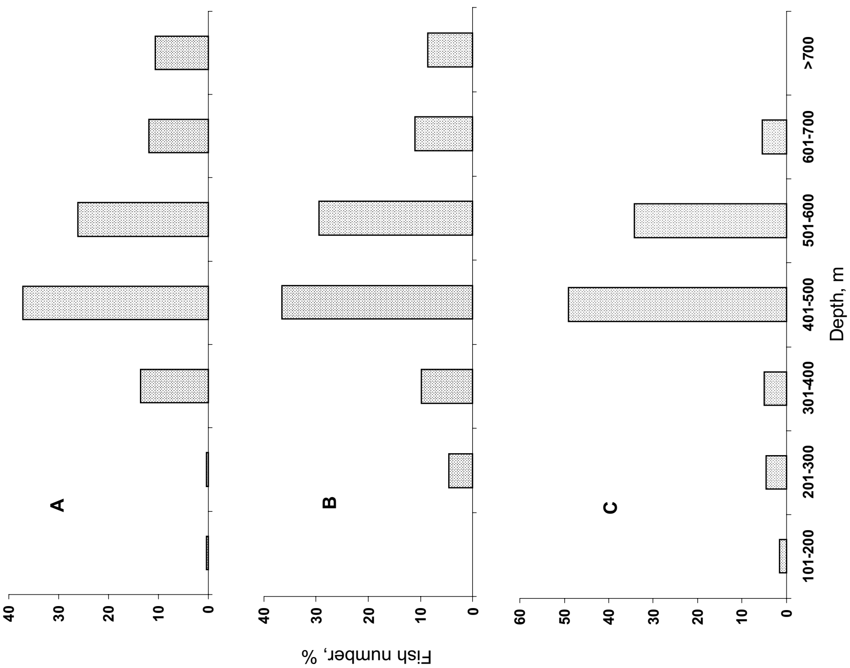

Fig. 3. Bathymetric distribution of roughscale sole in the Pacific waters off southeastern Kamchatka and the northern Kuril Islands, 1993-2000: A – May-July, B – August-October, C – November-December.

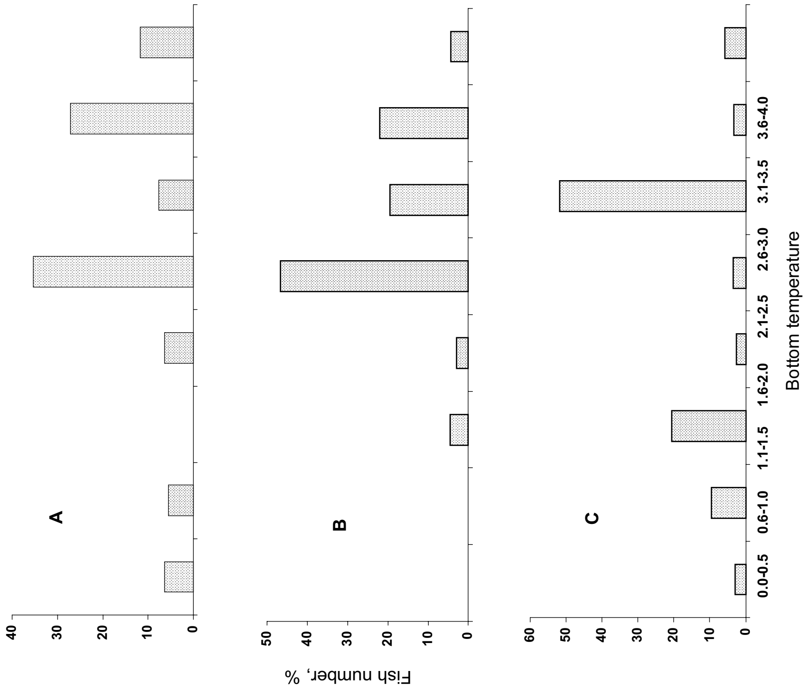

Fig. 4. Distribution of roughscale sole in the Pacific waters off southeastern Kamchatka and the northern Kuril Islands depending on bottom temperature (°C), 1993-2000: A – May-July, B – August-October, C – November-December.

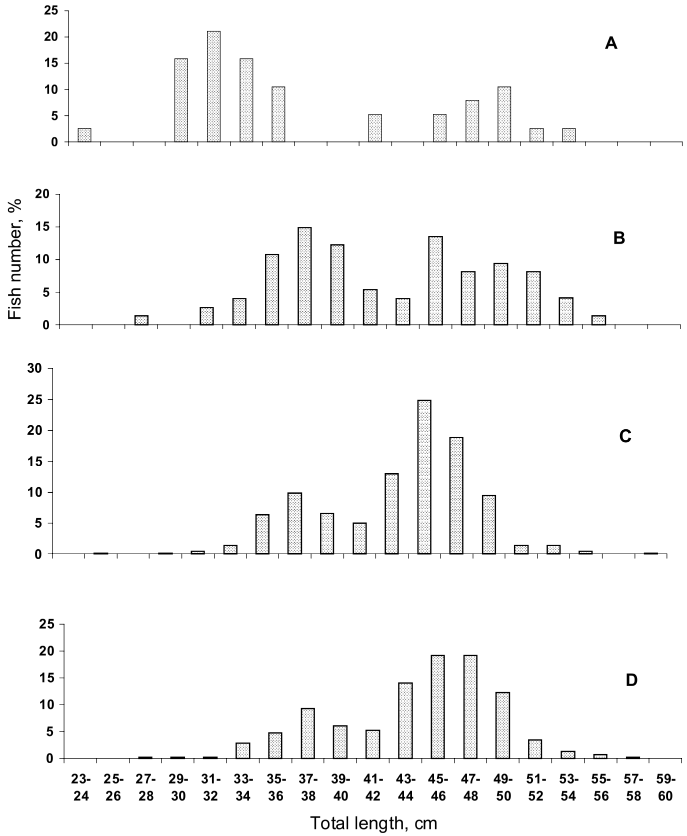

Fig. 5. Size composition of roughscale sole in various depth ranges, August-October 1993-1996 (n – number of fish measured, M – mean length ± Standard Error, cm): A – 201-300 m (n = 38, M = 36.7±1.3), B – 301-400 m (n = 74, M = 42.1± C – 401-500 m (n = 423, M = 43.3±0.2), D – 501-600 m (n = 375, M = 43.7±0.3).

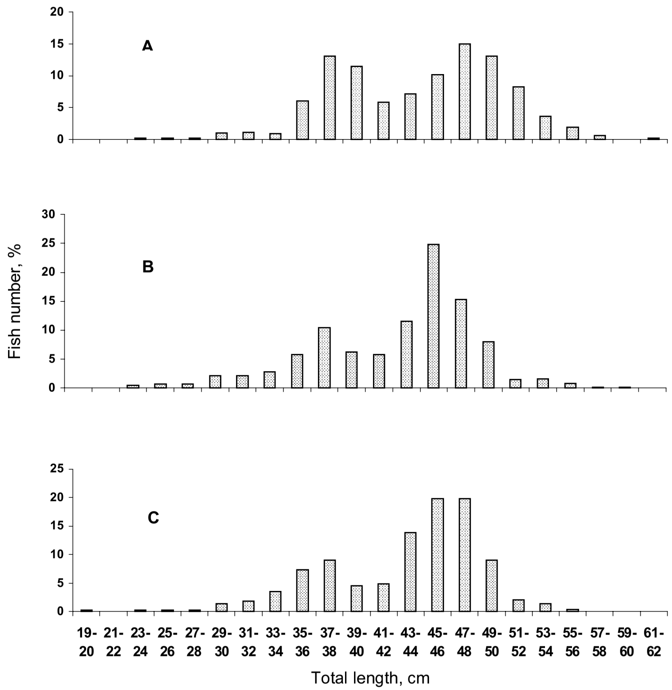

Fig. 6. Size composition of roughscale sole in various parts of the study area, May-December 1993-1999 (n – number of fish measured, M – mean length ± Standard Error, cm): A – 47°50´ –49°20´ N (n = 520, M = 43.7±0.3), B – 49°21´ – 50°50´ N (n = 855, M = 42.4±0.2), C – 50°51´ – 52° N (n = 288, M = 42.7±0.2).

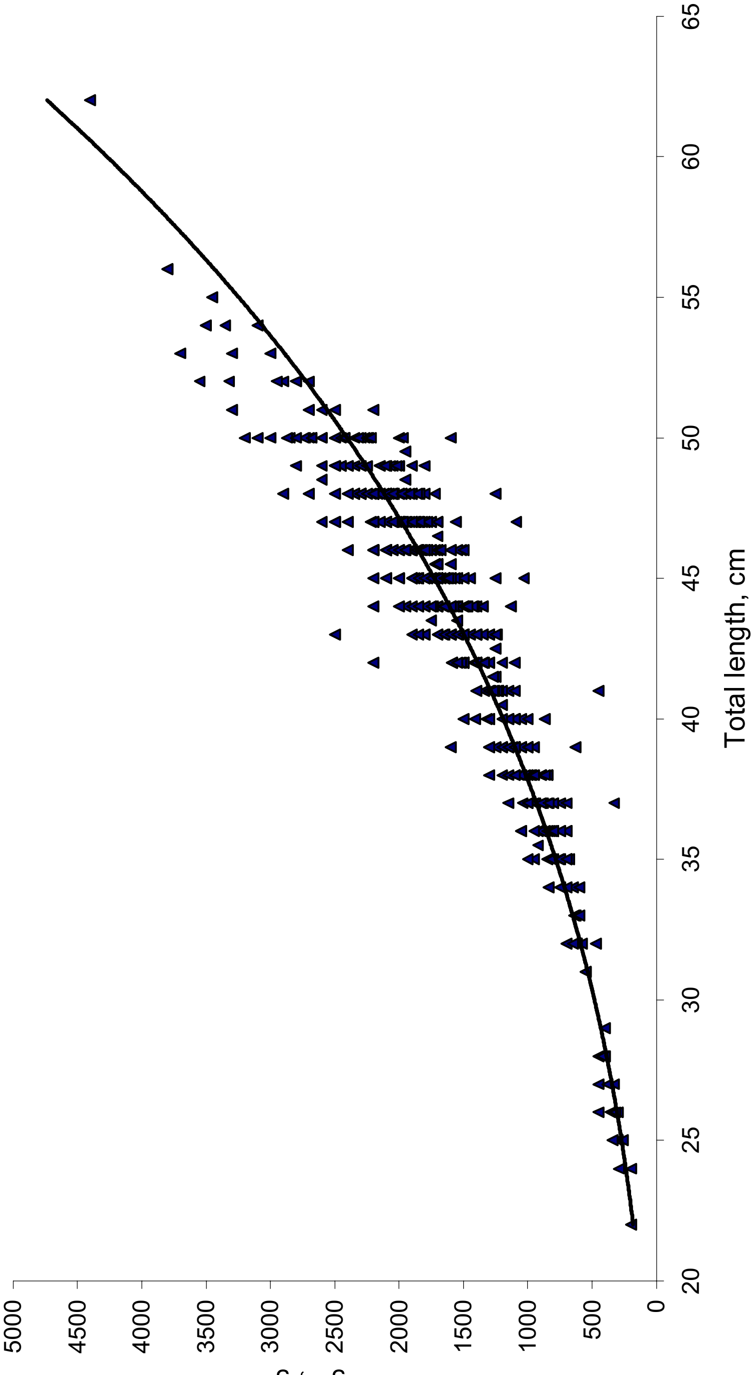

Fig. 7. Length-weight relation for roughscale sole, 1993-2000.

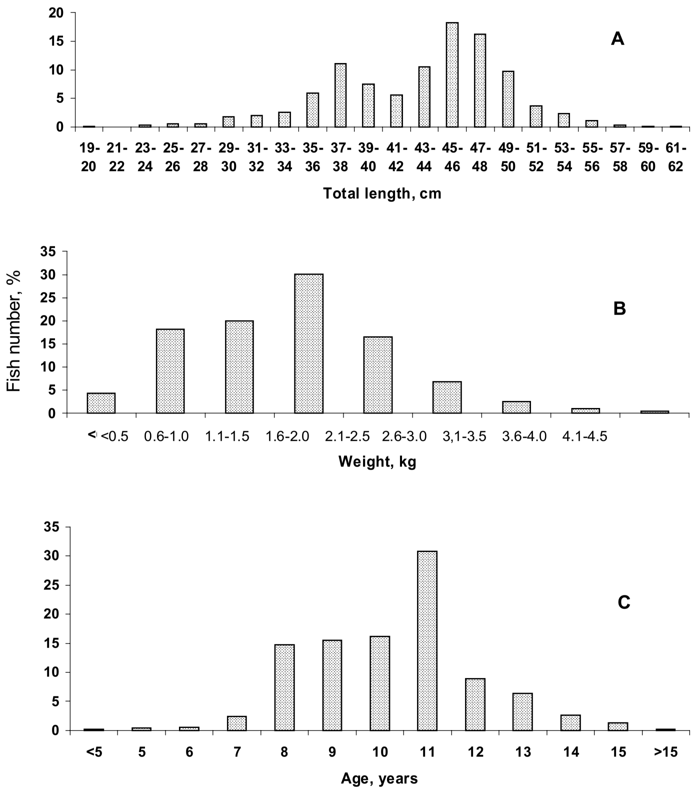

Fig. 8. Size (A), weight (B), and age (C) compositions of roughscale sole, 1993-2000 (n – number of fish sampled, M – mean value ± Standard Error, cm): A – n =1670, M = 42.8±0.2 cm, B – n = 896, M = 1.62±0.02 kg, C – n = 135, M = 10.3±0.1 yr.

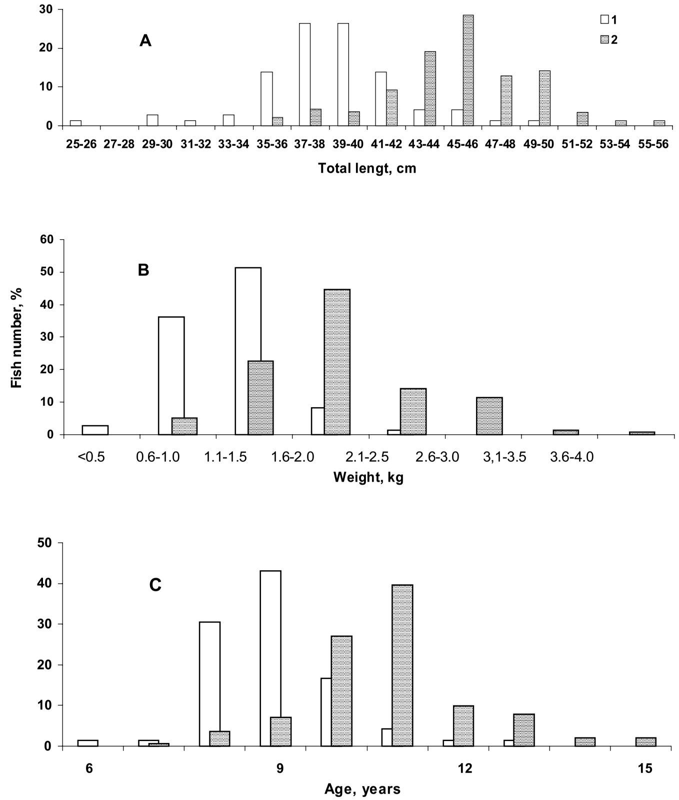

Fig. 9. Size (A), weight (B), and age (C) compositions of male (1) and female (2) roughscale sole, 1993-2000 (n – number of fish sampled, M – mean value ± Standard Error, cm): A – males (n = 72, M = 38.1±0.5 cm), females (n = 141, M = 44.8±0.4 cm), B – males (n = 72, M = 1.10±0.10 kg), females (n =141, M = 1.81±0.50 kg), C – males (n = 72, M = 9.0±0.1 yr), females (n = 141, M = 10.9±0.1 yr.

Table 1. Lengths and weights of male and female roughscale sole depending on age, 1993-2000 (numerators are range, denominators are mean values ± standard error)

Characters	Age (years)									
	6	7	8	9	10	11	12	13	14	15
	Males									
Length (cm)	26	–	30-38 35.2±0.5	38-41 38.0±0.2	40-42 40.5±0.5	–	–	–	–	–
Weight (g)	290	–	600-1200 856±39	1000-1260 1118±29	1000-1360 1200±100	–	–	–	–	–
Fish number	1	–	18	22	4	–	–	–	–	–
	Females									
Length (cm)	–	–	35-36 35.0±0.1	37-41 37.6±0.4	41-45 42.3±0.2	44-49 45.5±0.2	48-50 48.1±0.3	49-52 49.5±0.4	52-53 51.3±0.3	53–55 54.0
Weight (g)	–	–	780-850 800±29	800-1400 1064±45	1140-1950 1477±40	1550-2000 1823±56	1950-2900 2322±131	2000-2800 2475±96	2700-3720 3083±333	2750–3150 2950
Fish number	–	–	4	11	26	26	9	8	3	2

Sexual dimorphism

There was well-pronounced sexual dimorphism in sizes between male and female roughscale sole. Thus, males were considerably larger than females (Fig. 9, Tab. 1); this was probably related to the earlier maturation, reduced longevity and lower growth rates of males. As a result, these factors lead to the domination of females among the oldest fishes. During 1993-2000 the maximum size of male roughscale sole did not exceed 50 cm total length and 2.3 kg weight, while females were 62 cm and 4.4 kg. However, males with a total length of 34-43 cm (81%), a weight of 0.5-1.5 kg (over 87%) and aged 8-9 years (73%) were the most abundant in the catches. Fishes in the length range of 40 to 50 cm (84%) which weighed from 1.0 to 2.0 kg (67%) and were aged 10 to 11 years were dominated by females. Unfortunately, the total length of aged males did not exceed 42 cm and that of females 55 cm (the otoliths of larger specimens were not sampled).

Males dominated among small-sized roughscale sole (less than 40 cm). The relative abundance of females sharply increased in size classes 40-42 cm and larger, reaching 100% among fishes with lengths over 50 cm. Overall, the proportion of males to females in bottom trawl catches was as 2:1.

Feeding

The diet of roughscale sole in the Pacific waters off the northern Kuril Islands and southeastern Kamchatka consisted of representatives of six groups of benthic invertebrates (Tab. 2). However, the main dietary components were brittle stars (Ophiuroidea) and amphipods (Amphipoda), the frequency of occurrence of which was 36.6% and 19.6%, respectively. Most of the crustaceans belonged to the suborder Gammaridea.

Despite the size differences, the diets of males and females did not differ significantly (Tab. 2). Thus, brittle stars and amphipods were the most important dietary components of both males and females. However, large females had a broader food spectrum than males. It should be noted that about half the specimens examined had empty stomachs and food was found only in the intestines. The number of females with empty stomachs was almost three times that of males (Tab. 2).

Table 2. Diet composition of roughscale sole categorized by frequency of occurrence (%) of dietary components in stomachs, August-October, 1993-1997

Dietary component	Males	Females	Unsexed
Polychaeta	2.8	–	0.9
Isopoda	–	1.4	0.9
Amphipoda	13.9	22.7	19.6
Decapoda	–	2.8	1.8
Bivalvia	–	1.4	0.9
Ophiuroidea	23.6	43.3	36.6
Number of stomachs analyzed	72	141	213
Percent of empty stomachs	25.0	68.1	53.4

DISCUSSION

There are no previously published data on the spatial distribution of roughscale sole or on species which occur in bottom trawl catches along with the species considered.

According to the data of Fadeev (1987), the roughscale sole is a deep-water species inhabiting depths up to 1850 m with maximum occurrence within the depth range of 200-600 m off the Kuril Islands, 200-1100 m in the Sea of Okhotsk and 20-1850 m off Honshu. The data on the bathymetric distribution of roughscale sole obtained by us in the Pacific waters off southeastern Kamchatka and the northern Kuril Islands disagree slightly with those reported for the study area by Fadeev (1987) and agree well with those reported for other areas (Shuntov 1965, Nosov 1972, Fadeev 1984, 1987, Dudnik and Dolganov 1992, Orlov 1998).

There is very little information on the preferred temperature of roughscale sole. Fadeev (1987) noted that off Honshu this flatfish inhabits waters mostly with bottom temperatures ranging from 4 to 5°C while off the Kuril Islands and in the Sea of Okhotsk it prefers bottom temperatures of 1-2°C. Our data confirm the known temperature range extension of the species considered and provide detailed information on its seasonal changes in temperature preferences.

It is well known that juveniles and adults of many fishes inhabiting continental slope waters occupy different depth ranges. The size of some species can either decrease or increase with increasing depth (Shuntov 1965). Similar patterns of bathymetrical distribution of various size classes of roughscale sole have been observed in waters off the southern Kuril Islands and eastern Hokkaido (Nosov 1972, Fadeev 1987). However, in the Sea of Okhotsk small-sized individuals of the studied species (mean length 31-37 cm) mostly inhabit the 600-900 m depth range while larger fish (mean length 40-46 cm) occupy depths from 300 to 600 m (Shuntov 1965). According to our data, roughscale sole which inhabit the Kuril-Kamchatka area demonstrate similar patterns to those from waters off Hokkaido and the southern Kurils. The possible reason of these regional differences in the bathymetric distribution of the various size groups of this species is probably related to the different oceanological conditions of the waters of the Pacific Ocean and the Sea of Okhotsk and to the specific bottom relief of the Pacific waters from Hokkaido to Kamchatka (narrow shelf and sharp continental slope).

It has been reported previously (Tokranov 2000, Orlov 2001, Tokranov and Orlov 2001) that the sizes of some fishes inhabiting the study area gradually increased or decreased from north to south. Roughscale sole did not show such patterns.

According to published data, roughscale sole is a large representative of the righteyed flounder (Pleuronectidae) which has a deep, massive body. Their maximum total length and body weight in the northwestern Pacific Ocean are 60 cm and 2.6 kg, respectively (Nosov 1972, Fadeev 1984, 1987). This study has shown that the limits of the above values (especially for body weight) are much higher (62 cm and 4.4 kg). It is known that roughscale sole has pelagic eggs (Fadeev 1984) that, in our opinion, are transported by currents from deep to shallower waters where the development and settlement of juveniles occur. Subsequently, as roughscale sole increase in size they gradually migrate to deeper waters. This results in different size compositions at various depths and is the reason for bimodal length distribution in shallow waters. According to the data of Chen *et al.* (1994), in Chinese waters the modal classes of roughscale sole are represented by individuals 12-24 cm in length and aged 1-3 years; this is probably related to the limitation of the study area by coastal waters where only juveniles occurred.

The earlier maturation and lower growth rates of males and the larger sizes and the numerical domination of females among the oldest fishes found in the roughscale sole population in the study area are characteristic of many other fish species (Zamakhaev 1959). Taking into account the maximum known fish size and the difference in male and female maximum age in the samples (about 5 years), it is possible to suggest that the longevity of males is about 13-15 years and that of females about 18-20 years.

Previous studies have shown (Moiseev 1953, Mikulich 1954, Nosov 1972) that the roughscale sole is a typically benthophagic species which feeds mostly in the Sea of Okhotsk, off the southern Kuril Islands and Hokkaido on a variety of small brittle stars and small crustaceans. Similar to other areas, in the Kuril-Kamchatka waters the diet of this species consisted mainly of brittle stars and amphipods. Among the amphipods, representatives of the suborder Caprellidea were the most important in the diet of roughscale sole off the southern Kuril Islands (Moiseev 1953, Mikulich 1954, Nosov 1972). In the present study most of the crustaceans belonged to the suborder Gammaridea.

Mikulich (1954) found that the diets of male and female roughscale sole off the southern Kuril Islands were similar. The present study demonstrates similar findings.

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Preliminary results regarding the impact of perch-roach gillnets on pikeperch resources in the Vistula Lagoon

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Abstract. This paper addresses the problem of the impact of perch-roach gillnets on pikeperch resources in the Polish part of the Vistula Lagoon. The highest pikeperch by-catch was observed in May and June during the period when this species is protected. In subsequent months the catch efficiency of the perch-roach gillnets for pikeperch decreased. The flattened curve of the length distribution of the pikeperch caught in perch-roach gillnets indicates that the selectivity of this gear is low with regard to this species.

Key words: Vistula Lagoon, selectivity, gillnet fishery, pikeperch, perch, roach

INTRODUCTION

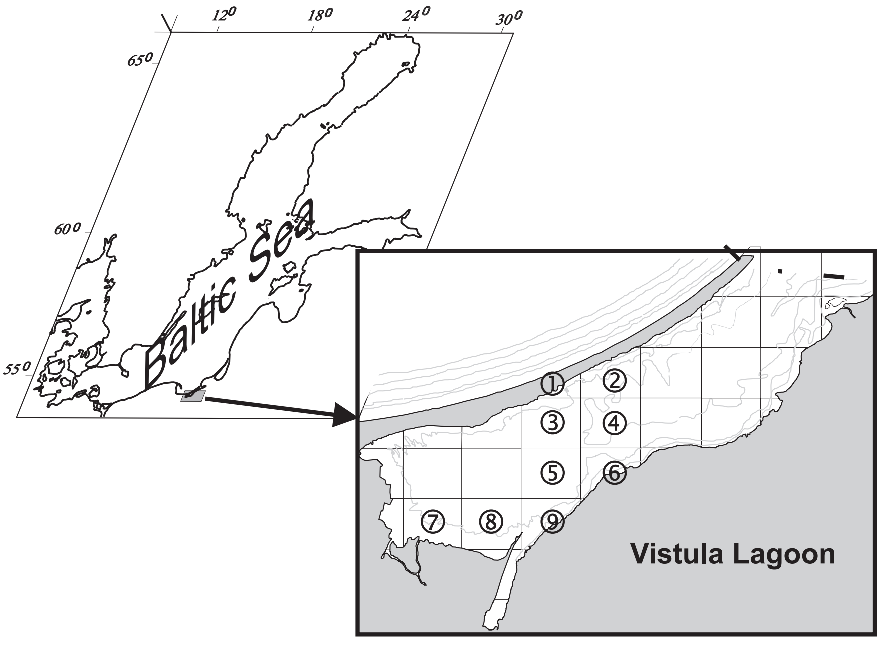
A total of approximately 500 tons of freshwater and diadromous fish species and approximately 1,000 tons of herring are caught annually in the Polish part of the Vistula Lagoon. Although this comprises only 2-3% of Polish Baltic catches, it provides employment for the majority of local residents (Borowski 2000). Catches in the Vistula Lagoon are made almost exclusively with two types of fishing gear – gillnets and fyke-nets (Borowski *et al.* 1996, Borowski and Dąbrowski 1998). The increasing intensity and improved fishing gear combined with decreasing stock levels is leading to a conflict between the exploitation and protection of valuable fish species (Hall 1999, Blaber 2000). In multi-specific fishery the application of gear which targets one fish species often has an adverse impact on the other components of the ichthyofauna.

The problem which has resulted from the application of perch-roach gillnets in the Vistula Lagoon is the impact this gear has on the juvenile pikeperch stocks in this basin. The minimum mesh size for perch-roach gillnets is 36 mm. For many years these nets were used by a small number of fishermen in the Polish part of the Vistula Lagoon. The demand for perch has increased since the mid 1990s and has been partially spurred by higher demand from the European market. In response, fishermen have significantly increased directed catches of this species. Simultaneously, gillnets made of thin nylon twine (monofilament) have come into widespread use as fishermen believe them to be more effective than gillnets made of steelon twine. Perch attain a maximum size of 35-40 cm TL, and there is no established protection size in the Vistula Lagoon. Pikeperch attain a length of approximately 95cm TL and its protection size in this basin is 46 cm TL. Since pikeperch spawning grounds are located in the Polish part of the Vistula Lagoon, there is a high percentage of juveniles of this species in the ichthyofauna structure.

The aim of this work was to determine the impact of directed perch-roach fishery on protected pikeperch juveniles. It was especially important to answer the question of whether the use of perch-roach gillnets in each season, independent of the deployment location, endangers pikeperch stocks.

Materials and methods

The materials were collected over the course of a two-year study cycle. Between May and September 1999 a total of 37 samples from control catches in nine fishery rectangles were collected [Fig. 1]. During May 2000 a total of 13 samples were collected in one fishery rectangle. The samples were collected during catches which lasted from one to nine days and employed from 10 to 24 net sets. The various fish species were weighed and measured to the nearest cm. The data were unified and are expressed in specimen/net/day units. A total of almost 9,000 fish of three species (pikeperch, roach and perch) which were caught using the perch-roach gillnets were measured during the studies. The results are presented in Table 1.



③ Statistical unit area of the lagoon (fishery square) in which samples were collected

Fig. 1. Geographical location of the Vistula Lagoon and sampling positions.

Table 1. Material collected in 1999-2000

Year	Number of measured spec.	Length range [cm]
	Perch	
1999	2,782	17-33
2000	1,560	19-33
	Roach	
1999	1,282	18-30
2000	1,720	19-29
	Pikeperch	
1999	1,042	15-57
2000	594	38-60

The information collected by the author indicates that there is currently no prescribed pattern for the construction of perch-roach nets. The nets used by fishermen in the Vistula Lagoon differ significantly. This is reflected in both the length and height of the nets, the hanging coefficient and in the length of the vertical line which shortens the relative height of the gillnet. Information obtained from interviews with fishermen from numerous fishing ports indicate that the mounting of netting on the headline and leadline differs in the majority of perch-roach gillnets. The difference in the lengths of these two lines in constructions with the same number of mounted netting meshes is usually 5 m per 40 m of ready gillnet. Mesh bar length is the only common parameter for perch-roach nets and usually varies from 36 to 45 mm. Since it was impossible to compare net parameters, it was also impossible to apply mathematical methods to determine the impact differences in construction have on catch results or selectivity.

In order to determine the impact on catch results of location and timing of setting nets, multidimensional PCA was conducted with geographic location factors (statistical rectangles) coded as nominal factors.

Data regarding landings of different fish species were obtained from official fisheries statistics provided by the Fisheries Inspectorate.

RESULTS

The greatest pikeperch by-catch was noted between May and June, and in both months the average pikeperch CPUE was approximately 2 specimens/net/day. In May the number of roach and perch specimens caught was insignificant, but in June the CPUE exceeded the value of this parameter for pikeperch four-fold (Fig. 2). Starting in June the perch CPUE remained stable at a level of 4-6 specimens/net/day, while the roach CPUE gradually increased until it reached its maximum in September.

The various fish length classes in catches made with perch-roach gillnets indicates the diversity of the impact this type of gear has on different species (Fig. 3). The majority of perch and roach caught with gillnets were from 21 to 28 cm in length (91% perch and 97% roach), while the pikeperch length distribution curve was significantly flattened. The contribution of fish from 38 cm to 50 cm in length was comparable.

The contribution of pikeperch which did not reach the minimum body size increased in subsequent months (Table 2), and from July their percentage reached 100% in total pikeperch catches.

The study was repeated in 2000 in only one fishery rectangle and the percentage of the various species varied significantly from the results obtained in the previous year. The average percentage of pikeperch (in specimens) registered in the total catches was only 38.6% (Table 3).

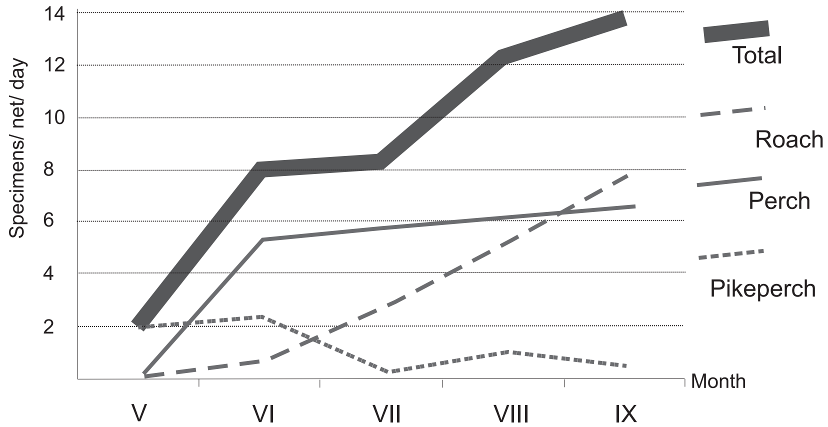


Fig. 2. The monthly dynamics of species catch per unit effort of gillnets.

Table 2. Percentage of pikeperch [specimens] in catches by sampling month in 1999

Month	Percentage of pikeperch in the total catch	Percentage of undersized fish in pikeperch catches
V	93.2	65.4
VI	28.8	76.6
VII	3.5	100
VIII	5.8	100
IX	2.2	100

PCA analysis, which displays the distribution of dependent and independent variables on a diagram created by the two first canonic axes, explains up to 91.7% of the total set variance. The geographic locations of the statistical rectangles, which are denoted by symbols, suggests that the diversity of efficiency corresponds to the location of the rectangle along an east-west axis. The increase in the roach CPUE index was strictly related to the passage of time, although it was not in the case of pikeperch. The results of analyses presented in the diagram indicate that the time factor (month) has no impact on the variability of perch CPUE (Fig. 3).

The results of the analysis of annual perch and roach catch statistics indicate that the largest catches occurred in spring (April-May) (Fig. 5). The magnitude of roach catches remained at a similar level throughout the year, with the exception of catches in 1996.

Table 3. Percentage of fish species [specimens] in samples in 2000

	Perch	Roach	Pikeperch	Percentage of undersized fish in pikeperch catches
Average	38.6	43.2	18.2	36.5
Min	10.3	0	6.7	22.5
Max	63.6	79.9	36.4	65.7

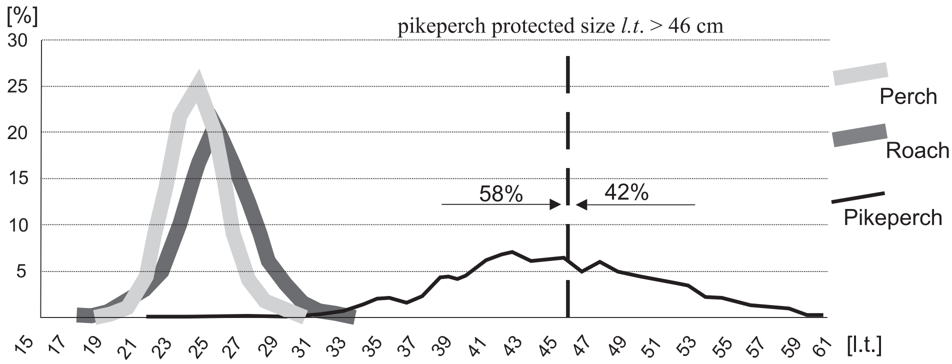


Fig. 3. Percentage of fish length classes caught using perch-roach gillnets.

Fig. 4. Diagram of PCA results.

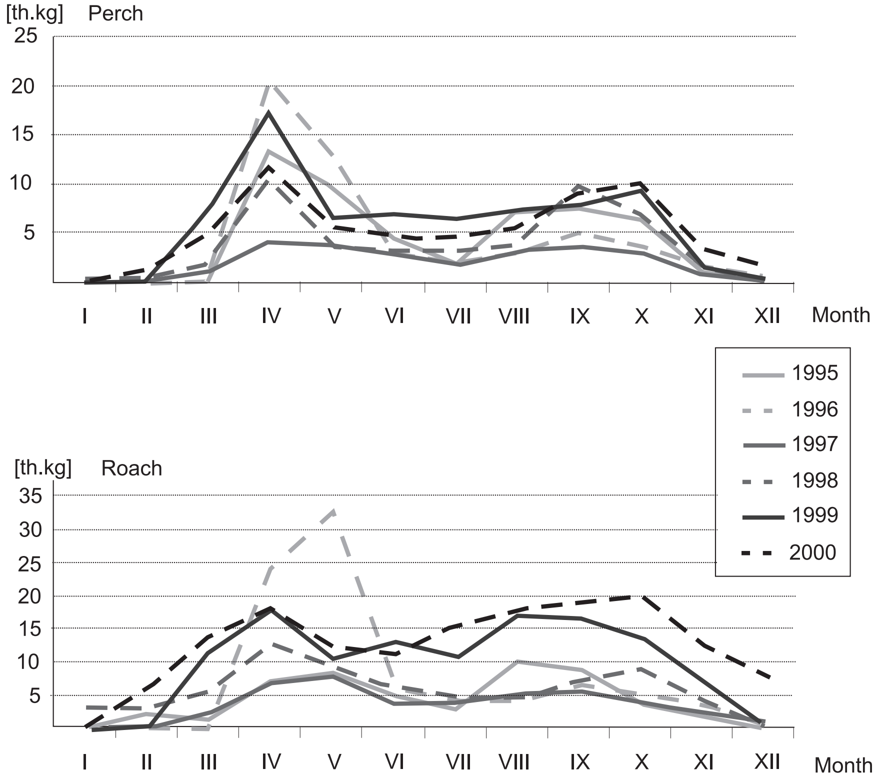


Fig. 5. Monthly catches of perch and roach in the Vistula Lagoon in 1995-2000.

DISCUSSION

Managing fisheries according to the principles of the Code for Responsible Fisheries (FAO 1995) requires that the applied fishing gear is selective. Optimum stock productivity can be achieved by determining the smallest size (age) of fish caught in the applied fishing gear according to biological traits which characterize a given stock (Gulland 1988). In practice, the values of the basic parameters either vary or are not complied with. As a consequence, the assumptions which are the foundations of management and which are used in models become inadequate in relation to the fishery model applied. In the case of pikeperch from the Vistula Lagoon, the problem is the value of the juvenile mortality index caused by directed catches of other species (eel fyke-nets and perch-roach gillnets).

Current Vistula Lagoon catch statistics register only catch magnitude, but they do not designate the type or magnitude of the fishing effort. The only data available regarding the potential of the effort come from a survey conducted in 1995 in which all the fishermen who operated in the Polish part of the Vistula Lagoon were interviewed (Borowski and Dąbrowski 1996). In light of variable socioeconomic conditions and the replacement of exhausted gear, these data may no longer be representative. In 1995 each of the 247 fishermen from the Polish part of the Vistula Lagoon used an average of 35 steelon gillnets and 12 monofilament gillnets; over 14% of the steelon nets and 33% of monofilament nets had mesh sizes smaller than 48 mm. Unpublished information obtained in 2002 from fishery inspectors operating in the Vistula Lagoon area indicate that the number of gillnets with mesh sizes below 48 mm increased since the survey was conducted. The fact that fishermen invest money in these types of nets despite Polish regulations prohibiting the use of gear with mesh sizes smaller than 55 mm in the Polish part of the Vistula Lagoon indicates that the law is not complied with. Only in directed perch-roach catches do the regulations allow for the use of 36 mm meshes. Since current regulations do not specify a minimum protection size for perch and roach, the acceptable size of these fish is set by market demand. One disputed issue is the criteria by which directed catches and by-catch are defined in multi-specific fishery, such as that in the Vistula Lagoon. This problem is the most apparent in directed eel catches which are the most profitable for fishermen. These catches are carried out using fyke-nets and impact all the fish which occur within the range of this gear. This includes juveniles which are especially susceptible to stress (Borowski *et al.* 1996). Although the catches are sorted quickly and pikeperch juveniles (most commonly specimens from the 0+ and 1+ age classes) are immediately returned to the water, significant mortality related to stress and predation by water birds was noted (Stempniewicz *et al.* 1996). The by-catch in perch-roach gillnets is dominated by older pikeperch specimens, which, however, are still under protection according to regulations. The difference between the by-catch of pikeperch in eel fyke-nets and perch-roach gillnets is reflected in the value of the fish caught; pikeperch juveniles (usually 2+ age class) caught in nets are of acceptable market size. Thus, fishermen are not compelled to strictly comply with regulations which require live, undersized specimens to be immediately returned to the water. A topic for further investigation is the mortality of pikeperch specimens which are caught and then released.

A separate problem are issues related to perch-roach gillnet construction. As this is not regulated in the Vistula Lagoon area, the development of constructions is mainly focused on increasing catchability without considering the protection of juvenile fish. Fish are caught in the nets differently - some by the operculum, jaw bones or teeth, while others become entangled in the netting (Nagięć and Ostrowski 1973). Entanglement loosens the tension of the nets made of thin nylon twine (monofilament) (Psuty 1996). The author observed that the most variable gillnet factors are the horizontal and vertical net hanging coefficients. Methods are commonly applied to modify the parameters of the nets and usually entail decreasing the height of the gear by hanging it on a vertical line. The result of this operation is that gillnets become more like trammel nets. This process increases the efficiency of the gear, especially with regard to pikeperch, and the contribution of undersized fish (Psuty 1996). A similar modification process is observed with perch-roach gillnets.

Over a period of several decades the highest annual perch catches have always been registered in the spring months from March to May and are related to spawning which occurs in April-May (Krawczak 1964). Roach also begins to spawn in May (Romański 1963), as does pikeperch. Pikeperch protection regulations prohibit its fishing from 20 April to 10 June with gear other than fyke-nets and set nets. Observations of research catches conducted from May to September indicated that the efficiency of perch-roach gillnets is the lowest with regard to the targeted species in May. However, the highest pikeperch by-catch was noted during this period, which confirms the prohibition of using all types of nets during this time. The number of pikeperch caught in perch-roach gillnets decreased in subsequent months and despite the 100% frequency of undersized specimens, their by-catch in research catches was at a level which permits the application of this fishing gear. The problem which is open to discussion is the use of perch-roach gillnets when the highest densities of these species are recorded, i.e. in the months when they spawn. Neither perch nor roach have designated protection periods in the Vistula Lagoon, and the desire of the fishermen to exploit these natural concentrations is understandable. The results of the study do not confirm that the application of these types of gear during the pikeperch spawning period has a negative impact. The results of the 1999 study indicated that in May the perch-roach gillnets caught pikeperch almost exclusively, but the materials collected in 2000 did not confirm this. In light of this, it is necessary to repeat the study. Analysis of information collected during interviews with fishermen indicate that a significant role is played by catch location. Due to the high variability of physical (water temperature, wind speed and direction, salinity) and biological (spawning period, spawning stock size) parameters and the inadequate sample size, it was not possible to use the results of the current study to draw unequivocal conclusions regarding the impact these parameters had on catch composition.

One advantage of gillnets is the possibility of selecting the length of the fish caught. A significant disadvantage, however, is its inability to select among species. The issue of allowing perch-roach gillnet catches during the pikeperch protective period is thus open and depends on the accepted model of stock protection for this species. The administrative means of protection are described in the regulations. When the allowable by-catch magnitude is exceeded the catch location must be moved and all protected fish must be released immediately. Both the information obtained by the author and her own observations indicate that there is a low degree of compliance with these regulations. Thus, this would justify the application of active protection, which is independent of the discretion of the fisherman. A rational solution for the protection of pikeperch stocks in the Vistula Lagoon is to maintain a total ban on gillnet use during the protection period for this species.

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BULLETIN OF THE SEA FISHERIES INSTITUTE
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A new record of *Piscicola borowieci* Bielecki, 1997 (Hirudinea, Piscicolidae) in Poland

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Abstract. A new record of the rare species *Piscicola borowieci* was found during a study of the bottom fauna in Łękuk Wielki Lake in the Borecka Primeval Forests.

Key words: Hirudinea, Piscicolidae, *Piscicola borowieci*

Fish leeches (Piscicolidae Johnston, 1865) occur in fresh waters, brackish waters and sea waters. They are the only group of leeches which has invaded the shelf of the Pacific Ocean from the polar basin to the shores of Antarctica (Epshtein 1987, Epshtein *et al.* 1994).

The piscicolids are parasites of ectotherm vertebrates (Bielecki 1988). Several studies show the mass occurrences of these fish leeches and the high mortality rates they cause in fish.

Fifteen species of *Piscicola* Blainvill, 1818 have been found in European waters to date (Bielecki 2001). Fourteen of them have been found in Poland. The identification of the species of this genus, which are morphologically very similar, is possible mainly on the basis of the structure of the reproductive system. Descriptions and identification keys to the species of the genus *Piscicola* can be found in Bielecki (1997).

Piscicola borowieci was described by Bielecki in 1997. The specimens designated as holotypes and paratypes originated from fish ponds near Legnica and Wołów (Bielecki 1997). These parasites were found on the fins and bodies of carp, *Cyprinus carpio* L., tench, *Tinca tinca* (L.), pike, *Esox lucius* L., pikeperch, *Stizostedion lucioperca* (L.) and grass carp, *Ctenopharyngodon idella* Val. To date, only these specimens of *P. borowieci* had been reported. Figure 1 presents the body of this species.

Fig. 1. *Piscicola borowieci* – ventral view of body: 1 – interior sucker, 2 – posterior sucker. Scale bar denotes 5 mm.

The new location *P. borowieci* was found in is Łękuk Wielki Lake. This small (21.5 ha surface area), eutrophic lake is situated between the western border of the Ełk Lakeland and the Great Mazurian Lakes in a micro region of the Borecka Primeval Forests. The *P. borowieci* specimen was collected together with benthic fauna from the detritus with a corer sampler. The samples were taken in November 1998 from the littoral zone of Łękuk Wielki Lake. This is the first record of this ectoparasitic species outside of the host.

Until it was found in the location described in this paper, *P. borowieci* had only been identified in material collected from a river in northern Germany and lakes in Finland (Bielecki unpubl.). This species probably also occurs throughout the country, but, due to the congeneric species of *Piscicola* and its similarity to most well-known, common species of *P. geometra*, it escapes detection during faunistic studies when specimen preparation is not conducted.

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The Bulletin of the Sea Fisheries Institute jest czasopismem naukowym, przyjmującym prace z całego świata. Autorzy obcojęzyczni proszeni są o składanie prac w języku angielskim, pracownicy MIR – języku polskim, a pozostali autorzy – w języku polskim i angielskim.

Prace złożone klasyfikowane są według trzech kategorii: 1) artykuły naukowe, 2) noty, 3) varia.

O przyjęciu pracy i zakwalifikowaniu jej do określonej kategorii decyduje Zespół Redakcyjny. Prace przyjęte do druku nie mogą być publikowane w innym czasopiśmie. Publikacja jest bezpłatna.

FORMA MASZYNOPISU

Prace należy składać w 2 egzemplarzach maszynopisu pisanego jednostronnie, formatu A4, z podwójnym odstepem (konieczna jest dyskietka z całością materiału). Słowa, które powinny być złożone drukiem pochyłym (kursywą), tzn. łacińskie nazwy gatunków i rodzajów oraz symbole wielkości zmiennych należy podkreślić wężykiem (~~~~~). Innych podkreśleń nie należy stosować.

W pracach kategorii 1 i 2 obowiązuje następująca kolejność:

1. Tytuł: krótki (do 100 znaków).

2. Imię i nazwisko autora oraz **nazwa i adres instytucji macierzystej.**

3. Abstrakt musi poprzedzać każdy artykuł naukowy i notę; objętość – najwyżej 1 strona maszynopisu.

4. Słowa kluczowe: kilka pojęć pozwalających na odszukanie danej pracy w systemach komputerowych.

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).

6. Podziękowania należy ograniczyć do niezbędnego minimum (inicjały imienia i nazwisko osoby, do której są adresowane, bez wymieniania tytułów naukowych i nazw instytucji).

7. Bibliografię należy zestawiać w porządku alfabetycznym, podając bezpośrednio po nazwiskach autorów rok wydania i wymieniając tylko prace cytowane w tekście (np. Kowalski 1990). Tytuły czasopism – w pełnym brzmieniu. Tytuły prac – w językach oryginału (z wyjątkiem tytułów w języku rosyjskim wydrukowanych alfabetem niełacińskim, np. cyrylicą, które należy przetłumaczyć na język polski lub angielski).

8. Przypisy oznacza się cyfrą arabską we frakcji górnej (...[1]) i numeruje kolejno w całym tekście, z wyjątkiem tabel; treść przypisów – na osobnych stronach.

9. Tabele są dodatkowym źródłem informacji; nie należy powtarzać w nich danych występujących w tekście lub na rysunkach. Tabele numerowane, każda na osobnej stronie, muszą mieć tytuł; powołanie na nie należy umieścić w tekście. Każdą kolumnę w tabeli opatruje się tzw. „główką" wyjaśniającą zawartość kolumny. Przypisy w tabelach należy oznaczyć literami, kursywą, we frakcji górnej (np. Lata[a]), a ich objaśnienie umieścić pod tabelą.

10. Ilustracje. Obowiązuje kolejna numeracja z przywołaniem każdego numeru w tekście. Podpisy pod ilustracjami – na osobnej kartce. Stosowane na rysunkach skróty, terminy i symbole muszą odpowiadać użytym w tekście. Każdy rysunek, umieszczony na osobnej kartce oraz opisany kolejnym numerem i nazwiskiem autora, po wyskalowaniu musi zmieścić sie w kolumnie; trzeba to uwzględnić stosując odpowiednią grubość linii i wielkość opisów na rysunkach. Redakcja przyjmuje wyłącznie rysunki wykonane techniką komputerową (konieczny wydruk i dyskietka). Prace można ilustrować fotografiami (mogą być kolorowe). Łączna objętość rysunków i zdjęć nie może przekraczać 30% objętości pracy.

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Plik powinien być zachowany na dyskietce w takim formacie, aby umożliwić odczytanie go w programach przez nas stosowanych. Preferowanym formatem jest Word for Windows. Rysunki wykonane techniką komputerową prosimy zapisywać na dyskietce w formacie wykonania.

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Po otrzymaniu recenzji autor jest zobowiązany do poprawienia pracy i wyjaśnienia na piśmie, co uwzględnił z sugestii recenzenta, a z czym się nie zgadza i dlaczego.

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EGZEMPLARZE AUTORSKIE

Każdy autor opublikowanego artykułu otrzymuje 1 egzemplarz czasopisma, autorzy prac kategorii 1 otrzymują ponadto 10 nadbitek swej pracy; kategorii 2 – 5 nadbitek.

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