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Early developmental stages of pikeperch in the Szczecin Lagoon: selected aspects of their biology and ecology from 1994 to 1998

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Abstract. This paper presents the results of five-year-long ichthyoplankton studies with a special focus on pikeperch. Estuarine areas, such as the Szczecin Lagoon, are highly dynamic. The bottom water temperature varied over the study period with *CV* values of 12, 22, 20, 26 and 8%. The differences in salinity among the stations reached 5‰. Results shows that the number of pikeperch reproduction sites has increased in comparison with observations made in the 1950s and the 1970s. Pikeperch spawning grounds were located on the slopes of the shoals around the Szczecin Lagoon. The abundance, or production, of pikeperch larvae in the 1995-1998 period varied significantly. During the study period, a highly abundant generation of pikeperch was hatched from eggs laid in 1995, while the weakest generation was observed in 1997. Additionally, changes were observed in ichthyoplankton species composition in relation to the inflow of sea waters. During inflows ichthyoplankton catches were dominated by the larvae of herring and goby. When the inflows subsided the occurence of freshwater fish species was observed.

Key words: *Stizostedion lucioperca*, ichthyoplankton, abundance, larvae distribution, spawning grounds, temperature, salinity, estuary, Szczecin Lagoon.

INTRODUCTION

Currently, there is a significant amount of world-wide research concerning the early developmental stages of pikeperch. Studies of Baltic ichthyoplankton have been being conducted for many years at the Sea Fisheries Institute . Studies in the Szczecin Lagoon have been conducted since the early 1990s by Szkudlarek-Pawełczyk and Porębski (1995, 1996, 1997); these authors have confirmed the presence of six taxa of fish larvae and compared their relative abundance and the variability of species composition in relation to the inflow of sea waters.

Few works which describe larval stages of pikeperch relate to different study areas. A very precise description of the larvae and spawn of the European pikeperch *Stizostedion lucioperca* L. from the Don delta were presented by Kryzhanowskij *et al.* (1953). A similar description for the American pikeperch *Stizostedion vitreum* (M.) was presented by Fritzsche (1978). Bjełyj (1960) addressed migrations of the early developmental stages of pikeperch in the Olszanka River (a tributary of the Dnieper River). Observations of the development of eggs at greater depths in the Kachowski Reservoir were conducted by Bjełyj (1962). The impact of salinity on the development of pikeperch eggs and larvae in the Dnieper River was also investigated (Bjełyj 1967). Deelder and Willemsen (1964) reported that although adult pikeperch can tolerate relatively high salinity (9-10‰), salinity exceeding 2.5-3‰ is too high for the normal development of the early stages of this species. Ostaszewska and Wojda (1997) confirmed the adverse impact of low water pH on pikeperch embryonic and larval development in controlled conditions. Urho (1996) presented results of studies on the identification of early developmental stages of pikeperch, perch and ruffe. Mani-Ponset *et al.* (1994) studied the development of the internal organs of pikeperch larvae, while Johnston and Mathias (1996) investigated the rate of food absorption in the intestines of American pikeperch larvae fed with zooplankton at different temperatures. Rieger and Summerfelt (1997) compared the behavior and development of American pikeperch larvae in clear and turbid water, and they determined that survival ability is three-fold higher among larvae from turbid waters than for those in clear water. Urho (1989) confirmed that European pikeperch larvae from the shallow, estuarial Bay of Vanhankaupunginlahti (Gulf of Finland) were highly susceptible to fin damage caused by sewage.

The aim of the present study was to locate spawning grounds and to analyze the distribution and abundance of pikeperch larvae at reproduction sites in light of variable environmental conditions in an estuarial reservoir, such as the Szczecin Lagoon.

MATERIALS AND METHODS

The material for the study was collected during spring-summer (April-July) cruises from 1994 to 1998. A total of 267 hauls were made at stations of the following depths: the Great Lagoon at 2, 4, 5 m; stations A, B, C1, K1, K2, K3 at 9 and 10 m; station W at 2 m; WM at 1.5 m. The location of stations is presented in Figure 1. The stations were chosen based on the materials of Wiktor (1956) and Wengrzyn (1986) regarding the location of pikeperch spawning grounds and the possibility of collecting samples with the fishing gear set in the area. The stations were located mainly in the coastal areas where it was expected to find the earliest pikeperch developmental stages. The dates of sampling at particular stations and years are presented in Table 1.

The larvae were collected using a set of two Bongo plankton nets with opening diameters of 600 mm and mesh diameters of 505 mm, both of which were equipped with a flow meter. The researcher made oblique hauls with the Bongo net from the surface to the bottom and back, at a trawling speed of 2 knots (1 m/s). The material was collected using the STYNKA II motorboat; the draught of the boat (1.2 m) did not allow it to penetrate shallower areas or to traverse the sandbank in the eastern part of the basin.

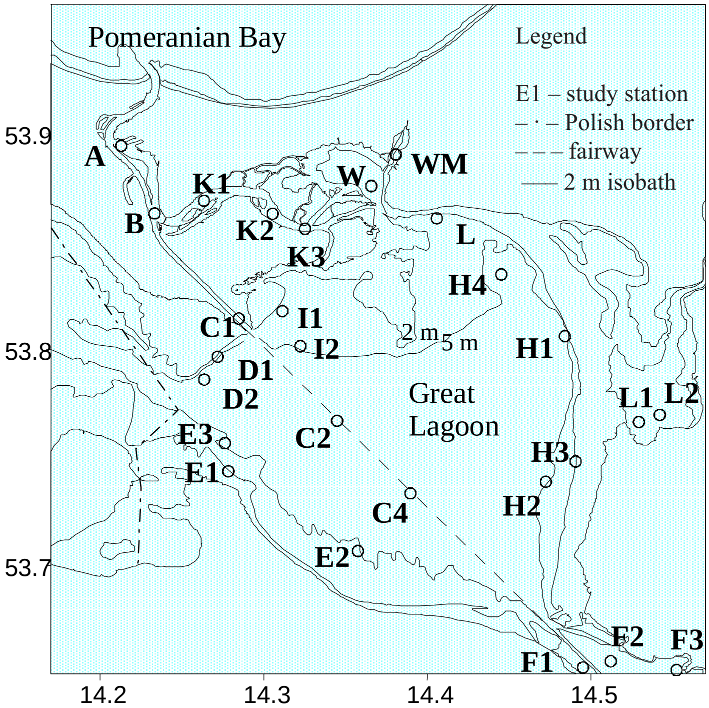

Fig. 1. Location of study stations in the Szczecin Lagoon from 1994 to 1998.

Immediately following the haul, the collected material was preserved with 4% formaldehyde buffered with borax. After sorting in the laboratory, the material was put into 80% ethanol. The larvae were identified to the species using systematic features published by Kryzhanowski (1949), Kryzhanowski *et al.* (1953) and Urho (1996).

At each sample collection at all stations, the temperature was measured and water samples were collected using a Ruttner bottle to determine the chloride contents in both the surface and benthic layers. The chloride contents were determined using the Mohr method, and then, using the Młodzińska formula, which is appropriate for waters of the Szczecin Lagoon (Majewski 1980), the chloride equivalent (*Cl*‰) was recalculated into salinity (*S*‰) as follows:

$$S‰ = 1.768\ Cl‰ + 0.2717$$

The coefficient of variation (*CV*) for the temperature and salinity of bottom water was determined by dividing the standard deviation by the arithmetic mean calculated for a given day.

A total of 11,852 pikeperch larvae were caught during the five years of the study. The number of pikeperch larvae from each haul was recalculated to 1000 m^3 of filtered water (Table 2).

Table 1. Date and location of sampling in the Szczecin Lagoon from 1994 to 1998

Date	Station	Date	Station
1994		**1997**	
23.05	A, B, C, D1, D2, E1, E3	22.04	K3, W, WM, H1, H4, L
27.05	F1, F2, F3	5.05	C1, C2, D1, D2, E1,
1.06	K1, K2, K3, W	7.05	B, K1, K3, W, WM,
10.06	H2, H3, L1, L2, I1, I2	14.05	I1, I2, E2, H2, C4
11.06	A, B, C, D1, D2, E1, E3	21.05	D1, D2, E1, E2, C2, H1
16.06	F1, F2, F3	23.05	K1, K3, W, WM, L
17.06	K1, K2, K3, W	28.05	B, C1, I1, I2,
28.06	H2, H3, L1, L2, I1, I2	6.06	H1, H2, H4, C2, C4
1995		11.06	D1, D2, E1, E2, I1, I2,
21.04	B, C1, C2, D1, D2, E1, E2	13.06	K1, K3, W, WM, L
6.05	K1, K3, W, I1, I2, H1, H2	27.06	B, C1, C2, C4, E2, H2, H4,
9.05	B, C1, C2, D1, D2, E1, E2	7.07	K3, W, WM, L
23.05	B, C1, D1	**1998**	
26.05	K1, K3, W, D2, E1, E2	28.04	K1, K3, W, WM, L
27.05	H1, H2, I1, I2, C2, C3	12.05	K1, K3, W, WM, L
13.06	B, C1, D1, D2, E1, E2	14.05	C1, D1, D2, E1
14.06	K1, K3, W, H1, H2	19.05	B, C1, I1, I2
20.06	C2, C3	22.05	K1, K3, W, WM, L
27.06	K1, K3, W	2.06	C1, C2, D1, D2, E1, E2, I1, I2
29.06	B, C1, C2, D1, D2, E1, E2, I1, I2	5.06	B, K1, K3, W, WM, L
1996		16.06	B, K1, K3, W, WM
9.05	W, WM, K1, K3	19.06	D1, D2, E1, E2, I1
17.05	I1, I2, C1, C2, B, D1, D2	23.06	C1, C2, I2
20.05	K1, K3, W, E2	3.07	K1, K3, W, WM, L
27.05	H1, H2, C4, F3		
3.06	K1, K3, W		
4.06	E1, E2, D1, D2, I1, I2, B, C1		
14.06	K1, K3, W, WM		
17.06	C2, C4, H1, H2, I1, I2		
21.06	D1, D2, E1, E2, C1, B		

Samples that were collected at fixed stations in every year of the study were used for statistical analyses. Data collected from 1995 to 1998 at stations B, C1, C2, D1, D2, E1, E2, I1, I2, H2, K1, K3 and W were analyzed. Samples from 1994 were not statistically analyzed. Throughout the paper, these data are regarded only as approximate since, due to technical reasons, material collection began in late May, while in the other years collection began in late April or early May (Table 1).

A statistical model was used to estimate year and station specific larval production,. To do this, certain assumptions and simplifications were made. A constant mortality was assumed. Larvae migrations between the stations was ignored – real immigration was thus included in the production and the real emigration in mortality (Heath 1992). It was assumed that the larvae production during the season changes in accordance with the normal distribution curve (Saville 1956). The numbers of larvae at a given station at time *t* is given as follows:

Table 2. Abundance of pikeperch larva at particular study stations in the Szczecin Lagoon from 1994 to 1998 [ind./1000 m^3]

Study date	Study station	Pikeperch larva abundance ind./1000m^3
1994		
23.05	A	29
	B	138
	C	31
	D1	126
	D2	561
	E1	1303
	E3	157
27.05	F1	0
	F2	0
	F3	0
1.06	K1	297
	K2	339
	K3	219
	W	27
10.06	H2	44
	H3	239
	L1	47
	L2	123
	I1	10
	I2	108
11.06	A	7
	B	7
	C	0
	D1	8
	D2	58
	E1	116
	E3	7
16.06	F1	0
	F2	0
	F3	36
17.06	K1	0
	K2	0
	K3	0
	W	37
28.06	H2	0
	H3	29
	L1	13
	L2	43
	I1	0
	I2	0
1995		
21.04	B	0
	C1	0
	C2	0
	D1	0
	D2	0
	E1	0
	E2	0
6.05	K1	16
	K3	0
	W	0
	I1	125
	I2	102
	H1	389
	H2	0
1995 continue		
9.05	B	480
	C1	1561
	C2	222
	D1	402
	D2	294
	E1	2222
	E2	3479
23.05	B	631
	C1	1456
	D1	323
26.05	W	0
	K1	243
	K3	0
	D2	290
	E1	240
	E2	4305
27.05	C2	4048
	C3	6
	I1	1382
	I2	954
	H1	405
	H2	313
13.06	B	3
	C1	10
	D1	23
	D2	0
	E1	52
	E2	66
14.06	K1	0
	K3	279
	W	608
	H1	0
	H2	121
20.06	C2	0
	C3	0
27.06	K1	0
	K3	7
	W	31
29.06	B	0
	C1	0
	C2	0
	D1	0
	D2	0
	E1	0
	E2	0
	I1	0
	I2	0
1996		
09.05	K1	0
	K3	34
	W	34
	WM	0
1996 continue		
17.05	B	394
	C1	624
	C2	539
	D1	781
	D2	272
	I1	378
	I2	426
20.05	K1	152
	K3	244
	W	138
	E2	344
27.05	H1	1930
	H2	452
	C4	97
	F3	68
03.06	K1	80
	K3	63
	W	55
04.06	B	189
	C1	35
	E1	35
	E2	200
	D1	260
	D2	10
	I1	306
	I2	197
14.06	K1	0
	K3	0
	W	7
	WM	15
17.06	I1	0
	I2	0
	H1	17
	H2	0
	C4	0
	C2	0
21.06	B	0
	C1	0
	D1	0
	D2	0
	E1	0
	E2	0
1997		
22.04	K3	
	H1	
	H4	
	L	
	W	
	WM	
5.05	C1	
	C2	
	D1	
	D2	
	E1	

Table 2. continue

Study date	Study station	Pikeperch larva abundance ind./1000m^3
1997 continue		
7.05	K1	0
	K3	0
	B	0
	W	0
	WM	34
14.05	C4	0
	I1	142
	I2	29
	E2	42
	H2	0
21.05	C2	0
	D1	288
	D2	1358
	E1	80
	E2	410
	H1	0
23.05	K1	229
	K3	144
	L	73
	W	244
	WM	190
28.05	B	0
	C1	0
	I1	280
	I2	423
6.06	C2	10
	C4	21
	H2	94
	H1	156
	H4	40
11.06	D1	20
	D2	0
	I1	0
	I2	22
	E1	32
	E2	75
13.06	K1	0
	K3	17
	L	0
	W	0
	WM	42
27.06	B	0
	C1	0
	C2	0
	C4	0
	E2	0
	H2	0
	H4	0
7.07	K3	0
	L	0
	W	0
	WM	0

Study date	Study station	Pikeperch larva abundance ind./1000m^3
1998		
28.04	K1	0
	K3	0
	W	4
	WM	0
	L	7
12.05	K1	1008
	K3	485
	W	1331
	WM	1232
	L	2765
14.05	C1	969
	D1	1363
	D2	2772
	E1	2087
19.05	B	385
	C1	280
	I1	2310
	I2	240
22.05	K1	0
	K3	66
	W	862
	WM	2844
	L	964
2.06	C1	21
	C2	18
	H2	34
	D1	12
	D2	38
	E1	160
	E2	353
	I1	0
	I2	15
5.06	B	0
	K1	8
	K3	18
	W	38
	WM	18
	L	61
16.06	B	0
	K1	0
	K3	0
	W	0
	WM	0
19.06	D1	0
	D2	0
	E1	0
	E2	0
	I1	0
23.06	C1	0
	C2	0
	H2	0
	I2	0
3.07	K1	10
	K3	21
	W	0
	WM	0
	L	0

$$N(t)=\sum_{i=1}^{t} N_{tot}\frac{1}{\sigma\sqrt{2\pi}}e^{\frac{-(i-\mu)^2}{2\sigma^2}}e^{-(t-i)Z}$$

where:

N_{tot} – denotes larvae seasonal production at a given station,
Z – mortality,
μ – production peak (the mean value in the mean in the normal distribution curve),
σ – parameter (standard deviation in the normal distribution curve).

Parameters N_{tot}, Z, μ and σ were determined using optimization – the sum of the squares of deviations between the observed numbers and the numbers generated by the model was minimized. The SOLVER function from Microsoft Excel was applied. Due to the relatively small number of observations per station during the season versus the number of parameters to be derived, the same Z and σ values were used for all stations in a given year.

Since the distribution of the calculated larvae production (N_{tot}) was not normal, parametric tests could not be applied. Thus, the nonparametric Kruskal-Wallis test was used. An additional test was conducted which compared the median production at selected stations between subsequent years. Both tests were conducted using the STATISTICA program. When the zero hypothesis was ruled out, the study focused on years between which significant differences occurred. Methods of multiple nonparametric comparisons and multiple median comparisons presented by Zara (1984) were applied.

The abundance of larvae generations was compared on the basis of the ratio of the median of the production in subsequent years and the median for the entire 1995-1998 period.

RESULTS

Hydrological conditions and ichthyoplankton structure

Estuarine areas, such as the Szczecin Lagoon, are highly dynamic. Variations of temperature and salinity can be rapid, as they are generated by the inflow of colder and more saline sea waters.

The bottom water temperature varied over the study period (Fig. 2), with *CV* values of 12, 22, 20, 26 and 8%. The small variations of water temperature in 1994 resulted from the study's late start. The variance in the next two years is fairly similar. In May 1995, the water temperatures varied from 12.9 to 16.0°C, and in June, from 16.1 to 20.1°C. In mid May, 1996, the temperature of benthic waters had still not exceeded 12°C. Significant variations of water temperatures were observed in 1997, when following a period of temperature increase a long-term temperature decrease occurred in late May and early June. Spring 1998 was definitely the warmest and the water temperatures were the most uniform.

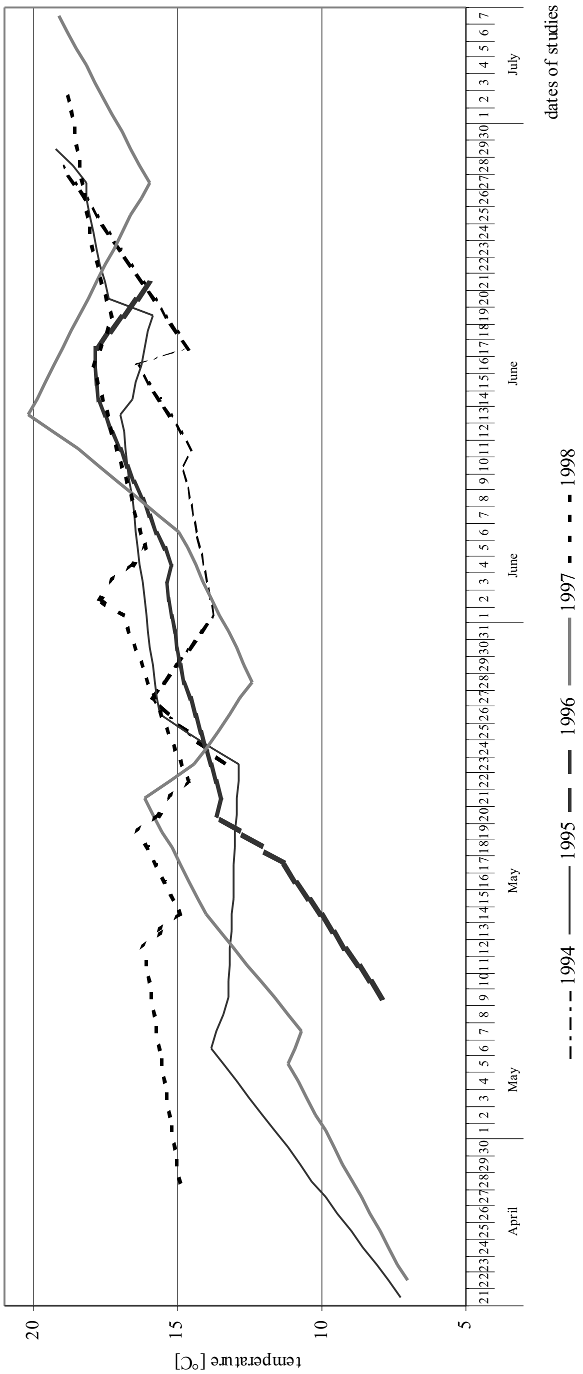

Fig. 2. Average bottom water temperature in the Szczecin Lagoom during study periods from 1994 to 1996.

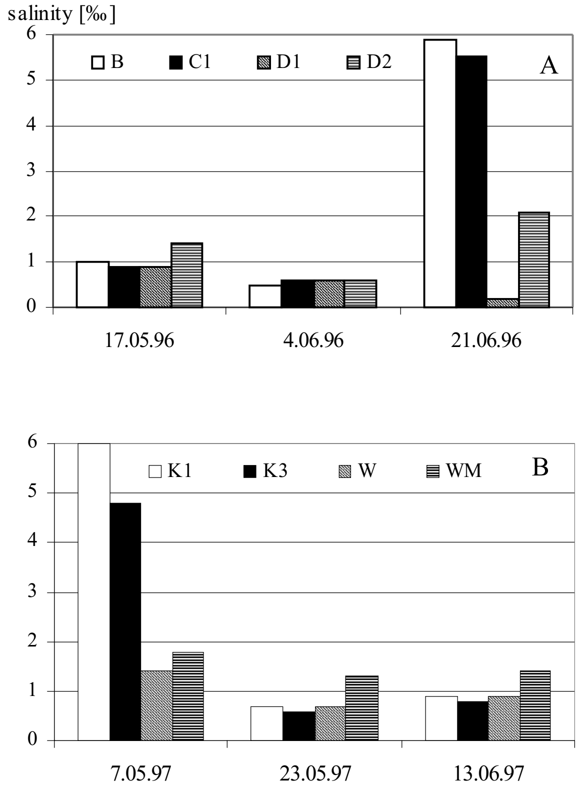

Fig. 3 A-B. Salinity of benthic waters in the Szczecin Lagoon at selected stations (K1, K3, W, WM) and dates [‰].

Inflows of sea water are primarily detected through increased salinity. The differences in salinity among the stations reached 5‰ (Fig. 3a, b) with annual *CV* values of 106, 51, 130, 80 and 56%.

The ichthyoplankton in the Szczecin Lagoon included pikeperch, smelt, perch and cyprinids (mainly roach and common bream) and, periodically, the larvae of herring and goby. In subsequent years, pikeperch larvae constituted 13, 75, 25, 9 and 45% of the ichthyoplankton.

Figures 3a, b and 4a, b show the changes in the ichthyoplankton species composition which resulted from the inflow of saline sea water. During inflows of Baltic Sea waters, higher salinity was observed as well as the occurrence of herring and goby larvae. When the inflows subsided and salinity decreased, ichthyoplankton catches were dominated by the larvae of freshwater fish species. These changes were observed in each season; however, they were most common at the northern stations.

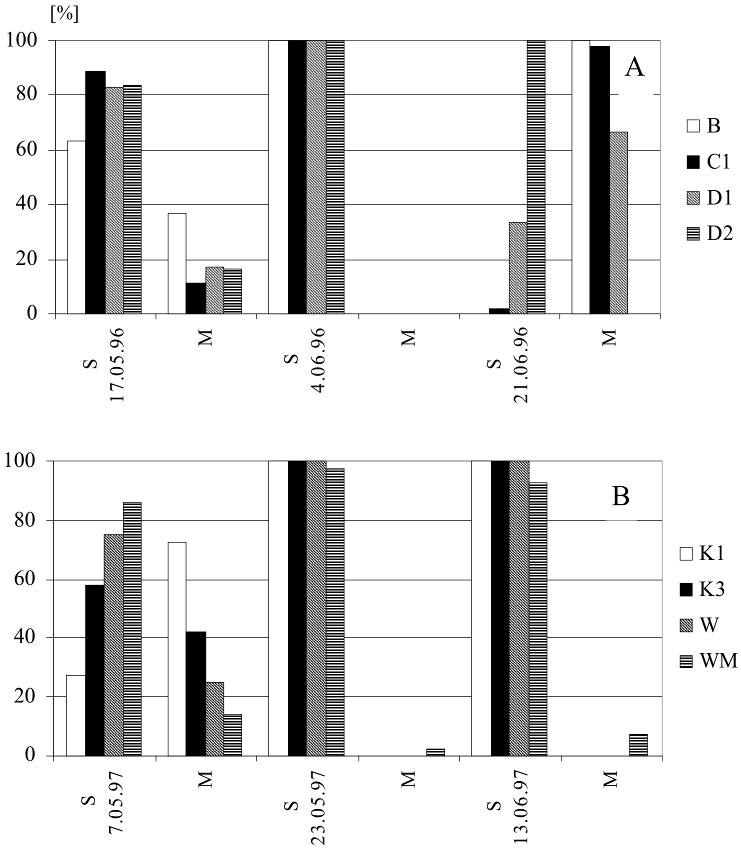

Fig. 4A-B. Percentage of particular ichthyoplankton components
(S – denotes freshwater species such as pikeperch, perch, smelt cyprinids,
M – denotes marine species such as herring and goby) sampling sites described in Fig. 3A-B.

Spawning ground location

Pikeperch spawning grounds were located on the slopes of the shoals around the Szczecin Lagoon. The criterion for designating a site as a spawning ground was the presence of larvae with yolk sacs.

Throughout the five-year study, yolk-sac larvae were observed at stations in both the northern and the southern areas of the Szczecin Lagoon and in the bays at stations W and WM (Fig. 5a-e). It is worth noting that for many years the area near station WM was polluted by municipal sewage. The opening of the biological sewage treatment factory in 1995 improved the state of waters to such an extent that in 1998 the first yolk-sac larvae were caught there.

Each year, larvae in early developmental stages were caught at some of the study stations. In 1994, larvae were caught at three stations, in 1997 at two stations and in other years at six to eight stations (Fig. 5a-e). The studies revealed that the pikeperch spawning

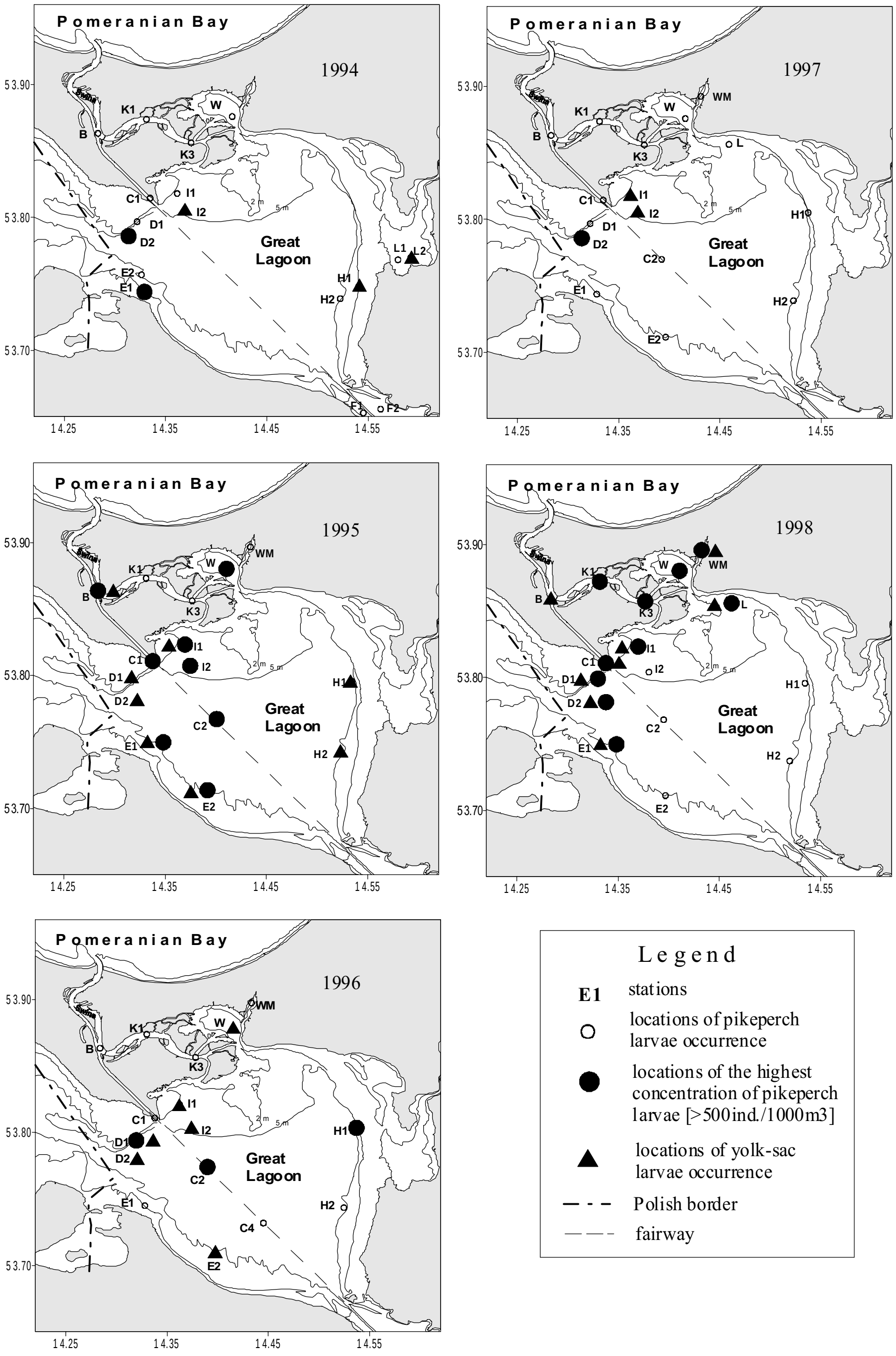

Fig. 5. Sites where larvae with yolk sacs occurred and those of the largest concentrations of *Stizostedion lucioperca* L. in the Szczecin Lagoon from 1994-1996.

grounds in the coastal areas of the lagoon are located in waters from 1.2-2 m, as well as at a depth of 5 m. However, yolk-sac larvae were caught in deep waters (8-10 m) only in 1995 and 1998. They were probably carried by currents to these areas from nearby spawning grounds in shallower arms of the river near station B.

Distribution and abundance of pikeperch larvae

Pikeperch larvae occurred at all stations in each of the five years of the study (Table 2).

Based on the abundance of pikeperch larvae in samples collected at selected, fixed stations, the seasonal larvae production was estimated. This yielded the larvae production per 1000 m^3 at each station from 1995 to 1998. Larvae production varied significantly among stations in a given year (Table 3, Fig. 6), while larvae mortality in subsequent years varied from 0.23 to 0.40.

The nonparametric Kruskal-Wallis test was used to compare production distributions. This test is applied to investigate the differences between groups when analyzed populations* do not have a normal distribution and when it is impossible to determine the distribution type. The zero hypothesis (H_0) was accepted based on the assumption that there were no significant differences between the distributions of larvae production in the years investigated.

Using the Kruskal-Wallis test to compare the production distribution at stations in subsequent years, H was 13.2 ($df = 3$, $n = 52$), which yielded $p = 0.0043$. On the other hand, with the application of the test for the production median differences a value of $c^2 = 8.9$ was obtained at a degree of freedom $df = 3$, which yielded $p = 0.0303$. The results obtained reveal that pikeperch larvae production varied significantly over the 1995-1998 period. Further comparisons between pairs of years showed significant differences only between 1995 and 1997.

Assuming that environmental variability during the course of the study affected the entire area and not only the selected study stations, then the production medians calculated for selected stations reflected the larvae abundance throughout the studied basin. The following total median production values were obtained (individuals/1000 m^3):

1995 – 5.189; 1996 – 3.092; 1997 – 1.386; 1998 – 3.937.

For the purposes of this paper, a larvae abundance scale was established as the ratio of the median larvae production in a given year to the median from 1995-1998, as follows:

low < 0.6; average 0.6 – 1.4; high > 1.4.

The ratios of the median larvae production in a given year to the median from the four-year-period were as follows:

1995 – 1.77;
1996 – 1.05;
1997 – 0.47;
1998 – 1.39.

*The word “population” is used here in its statistical meaning.

Table 3. Estimated larvae production per 1,000 m^3 at selected stations in the lagoon

	Station												
	B	C1	C2	D1	D2	E1	E2	H2	I1	I2	K1	K3	W
1995													
Mortality, Z	0.23												
Production peak	13 V	13 V	18 V	13 V	14 V	10 V	14 V	31 V	15 V	15 V	15 V	31 V	7 VI
Parameter σ	3.73												
Production [thou. ind./1000 m^3]	4.3	11.1	23.7	2.6	3.3	7.4	45.7	2.3	15.1	10.9	2.1	5.2	2.5
1996													
Mortality, Z	0.40												
Production peak	21 V	16 V	15 V	21 V	15 V	23 V	24 V	20 V	24 V	22 V	23 V	21 V	22 V
Parameter σ	6.50												
Production [thou. ind./1000 m^3]	3.8	3.6	3.1	6.6	1.6	0.6	2.8	3.4	4.6	4.0	1.1	1.5	0.9
1997													
Mortality, Z	0.26												
Production peak	–	–	2 VI	24 V	16 V	25 V	25 V	28 V	18 V	20 V	18 V	26 V	17 V
Parameter σ	2.35												
Production [thou. ind./1000 m^3]	0.0	0.0	0.0	1.8	4.1	1.9	5.4	0.9	2.9	2.9	0.8	1.4	0.9
1998													
Mortality, Z	0.32												
Production peak	18 V	11 V	28 V	14 V	14 V	17 V	23 V	18 V	14 V	20 V	6 V	12 V	14 V
Parameter σ	2.66												
Production [thou. ind./1000 m^3]	0.9	2.6	0.1	3.9	8.4	16.9	5.4	3.0	8.8	0.8	4.7	1.3	7.2

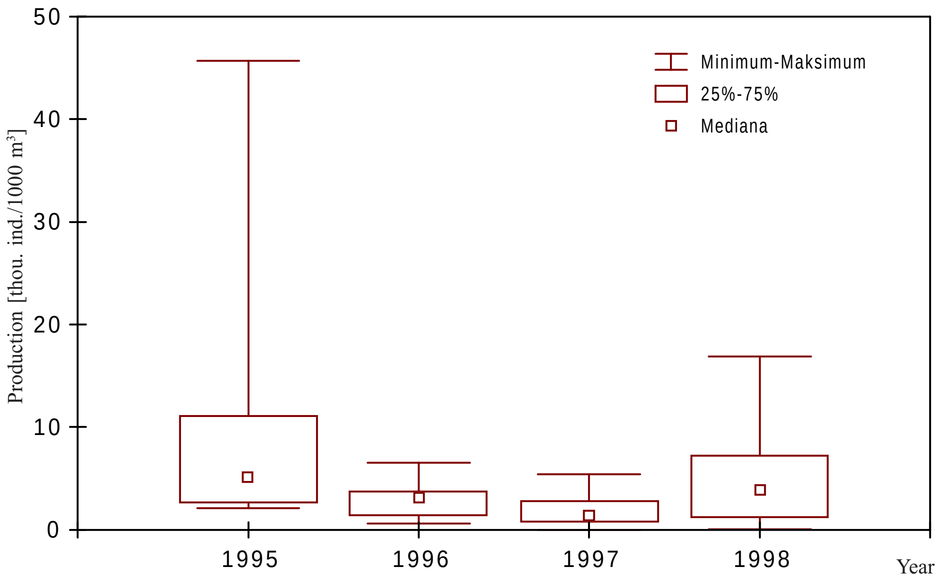

Fig. 6. Comparison of larvae production in subsequent years (in thousands of specimens/1,000m^3).

The indicators above allowed pikeperch larvae abundance to be classified in accordance with the accepted scale. The generation born in 1995 can be regarded as abundant, average abundance was observed for generations born in 1996 and 1998 and low abundance for generations born in 1997.

In years when abundance was either low or average, large pikeperch larvae concentrations were observed only at a few stations in the lagoon. In 1996, such concentrations were observed at stations D1, C2, H1, in 1997 only at station D2, and in 1998 at eight stations. When there was high abundance, large pikeperch larvae concentrations were observed at the majority of the stations. These stations were located in the Lagoon Proper as well as in the northern area near the mouth waters (Fig. 5a-e).

DISCUSSION

Many fish species reproduce and grow in the Szczecin Lagoon. To date, no research has been conducted on the early developmental stages of pikeperch in this lagoon. However, as Wiktor (1964) stated, due to the abundance of zooplankton in this lagoon, there are good feeding conditions for larvae of various fish species. According to Poleszczuk (1997), in 1985-1994 the lagoon waters were well oxygenated. Using 38 water quality indices, Poleszczuk concluded that the aquatic environment of the Szczecin Lagoon provides “comfortable hydrochemical conditions” for pikeperch. However, he also observed that the variations in salinity and the increase of the average salinity may be disadvantageous.

The location of the pikeperch spawning grounds in the Szczecin Lagoon were initially determined by Wiktor (1954) in 1950-1951 based on catch analyses and studies of the bottom character. Wengrzyn (1986) located the most important pikeperch spawning grounds in 1976-1977 using the results of catches of specimens with gonads in maturity stage VII on the Maier scale. Wengrzyn confirmed that the spawning ground sites in the Szczecin Lagoon had decreased in comparison to the results obtained by Wiktor (l.c.). In the current paper, the reproduction sites were located based on catches and the location of the early life stages of pikeperch, i.e. yolk-sac larvae which do not migrate actively in order to find food. According to Kryzhanowski (1949), they live near the bottom for 2-3 days, then they move to the pelagic zone. However, Kryzhanowskij *et al.* (1953) and Korycki (1976) both reported that these larvae can swim to the surface several hours after hatching. Lehtonen *et al.* (1996) and Virbickas *et al.* (1974) stated that the larvae stay near the bottom for several days after hatching.

In comparison with the data cited from Wiktor and Wengrzyn, the current pikeperch spawning sites are found at depths of 1.2 to 5 m in all the locations where the study was conducted. Figure 7 presents the location of the spawning grounds in the 1950s, 1970s

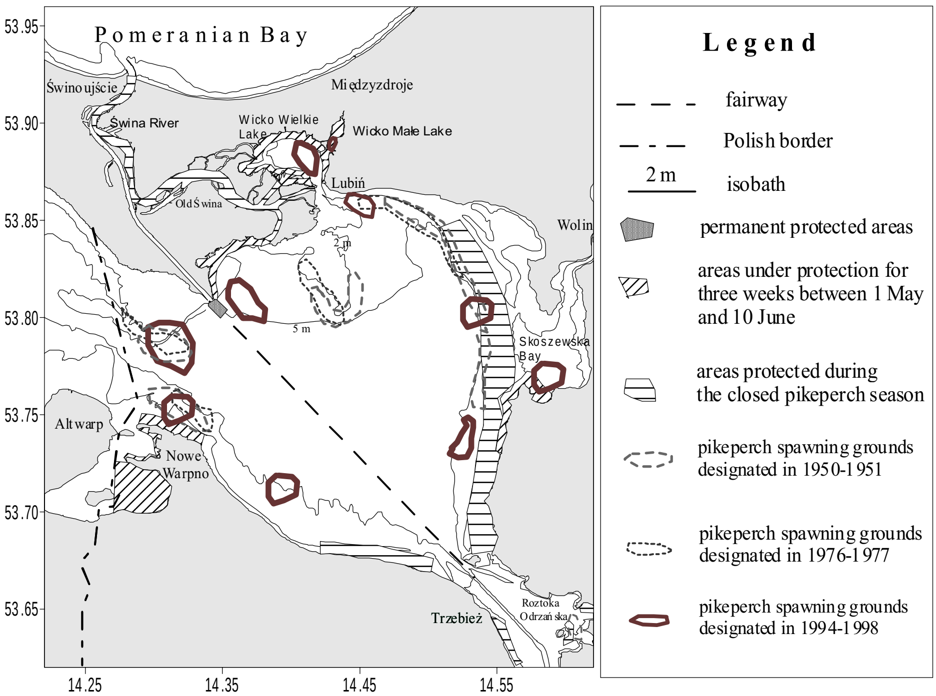

Fig. 7. Permanent and periodical protected areas and more important pikeperch spawning grounds in the Szczecin Lagoon:
in 1950-1951 (by Wiktor, 1954); in 1976-1977 (by Wengrzyn, 1986); 1994-1998 (by the author).

and 1990s. In the central lagoon basin these areas are sandy shoal banks, but in inlets the bottom is covered by mud. The latter does not have a negative impact on the larval development as it remains under the continuous care of the male until hatching (Korycki 1976).

The presence of pikeperch in the early life stages in the deep waters of station B indicates that the spawning grounds are located in the numerous nearby arms of the river, and they migrate from their hatch areas on the fast river currents. However, according to Bjelyi (1962) pikeperch can deposit eggs at depths greater than 5 m provided that they find the proper bottom type. He observed the presence of live pikeperch eggs at depths of up to 17 m.

Pikeperch larvae were observed relatively soon in the season, i.e. in early May, not only near the spawning grounds but also in open waters in the middle of the lagoon and on the fairway to Szczecin. It can be assumed that shortly after hatching the pikeperch larvae had been distributed throughout the entire lagoon. According to Bjelyi (1960), pikeperch larvae avoid flowing waters but they can drift with currents. Estuarial currents may be advantageous for fish species which scatter after hatching since, according to Urho *et al.* (1990), they increase the fish's area of occurrence and feeding. Kluczka (2000) studied the distribution of pikeperch and perch larvae in the Vistula Lagoon and she determined that pikeperch was more abundant in the stations of the open lagoon, while perch dominated at the coastal stations.

Inflows of sea waters are caused by winds or tides. They cause the stagnation and stratification of lagoon waters, which, however, disappear quickly with poly-mixing in the lagoon (Buchholz 1991, Anon. 1993). These conditions have an impact on larvae distribution. Depending on the value of the increased water salinity, the larvae of sea species are observed in catches along with the more or less abundant larvae of freshwater species. Sometimes the domination of herring and goby larvae is very clear (Porębski and Szkudlarek-Pawełczyk, 1995). Margoński (2000) investigated the presence of larvae and young smelt in the Vistula Lagoon and confirmed that it depended mainly on the wind direction and force as well as the transfer of large water masses.

The variable water salinity, especially near the mouth, may have an impact on the presence and abundance of larvae since, according to Bjelyi (1967), salinity has a greater impact on newly hatched embryos (70% of the larvae expired at 8‰ salinity) than on two-day-old embryos (only 18% expired). However, Deelder and Willemsen (1964) reported that the early pikeperch developmental stages could not survive salinity of 9-10‰, and even 2.5-3‰ is too high for normal development. Still, according to Lehtonen *et al.* (1996), egg development was also possible at 10‰. Lehtonen *et al.* (1996) stated that there is a short critical period when larvae can survive only when salinity is lower than 4.5‰. During the five-year-long study, the author observed the presence of pikeperch larvae in catches even then when the water salinity was 6.0‰; however, it is difficult to determine how long they could have survived under such conditions.

Statistically significant differences of the distribution of pikeperch larvae production in the 1995-1998 period were confirmed. Pikeperch larvae production varied significantly in subsequent years. The ratio of the strongest "generation" to the weakest one was 3.7 times. The only generation with high abundance was born in 1995. Although the abundance of this generation was evaluated as average in 1998, the value of the abundance index was at the top of the range. In both seasons, the water temperatures exceeded 12°C starting in early May and no long periods of cold were recorded. The water salinity also varied to the least extent in these periods. These conditions might be advantageous for larvae. Lehtonen *et al.* (1996) reported that higher summer temperatures caused the appearance of abundant pikeperch generations. Nagięć (1978) reported more abundant generations in years of relatively high, but not the highest May temperatures. After a temperature of 12°C was reached, it did not drop below this value. Wiktor (1956) also indicated the adverse impact of cold May temperatures which occurred at the end of the first decade and the beginning of the second decade in May. According to Kamler (1992), it is difficult to separate the impact of temperature from that of food, which is metabolized faster in higher temperatures. The availability of proper food is very important while larvae are developing.

The low abundance of the generation from 1997 may be related to the adverse impact of the decreased temperature which occurred in late May and early June. Under these conditions, the increased intensity of sea water inflows could also have an adverse impact.

According to Nagięć (1978), the amplitude of the generation abundance increases as eutrophication increases. Abiotic factors play a more important role if exploitation is intense and the eutrophication processes become more intense. Significant diversity in generation abundance in the Baltic Sea was observed by Lehtonen *et al.* (1996). These authors also cite the results of long-term monitoring studies conducted by Lappalainen *et al.* (1995) in Pärnu Bay. The latter confirmed a significant correlation between the abundance of pikeperch generations and water temperature during the first four years of life.

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The food and feeding of the round goby (*Neogobius melanostomus* Pallas, 1811) from the Puck Bay and the Gulf of Gdańsk

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Abstract.This work presents the results of studies of the food and feeding patterns of the round goby *Neogobius melanostomus*, a new fish species in the Puck Bay and the Gulf of Gdańsk. The food composition of this fish was determined based on the analyses of 829 stomachs from specimens collected in 2001. The following methods were applied: number contribution; weight contribution; frequency of occurrence. The analyses of stomach contents revealed the presence of 12,407 food units of a combined weight of 1,475.35 g. Benthic invertebrates dominated and bivalves were observed in all of the stomachs. Both mollusks and crustaceans were noted in the food of specimens from all length classes. Round goby spawn was confirmed in the food of the males.

Key words: southern Baltic, Puck Bay, Gulf of Gdańsk, *Neogobius melanostomus*, food, feeding

INTRODUCTION

The round goby *Neogobius melanostomus,* whose natural area of occurrence is the Ponto-Caspian basin, has recently come to inhabit the coastal waters of the southern Baltic Sea. It was first reported in Polish waters in 1990 in the Puck Bay near the port in Hel (Skóra and Stolarski 1993), and in 1995 it was reported to be on sale at the Gdynia Fish Market (Kuczyński 1995). Two specimens were found on the beach in Dębki in May 1995 (Grygiel 1995), and round goby was documented in research catches of the r/v BALTICA in the Puck Bay in 1996 (Wandzel 2000). In 1997, round goby was caught outside the Puck Bay near the mouth of the Vistula River and near Krynica Morska, and by 2001 round goby was already occurring regularly in commercial catches made with fyke-nets in the Vistula Lagoon (author's observations).

The round goby is currently observed in all coastal areas of the Gulf of Gdańsk. It occurs on a mass scale in the Puck Bay. This fish inhabits mainly stony bottoms and areas located near hydrotechnical constructions, such as piers, jetties and breakwaters (Skóra 1996a). This species is currently the most common representative of the *Gobiidae* family in the southern Baltic Sea.

N. melanostomus is a bottom-feeding fish which consumes mainly bivalves, snails, crustaceans, polychaetes and small fish. This species has been the subject of studies by many researchers. Bogachik (1967) and Kobiegenowa and Dżumaliew (1991) described the adaptation of its mouth, teeth and digestive tract to absorb this type of food. Skazkina and Kostiuczenko (1968), Strautman (1972) and Kovtun *et al.* (1974) all analyzed the food composition of round goby inhabiting European waters.

The food composition of round goby, a non-indigenous inhabitant of the Great Lake system in North America, was analyzed by Jude *et al.* (1995) using fish from the River St. Clair and by Ray and Corkum (1997) using round goby from the Detroit River. The bivalve *Dreissena polymorpha* dominated the food of fish with a body length exceeding 70 mm. The remaining food components were snails and other water invertebrates, such as insect larvae, crustaceans and zooplankton. Large benthic cladocerans of the genus *Eurycercus* dominated the food of smaller specimens (40-60 mm).

Ghedotti *et al.* (1995) described an experiment in which round goby grazed on the zebra mussel *Dreissena polymorpha* under laboratory conditions. Another study conducted in aquaria by Chotkowski and Marsden (1999) indicated that round goby, when presented with a wide selection of food types, grazed on lake trout spawn.

The aim of the present work was to study the feeding patterns and food composition of the round goby *Neogobius melanostomus* from the Puck Bay and the Gulf of Gdańsk.

MATERIALS AND METHODS

Materials for the study were collected in 2001 in the Puck Bay and the Gulf of Gdańsk during ten research catches made with a benthic trawl from aboard the r/v BALTICA and ten trawl catches made by a commercial fishing vessel. The r/v BALTICA catches were made with a WP-20/25 benthic, herring trawl equipped with an insert at the end of the codend with an 11mm mesh bar length. The trawling speed was approximately three knots and haul duration was 30 minutes. The fish were caught at depths from 20 to 70 m in the Gulf of Gdańsk. The commercial fishing vessel catches were made with a benthic trawl with the following technical parameters: horizontal opening - 5 m; vertical opening – 1 m; mesh bar length at the end of the codend – 15 mm. Haul duration was 30 minutes, and the catches were made at depths of 5-35 m in the Puck Bay.

A total of 1,080 fish were analyzed (Table 1). Total length (L_t) was measured to the nearest 0.1 centimeter, and the fish were sorted according to 1 cm length classes rounding up or down to the nearest class (Kompowski and Horbowy 1992).

Some authors reported body length *lc* of the measured fish (Berg 1949, Jude *et al.* 1992), and in order to compare their data with total length *lt*, the values of *lc* were recalculated to *lt* using the formula proposed by Charlebois *et al.* (1997):

$$lc = -1.35 + 0.859\ lt$$

Fish weight (W) was determined to the nearest 0.1 gram.

Table 1. List of materials used in the analyses of digested food

Date	Depth [m]	No. of specimens	Range of L_t [cm]	Average L_t [cm]	Average W [g]	Full stomachs	
						[no.]	[%]
16-02-2001	30	1	12.1	12.1	28.8	0	0.0
19-02-2001	40	44	9.8 – 20.2	13.9	43.8	30	68.2
19-02-2001	50	50	10.2 – 21.2	14.1	46.8	30	60.0
19-02-2001	60	50	9.2 – 19.9	14.7	53.2	29	58.0
19-02-2001	60	8	12.1 – 13.8	12.6	34.2	3	37.5
19-02-2001	70	7	11.6 – 12.9	12.1	32.8	2	28.6
20-02-2001	20	2	11.5 – 11.9	11.7	30.2	0	0.0
24-02-2001	60	24	8.8 – 19.6	14.9	68.2	7	29.2
25-02-2001	60	8	11.2 – 15.8	12.9	38.4	5	62.5
26-02-2001	60	64	7.4 – 20.3	14.2	46.2	45	70.3
20-04-2001	35	36	11.2 – 20.3	14.7	61.4	22	61.1
11-05-2001	20	83	10.5 – 19.6	15.8	74.8	70	84.3
25-05-2001	20	90	10.9 – 20.8	15.4	70.6	75	83.3
12-06-2001	15	83	11.3 – 19.4	15.1	62.6	66	79.5
26-06-2001	25	74	10.7 – 19.5	15.7	76.6	62	83.8
13-07-2001	15	97	11.4 – 19.9	14.8	64.8	78	80.4
30-07-2001	10	93	11.0 – 20.4	14.9	65.2	73	78.5
13-08-2001	5	78	11.8 – 19.6	15.3	59.2	72	92.3
28-08-2001	20	82	10.8 – 20.7	15.1	68.4	58	70.7
14-09-2001	25	106	11.0 – 19.4	15.3	68.6	102	96.2
Total		1,080	7.4 – 21.2	14.5	53.4	829	76.8

The composition of round goby food in the area of the Gulf of Gdańsk was determined based on the content of 829 digestive tracts. During detailed analyses of the round goby collected for the feed composition study, only those in which food was confirmed to be in the stomachs were selected for further study (Table 1).

The amount and composition of the food were analyzed as follows. An incision was made in the stomach and its contents were flushed out and placed on a scale tray filled with water. The various food components were identified to the smallest possible systematic unit. Then the number of the various components was determined, and taking into consideration the degree of digestion, their lengths were estimated. The next stage of the analyses was to estimate the weight of the various food components prior to digestion. This was done by multiplying the number of the various units by applicable standard unit weights. The unit weights were determined from the results of the author's own calculations and from data in the literature (Anon. 1985; Rumohr *et al.* 1987). The primary wet weight of organisms was applied in all subsequent calculations using the following formula:

$$W = a \times L^b$$

where: W – weight,
L – length,
a and b – equation coefficients.

The food composition was determined using the following methods:

1/) number contribution: $N(\%) = \frac{n_x}{n} \times 100$,

2) weight contribution: $W(\%) = \frac{w_x}{w} \times 100$,

3) frequency of occurrence: $F(\%) = \frac{f_x}{f} \times 100$,

where: $N(\%)$ – percentage of the number of component x,
n_x – number of components x,
n – number of all confirmed food components,
$W(\%)$ – weight percentage of component x,
w_x – reconstructed weight of component x,
w – total food weight,
$F(\%)$ – frequency of occurrence of component x in the studied fish sample,
f_x – number of fish with component x in food,
f – number of all studied fish with full digestive tracts.

The analyses of digested food indicated that there were differences in the food composition between fish of different lengths, thus, the study material was divided into three length classes. The first group was comprised of fish up to L_t 10 cm. The second class included fish from 10.1 to 15.1 cm, and the third included round goby of lengths exceeding L_t 15 cm.

Using the data available in the literature (Osowiecki 1995, 2000), an attempt was made to evaluate the use of the food base and to estimate the food selectivity indexes for the round goby *N. melanostomus*. This was accomplished by comparing the composition of benthic fauna with the food composition of the round goby caught in the same area. This comparison was made taking into consideration the location which the greatest amount of material came from, such as the fishing ground near Jastarnia.

The food selectivity indexes were derived using the formula proposed by Iwlew (1955):

$$E = \frac{r_x - p_x}{r_x + p_x}$$

where: E – food selectivity index,
r_x – percentage of component x in the food,
p_x – percentage of component x in the environment.

The range of the index derived was as follows: $-1 < E < 1$, where the negative values indicate that the fish avoid a given food element and the positive ones indicate that the given food element is chosen by the fish.

RESULTS

The analyses of the content of the digestive tracts of round goby *N. melanostomus* indicated the presence of 12,407 food units with a combined weight of 1,475.35 g. The following elements were identified:

Macrozooplankton

Crustacea

Neomysis integer

Macrozoobenthos

Oligochaeta

Polychaeta

Hediste diversicolor
Pygospio elegans

Crustacea

Bathyporeia pilosa
Gammarus salinus
Gammarus zaddachi
Cyathura carinata
Corophium volutator
Idotea chelipes
Diastylis rathkei

Chironomidae

Non det.

Bivalvia

Mytilus edulis trossulus
Macoma baltica
Mya arenaria
Cardium glaucum

Gastropoda

Hydrobia sp.

Fish

Gasterosteus aculeatus
Pomatoschistus sp.
Neogobius melanostomus – spawn

The greatest number of food units was observed in the September samples with a total of 1,987 food units found in 102 digestive tracts, which, divided by the number of fish, means that there were 19 units per stomach (Table 2). A total of 17 food elements per stomach were found in the samples from June and July. The smallest average number of organisms and spawn grains was found in the samples collected in May (only 10). In September, the highest average food mass per digestive tract was observed (2.11 g), which

Table 2. Indexes of *Neogobius melanostomus* feeding

Month	II	IV	V	VI	VII	VIII	IX
Average length L_t [cm]	14.6	14.9	15.6	15.3	14.9	15.2	15.5
Average weight W [g]	60.8	64.6	71.3	68.8	64.8	66.9	70.6
No. of full stomachs	151	22	145	128	151	130	102
Total no. of food organisms	2,303	243	1,514	2,128	2,531	1,701	1,987
Total food weight [g]	314.60	34.19	182.73	195.92	309.00	223.33	215.58

yielded an average food mass of 0.030 g food/g of total fish weight. Relatively high values of these coefficients were also observed in February, and 2.08 g of food was observed per fish, which yielded 0.034 g of digested food per gram of total fish weight. The lowest, average food masses were observed in May and August at 1.26 and 1.72 g/stomach and 0.024 and 0.013 g/g of total fish weight, respectively.

The analyses of the diversity and the number of specimens in the composition of round goby food indicates that it differs significantly throughout the year.

Bivalvia mollusks dominated in all the stomachs analyzed, with the highest numbers (*N*) in February at 71.8% and lowest in June at 47.89% (Table 3a, 3b). The weight contribution (W) of specimens from this group of food was also high, although the share of bivalves in the total weight of consumed food was at its lowest in April at 82.40% while in the July samples it was as high as 95.15%. The frequency (*F*) of bivalve occurrence in each analyzed sample exceeded 100%, which indicated that bivalves were present in all stomachs throughout the study season. Four *Bivalvia* representatives were observed in the digestive tracts, but two species were the most abundant – *Macoma baltica* and the edible mollusk *Mytilus edulis trossulus*. The abundance and weight contribution of *Macoma baltica* in the total amount of consumed food varied from 38.60% of the specimens and 45.78% of the weight in February to 25.10% of the specimens and 28.91% of the weight in April. The abundance of Mytilus edulis trossulus was estimated at 33.74% in April and only 19.41% in June, although in terms of weight it was 35.68% in February and 46.41% in May.

Small snails from the genus *Hydrobia* sp. also played an important role in food of the round goby specimens analyzed. Their number share of the total food content was 17.81% and 35.28% in August and September. Their weight contribution was not as significant. Its minimum value was observed in April (0.74%) and the maximum in September (1.82%). The frequency of occurrence varied from 33.08% in August to 76.47% in September.

Crustaceans (*Crustacea*) were represented by nine taxa. Their frequency of occurrence was estimated at 11.72% in May and 48.44 % in June. Their number contribution in July was 2.53%, and it increased to 5.58% in August. The weight contribution of crustaceans ranged from only 1.31% to 1.63%, with the exception of July when it was only 0.96%.

Polychaeta (*Polychaeta*) was represented by two species, *Hediste diversicolor* and *Pygospio elegans*, which were the least common in round goby food in February and the most abundant in September. The maximum number and highest weight contributions of *Polychaeta* were observed in April (6.58 and 1.68%) and the minimum in June and July, at 1.32 and 0.49%, respectively.

Oligochaeta (*Oligochaeta*) constituted a very small part of the total goby food weight. Its frequency (*F*) did not exceed 10% and varied from 9.09% in April to 5.38% in August.

It was estimated that the number contribution to the total amount of food was 3.90% in May, while in September it was only 0.45%. The weight contribution never exceeded hundredths of a percent.

Fish were not found in the food only in September. The species found in the food of the round goby included ruffe *Gasterosteus aculeatus* and species of the genus *Pomatoschistus* sp. In comparison with other groups of organisms, the frequency of occurrence of fish was very low. They were the most common in February at only 5.30%, while in July their contribution was as low as 1.32%. The weight contribution of fish to the total weight of the food consumed was 13.58% in April and 2.23% in September. Their number contribution did not exceed 1.00%.

Chironomidae larvae were observed in the food of round goby seasonally and were observed in the samples between May and August. Their frequency of occurrence varied from 4.83% in May to 0.77% in August. Their number contribution did not exceed 1.00%, and the weight contribution was in the hundredths of a percent.

The spawn of goby *N. melanostomus* was also observed seasonally in the food of round goby males. It was noted in the analyzed stomachs in the late spring and summer (May-August), with the maximum in June at 17.25% and the minimum in August at 2.41%. The weight contribution of goby *Neogobius melanostomus* spawn throughout the season did not exceed 1.00%, and the frequency of occurrence varied from 0.69 to 7.03%.

The seasonal variations of weight contribution are illustrated in Fig. 1 and Tables 3a and 3b. The greatest contribution of *Oligochaeta* and *Polychaeta* to the total food weight was observed in spring (April, May), while in February and summer it was much smaller. Seasonal variations in the weight contribution of crustaceans were not observed. The lowest weight contributions were observed for bivalves in April (82.4%). The contribution of bivalves to round goby food began to increase in May, while that of snails from the genus *Hydrobia* sp. remained at a constant level not exceeding 1.00%. Only in June and July was the snail contribution slightly higher. The highest weight contribution of fish to the food of the analyzed round goby was observed in April at 13.58%. Its contribution began to drop in May and reached its lowest value in July and September. The highest weight contribution of *Chironomidae* larvae in round goby food was observed at the beginning of the season in May (0.02%). In each subsequent month it decreased until it fell to a level of <0.01% in August. Only in June was the weight contribution of *Neogobius melanostomus* spawn higher at 0.56% than in all the other months in which this component was noted (May, July and August).

The results presented in Table 4 indicate that bivalves, which constituted an average of 69.79% of the food weight, dominated in the stomachs of round goby under 10 cm in length. The contribution of bivalves was higher among fish from the 10.1 to 15.0 cm L_t length class and was, on average, 92.31%. It was noted that bivalves constituted only 80.54% of the total food weight in the largest fish exceeding 15 cm in length. Fish were a rare component of the food of the largest goby specimens comprising 16.93% of the food weight. No fish were found in the digestive tracts of the round goby from the two smallest length classes.

The analyses of the weight contribution of crustaceans and snails indicated significant differences in the values of the weight contribution in the stomachs of round goby from different length classes. Crustaceans constituted 16.65% of the weight of consumed

Table 3a. Food composition of *Neogobius melanostomus* in 2001
(*N* – number contribution %, *W* – weight contribution %, *F* – frequency of occurrence %, *n. det* .- not determined, 0.00 – values < 0.01)

	February			April			May			June		
	N	*W*	*F*	*N*	*W*	*F*	*N*	*W*	*F*	*N*	*W*	*F*
Hediste diversicolor	1.69	0.88	7.95	3.29	1.67	18.18	2.31	1.36	13.10	0.99	0.76	8.59
Pygospio elegans	0.74	0.00	3.31	3.29	0.02	4.55	2.58	0.01	8.97	0.33	0.00	3.13
Oligochaeta n. det.	0.96	0.01	5.96	2.06	0.01	9.09	3.90	0.03	7.59	0.89	0.01	7.03
Neomysis integer	0.56	0.01	3.31	–	–	–	1.25	0.01	2.76	0.52	0.01	1.56
Bathyporeia pilosa	0.17	0.03	1.99	–	–	–	–	–	–	0.14	0.03	1.56
Gammarus sp.	1.26	0.55	15.23	–	–	–	1.12	0.56	8.97	0.85	0.55	5.47
Gammarus salinus	1.43	0.63	10.60	3.70	1.58	13.64	1.78	0.88	4.83	1.27	0.82	7.03
Gammarus zaddachi	0.09	0.04	1.32	–	–	–	–	–	–	0.09	0.06	1.56
Cyathura carinata	0.17	0.01	2.65	0.41	0.02	4.55	0.92	0.04	2.76	0.23	0.01	2.34
Corophium volutator	0.04	0.00	0.66	–	–	–	–	–	–	–	–	–
Idotea chelipes	0.35	0.05	2.65	–	–	–	0.40	0.07	0.69	–	–	–
Diastylis rathkei	0.09	0.00	1.32	–	–	–	–	–	–	–	–	–
Mytilus edulis trossulus	26.10	35.68	78.15	33.74	44.81	100.00	29.99	46.41	84.83	19.41	39.38	71.09
Macoma baltica	38.60	45.78	96.03	25.10	28.91	81.82	25.69	34.49	91.03	24.95	43.91	72.66
Mya arenaria	3.95	5.27	28.48	2.06	2.66	9.09	1.59	2.39	7.59	2.30	4.55	17.97
Cardium glaucum	3.17	2.81	22.52	7.00	6.02	22.73	3.83	3.84	26.21	1.22	1.61	10.16
Hydrobia sp .	20.19	0.83	43.05	18.52	0.74	36.36	18.96	0.88	67.59	28.81	1.75	53.91
Gymnocephalus cernuus	0.35	5.90	3.97	0.82	13.58	4.55	0.46	8.89	2.76	0.19	4.74	2.34
Pomatoschistus sp.	0.09	1.53	1.32	–	–	–	–	–	–	0.05	1.22	0.78
Chironomidae n. det	–	–	–	–	–	–	0.99	0.02	4.83	0.52	0.01	3.91
Gobiidae – spawn	–	–	–	–	–	–	4.23	0.11	0.69	17.25	0.56	7.03
Polychaeta	2.43	0.89	9.27	6.58	1.68	18.18	4.89	1.38	14.48	1.32	0.77	10.94
Oligochaeta	0.96	0.01	5.96	2.06	0.01	9.09	3.90	0.03	7.59	0.89	0.01	7.03
Crustacea	4.17	1.31	25.83	4.12	1.59	18.18	5.48	1.56	11.72	3.10	1.49	48.44
Bivalvia	71.82	89.54	100.00	67.90	82.40	100.00	61.10	87.13	100.00	47.89	89.45	100.00
Gastropoda	20.19	0.83	43.05	18.52	0.74	36.36	18.96	0.88	67.59	28.81	1.75	53.91
Pisces	0.43	7.43	5.30	0.82	13.58	4.55	0.46	8.89	2.76	0.23	5.96	2.34

Table 3b. Food composition of Neogobius melanostomus in 2001
(N – number contribution %, W – weight contribution %, F – frequency of occurrence %, n. det .- not determined, 0.00 – values < 0.01)

	July			August			September		
	N	*W*	*F*	*N*	*W*	*F*	*N*	*W*	*F*
Hediste diversicolor	0.83	0.48	8.61	1.53	0.83	14.62	1.41	0.93	17.65
Pygospio elegans	1.11	0.01	7.95	0.53	0.00	5.38	0.81	0.01	6.86
Oligochaeta n. det.	0.71	0.00	7.28	1.23	0.01	5.38	0.45	0.00	5.88
Neomysis integer	0.28	0.00	1.32	0.41	0.00	2.31	–	–	–
Bathyporeia pilosa	–	–	–	0.29	0.05	3.08	0.35	0.07	1.96
Gammarus sp.	0.51	0.25	4.64	0.65	0.29	3.85	0.25	0.14	2.94
Gammarus salinus	1.42	0.70	11.92	2.59	1.18	13.08	1.86	1.03	10.78
Gammarus zaddachi	–	–	–	–	–	–	–	–	–
Cyathura carinata	0.24	0.01	1.99	1.23	0.05	14.62	0.15	0.01	1.96
Corophium volutator	–	–	–	0.12	0.00	1.54	–	–	–
Idotea chelipes	–	–	–	0.29	0.05	3.08	0.25	0.05	4.90
Diastylis rathkei	0.08	0.00	1.32	–	–	–	–	–	–
Mytilus edulis trossulus	30.38	46.49	88.74	28.63	40.73	75.38	26.22	45.14	85.29
Macoma baltica	31.77	42.15	93.38	33.86	41.78	93.85	31.05	46.36	97.06
Mya arenaria	1.82	2.71	15.23	3.47	4.81	17.69	0.35	0.59	2.94
Cardium glaucum	3.83	3.80	24.50	4.47	4.12	23.85	1.46	1.63	16.67
Hydrobia sp.	22.20	1.02	35.76	17.81	0.76	33.08	35.28	1.82	76.47
Gymnocephalus cernuus	0.12	2.25	1.32	0.18	3.12	1.54	–	–	–
Pomatoschistus sp.	–	–	–	0.12	2.15	1.54	0.10	2.23	1.96
Chironomidae n. det	0.28	0.01	2.65	0.18	0.00	0.77	–	–	–
Gobiidae – spawn	4.43	0.11	1.32	2.41	0.06	0.77	–	–	–
Polychaeta	1.94	0.49	13.91	2.06	0.83	16.92	2.21	0.93	22.55
Oligochaeta	0.71	0.00	7.28	1.23	0.01	5.38	0.45	0.00	5.88
Crustacea	2.53	0.96	13.91	5.58	1.63	23.08	2.87	1.29	12.75
Bivalvia	67.80	95.15	100.00	70.43	91.45	100.00	59.08	93.73	100.00
Gastropoda	22.20	1.02	35.76	17.81	0.76	33.08	35.28	1.82	76.47
Pisces	0.12	2.25	1.32	0.29	5.27	3.08	0.10	2.23	1.96

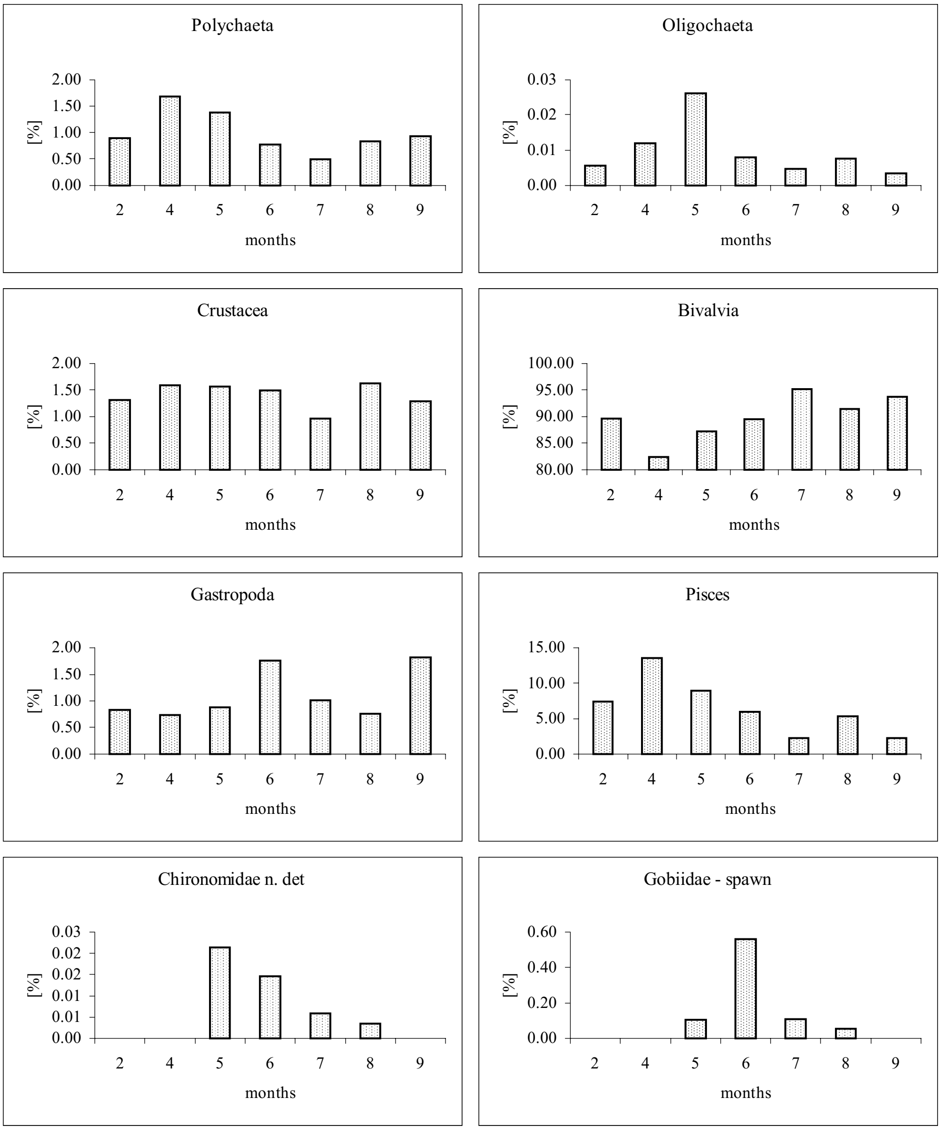

Fig.1. Seasonal variations of weight contribution (%) coefficients of particular groups of organisms in the food of *Neogobius melanostomus*.

food in the stomachs of the smallest fish. The *W*(%) parameter was smaller at 1.80% in round goby from the 10.1 to 15.0 cm length class, and this figure for the largest fish was 0.56% (Table 4). Snails from the genus *Hydrobia* sp. constituted 9.01% of the food weight in fish under 10.1 cm *lt*. The weight contribution of snails in fish from the two longer length classes was 3.06 and 0.75%. Oligochaeta and polychaeta also constituted a larger share of the food weight among fish from the smallest length class.

Table 4. Weight contribution of various *Neogobius melanostomus* food groups in 2001
(II – IX – months; n. det.– not determined; 0.00 – values < 0.01)

	II	IV	V	VI	VII	VIII	IX	Average
Fish ⩽ 10.0 cm L_t								
Polychaeta	3.13	2.81	2.11	3.06	1.90	1.83	2.07	2.14
Oligochaeta	2.11	0.54	1.32	1.76	0.91	0.97	0.12	1.14
Crustacea	23.57	19.52	19.43	13.56	14.23	11.98	15.01	16.65
Bivalvia	62.17	67.12	69.02	71.23	73.42	75.12	74.01	69.79
Gastropoda	9.02	10.01	8.11	9.70	8.64	9.70	8.79	9.01
Pisces	–	–	–	–	–	–	–	–
Chironomidae n. det.	–	–	0.01	0.01	0.90	0.40	–	0.59
Gobiidae – spawn	–	–	–	0.68	–	–	–	0.68
Fish 10.1 – 15.0 cm L_t								
Polychaeta	2.74	0.33	1.61	0.59	0.82	0.56	0.45	1.01
Oligochaeta	0.01	–	–	0.02	0.01	0.09	0.08	0.04
Crustacea	1.23	2.24	2.31	1.90	1.38	2.04	2.23	1.80
Bivalvia	90.00	93.42	91.19	93.73	94.14	95.10	96.12	92.31
Gastropoda	6.02	4.01	4.86	2.04	1.46	1.89	1.12	3.06
Pisces	–	–	–	–	–	–	–	–
Chironomidae n. det.	–	–	0.03	–	1.17	0.32	–	0.51
Gobiidae – spawn	–	–	–	1.72	1.02	–	–	1.27
Fish > 15 cm L_t								
Polychaeta	0.09	0.76	0.71	0.37	0.29	0.69	0.56	0.50
Oligochaeta	–	–	–	0.67	0.13	–	–	0.40
Crustacea	1.11	0.87	0.56	0.34	0.33	0.43	0.29	0.56
Bivalvia	86.48	70.98	81.11	81.14	83.08	81.12	82.70	80.54
Gastropoda	0.12	0.15	0.26	1.04	1.05	1.54	1.12	0.75
Pisces	12.20	27.24	16.12	16.31	15.12	16.21	15.33	16.93
Chironomidae n. det.	–	–	0.01	0.05	0.00	0.00	–	0.02
Gobiidae – spawn	–	–	1.23	0.08	0.00	0.01	–	0.30

Table 5 presents the weight percentage of various components of round goby food dependent on the location in which the studied fish were caught. Species such as *Cardium glaucum* and *Mya arenaria* were not noted in the round goby caught at the Bromka and Wisłoujście fishing grounds. However, *Macoma baltica* dominated with a weight contribution of 79.65% (Bromka) and 84.20/% (Wisłoujście). The contribution of mussels to the total food weight was 19.13% and 12.03%, respectively. The remaining components were observed in trace amounts. In the Puck Bay both mussels and *Macoma baltica* contributed equally to round goby food. The food spectrum of the round goby in this area is wide (11 food units) in comparison with that in the Wisłoujście and Bromka areas (6 units).

The food selectivity index *E* for certain food groups was calculated based on data from the literature regarding the zoobenthos composition in the areas where research catches were made. The following index values were obtained:

Table 5. Percentage composition of the food of *Neogobius melanostomus* caught in different parts of the Gulf of Gdańsk (weight contribution)

	Fishing ground		
	Wisłoujście	Bromka	Puck Bay
Polychaeta	0.43	0.02	1.00
Oligochaeta	0.02	0.01	0.01
Crustacea	2.12	1.17	1.41
Mytilus edulis trossulus	12.03	19.13	40.95
Macoma baltica	84.20	79.65	41.81
Cardium glaucum	–	–	3.64
Mya arenaria	–	–	3.33
Gastropoda	1.2	0.02	1.11
Pisces	–	–	6.52
Chironomidae n. det.	–	–	0.01
Gobiidae – spawn	–	–	0.21
Total	100.00	100.00	100.00

	E
Oligochaeta –	0.97
Polychaeta –	0.85
Crustacea –	– 0.96
Bivalvia –	– 0.04
Gastropoda –	0.81
Chironomidae –	0.81.

The estimated food selectivity indexes clearly indicate that round goby avoided crustaceans. The index value near zero obtained for bivalves indicates that the fish neither avoided nor selected this food component.

DISCUSSION

Benthic invertebrates dominated the food of goby *N. melanostomus*. Bivalves were confirmed in all the stomach contents analyzed in 2001. In addition to benthic invertebrates, which constituted from 80 to 90% of the food content, and fish (from 2 to 13%), trace amounts of snails, oligochaeta, polychaeta, crustaceans, *Chironomidae* larvae and goby spawn were also noted. Similar food composition for goby was also reported by Berg (1949) and Miller (1986). According to these authors, goby *N. melanostomus* which inhabit the Azov Sea consume over 13% of the annual zoobenthos production. In the spring-fall period over 90% of the weight of the food consumed was comprised of mollusks (Skazkina and Kostyuchenko 1969). In their analysis of the food composition of round goby from the Azov Sea, Nekrasowa and Kovtun (1976) reported that the contribution of mollusks ranged from 62.1 to 97.1% of the total food weight. Very similar results are reported in another paper which described the food composition of round goby in the Azov Sea (Kovtun *et al.*,

Table 6. Food of *Neogobius melanostomus* from different basins by months (weight contribution %)

	Sea of Azov 1956-1957*			Sea of Azov 1968-1972*			Puck Bay Gulf of Gdańsk 2001		
	IV	VII	X	IV	VII	X	IV	VII	IX
Mollusks	77.8	94.2	90.3	77.7	94.7	83.8	83.1	96.2	95.6
Crustaceans	10.1	1.6	7.4	9.1	2.9	8.6	1.6	1.0	1.3
Polychaeta	5.9	0.8	0.7	4.6	1.6	1.3	1.7	0.5	0.9
Fish	3.1	1.4	0.1	7.2	0.8	6.3	13.6	2.3	2.2

* Kovtun *et al*. (1974)

1974); the food composition described included mollusks – 78%, crustaceans – 10%, insect larvae – 6% and fish – 3%. Nikolski (1956) observed a lower weight contribution of mollusks (45%) in the food of round goby from the Caspian Sea. Strautman (1972) analyzed the food composition of round goby in the Dnieper Estuary and reported the contribution of bivalves to be approximately 40%. Unidentified mollusks and snails were also observed, and the contribution of crustaceans was estimated to be over 25% of the food weight.

In comparison with the results obtained by Strautman (1972) and Kovtun et al. (1974), the weight contribution of crustaceans in the food of round goby from the Puck Bay and the Gulf of Gdansk was observed to be much lower (Table 6). This is due to the marginal share of *Crustacea* in the biomass of the zoobenthos in this basin. Adverse changes in the biocenosis of the Puck Bay, which have been observed since the mid 1970s, resulted in a decrease in the abundance of crustaceans, a general increase in the biomass of benthic macrofauna and the stable domination of bivalves (Żmudziński and Osowiecki 1991, Osowiecki 1994).

In North American waters the zebra mussel *Dreissena polymorpha*, an invasive species from Europe, is the main *Bivalvia* representative present in the food of *N. melanostomus* (Jude *et al*. 1992). The mussel *Mytilus edulis trossulus* dominates in the Puck Bay and the Gulf of Gdańsk, and other mussels which are also present in the food include *Cardium glaucum*, *Macoma baltica* and *Mya arenaria*.

Mollusks are the basic food component in summer in the Azov Sea. During this period the share of fish (mainly *Cluponella*) increased and reached over 40% of the weight contribution (Skazkina and Kostyuchenko 1968).

The analyses of the various components of round goby food in the Puck Bay indicate that only *Chironomidae* larvae and the spawn of *N. Melanostomus* are seasonal. These two groups were observed in the food only in the late spring and summer. The main fish representatives in the food of round goby in the Puck Bay were ruffe *Gymnocephalus cernuus* and another goby of the genus *Pomatoschistus* sp. No seasonal variations in the occurrence of snails and crustaceans were observed in the food of goby from this region. The contribution of mollusks was low in April and highest in the summer. Polychaeta and oligochaeta were quite numerous in the food composition in spring.

The spawn found in the digestive tracts of the goby studied by this author belonged to the goby species analyzed. It was found only during spawning and only in male stomachs.

The weight contribution of food groups varied with fish length. This is especially apparent when comparing the *W* (%) parameters derived for crustaceans, mollusks and fish. According to Skazkina and Kostyuchenko (1968), mollusks and crustaceans were found in the food of goby fish of all sizes. Small and medium goby specimens also fed on worms (mainly polychaeta), and fish were found in the stomachs of only the largest fish. Kovtun *et al*. (1974) analyzed the food composition of gobies from the Azov Sea with regard to their lengths. Fish were noted in the digestive tracts of the largest fish analyzed (≥11.8 cm *lt*).

The food of gobies from North America was analyzed by Jude *et al*. (1995). Mainly benthic *Cladocera*, *Chironomidae* larvae and mollusks *Bivalvia* and snails *Gastropoda* were observed in the stomachs of small specimens (47-59 mm *lt*). The contribution of mollusks varied with the size of the studied fish; it was 39% in goby specimens from 47 to 59 mm in length and 82% in those measuring from 80 to 90 mm.

During the current study in the Puck Bay and the Gulf of Gdańsk, mollusks and crustaceans were present in the food of fish from all length classes. The analyzed goby specimens were divided into three groups, and then it was clear that *Bivalvia* are of lesser importance in the food of the smallest fish, in which the weight contribution of crustaceans is much greater. The greatest weight contribution of *Bivalvia* was observed in medium-sized fish from 10.1 to 15.0 cm in length. The lesser contribution of bivalves to the food of the longest gobies was caused by the presence of fish in their stomachs. Although innumerous, they still constituted almost 17% of the food weight.

Based on the analyses of the available literature and the author's own studies, it can be postulated that *Bivalvia* are the most important food element of goby inhabiting the waters of both Europe and North America. Ray and Corcum (1997) observed under laboratory conditions gobies of various sizes grazing of different sized bivalves (*Dreissena polymorpha*). The results of this study indicated that bivalves smaller than 10 mm were eaten by specimens of all length classes (6.6-12.1 cm L_t). Larger shells (10.0-12.9 mm) were present in the digestive tracts of fish longer than 8.5 cm L_c. In the current study, the occurrence of bivalves larger than 10.0 cm was observed in goby specimens ≥ 12.0 cm L_t.

According to Ghedotti *et al.* (1995), gobies crush bivalves with their throat teeth and then discard the broken shells before swallowing the mussel. Only a small number of bivalves without shells were confirmed in the stomachs of the Gulf of Gdańsk gobies. During the current analyses of digested food, mostly complete or broken shells were found in the digestive tracts. Similar observations were also made by Jude *et al*. (1995).

The food composition of *N. melanostomus* differed depending on where the specimens were caught. The greatest number of taxa were observed in the Puck Bay, where two mollusk species *Mytilus edulis trossulus* and *Macoma baltica* dominated. The specimens for analyses were caught in the Outer Puck Bay on silty and silty-sandy bottoms (Warzocha 1995). Despite the continuing impoverishment of the species composition of benthic macrofauna, the Puck Bay is still a basin abundant in macrozoobenthos taxa. Studies conducted in 1999 revealed the presence of 33 taxa – species and higher taxonomic units (Osowiecki 2000). The benthic fauna in the areas where catches had been made were categorized as either *Macoma baltica – Mya arenaria* or *Macoma baltica – Mesidotea entomon* groups. The first was dominated by the presence of the bivalves *M. edulis trossulus* and *M. baltica*, while the second was dominated by *M. baltica* with a small contribution of mussels (Warzocha 1995).

A lower weight contribution of mussels and a significantly greater contribution of *M. baltica* were observed in the food at the Bromka fishing ground. The macrozoobenthos assemblages which occur here belong to the *Macoma baltica – Mya arenaria* and *Scoloplos armiger – Macoma baltica* groups. The second of these is characterized by the lack of mussels (Warzocha 1995).

The macrofauna in the Wisłoujście fishing ground is comprised of the *Macoma baltica – Mesidotea entomon* group, which means that *M. baltica* dominate and there is a smaller contribution of mussels than in the Puck Bay.

The coefficients of food selectivity which were derived indicate that gobies avoided crustaceans and chose snails, oligochaeta and polychaeta and *Chironomidae* larvae. They also indicate that gobies neither chose nor selected bivalves. The data from the literature regarding the benthic macrofauna composition do not precisely refer to the goby sampling areas. Ghedotti *et al*. (1995) and Ray and Corcum (1997) performed laboratory studies of fish food selectivity in aquariums.

When *N. melanostomus* appeared in the coastal waters of the Baltic Sea and in the waters of the Great Lakes in the North America, the question was raised regarding the impact they would have on the ecosystems and the fisheries of the areas inhabited by them.

Goby *N. melanostomus* compete for food with benthic-feeding fish species which inhabit the Puck Bay. The goby area of occurrence overlaps with that of the following species: eelpout (*Zoarces viviparus*); flounder (*Platichthys flesus*); black goby (*Gobius niger*) (author's own observations). These fish species feed on benthic fauna just as gobies do, and this competition may limit the populations of species which are native to the Puck Bay (Skóra 1996b).

The stomach contents of eelpout caught at the same time as the *N. melanostomus* specimens were analyzed for the purpose of comparison. These analyses confirmed the presence of numerous crustaceans and bivalves, although the shells were small in comparison to those found in goby stomachs. It is the author's opinion this was due to the smaller mouth of the eelpout. Flounder in the Puck Bay also feed on benthic fauna, but smaller specimens avoid bivalves and prefer polychaeta and oligochaeta (Mulicki 1947). Only large flounder specimens feed on organisms from the *Bivalvia* group.

It would seem that gobies preying on the spawn and hatch of other fish is more of a threat than food competition. The fact that the spawn of different species was not confirmed in the stomachs of the gobies analyzed in the current study may be related to poorly located sampling sites.

Jude *et al.* (1995) drew attention to the fact that as goby feed on the bottom they may consume the spawn and hatch of other fish species such as *Percina caprodes, Cottus bairdi* and *Etheostoma nigrum*. These authors link population limitation of the first species with gobies preying on its spawn and hatch. Laboratory studies of goby feeding patterns conducted by the American researchers Chotkowski and Marsden (1999) indicated that gobies intensively consumed the spawn and hatch of sea trout even though other types of food were also available. The negative impact of *N. melanostomus* on *Cottus bairdi* is well described in the American literature. Jude and DeBoe (1996) attribute to the goby the reduction and migration of the *Cottus bairdi* population in the St. Clair River as well as the significant reduction of populations of such benthic species as *Percina caprodes*. Gobies are credited with having a positive impact on the environment by limiting populations of another invasive species, the zebra mussel *Dreissena polymorpha*. These mollusks occur on a mass scale in the southwestern part of Lake Michigan and have an adverse impact on hydrotechnical constructions.

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Hysterothylacium incurvum (Rudolphi, 1819) (Nematoda: Anisakidae) – a parasite of swordfish (*Xiphias gladius* L.)

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Abstract. The alimentary tract (mainly the stomach) of a single swordfish (*Xiphias gladius* L.) caught in Georges Bank (NW Atlantic) yielded a total of 103 nematodes (72 females and 31 males) identified as *Hysterothylacium incurvum* (Rudolphi, 1819). A morphological description of the nematodes, complete with measurements of female and male specimens, and photographs are presented. We concluded that the labial and interlabial structures are the major characters which distinguish *H. incurvum* from *H. corrugatum* Deardorff and Overstreet, 1980. On the other hand, the ratio between spicule length and male body length cannot be used as a diagnostic character.

Key words: parasitic nematode, *Hysterothylacium incurvum*, morphology, fish, swordfish

INTRODUCTION

Nematodes parasitizing the swordfish (*Xiphias gladius* L.) were first described by Rudolphi (1819) as *Ascaris incurva*. The material originated from the Baltic Sea. However, Rudolphi's description of the parasite was very brief and lacked illustrations. Dollfus (1935) published a schematic illustration of the alimentary tract of this species. The worm was assigned by him to *Contracaecum (Thynnascaris) incurvum* (Rud.). *C. incurvum* was found in the stomach of swordfish from the western Atlantic (Tibbo *et al*. 1961). The authors made note only of the parasite's body length. During examinations of a total of 22 swordfish individuals, Iles (1971) found numerous nematodes in the stomachs of 16 fish and in the intestine of one fish. Based on the two papers referred to above, Margolis and Arthur (1979) mentioned the presence of *Thynnascaris incurva* (Rud.) Dollfus, 1935 in the swordfish in their list of Canadian fish parasites. According to Yamaguti (1961), the nematode *C. incurvum* parasitizes the swordfish and five other marine fish species (*Scomberomorus maculatus, Tetrapterus imperator, Seriola zonata, S. lalandi* and *Hipoglossus platessoides*) in the Atlantic and the Pacific oceans and the Mediterranean Sea. Detailed descriptions and illustrations of this swordfish parasite (identified as *Th. incurva* (Rudolphi)) were provided by Hartwich (1975), while Deardorff and Overstreet (1980) and Petter and Maillard (1987) published detailed data on the swordfish parasite they identified as *Hysterothylacium incurvum* (Rudolphi). Deardorff and Overstreet (1980) described a new nematode species, *H. corrugatum*, from swordfish caught off of Florida and Ecuador. Furthermore, Sheenko

(1991) described *H. petteri* sp. n. found in swordfish caught in the Pacific's Kuroshio and assigned material from a swordfish caught off of Tunisia, reported as *Hysterothylacium* sp. by Petter and Maillard (1987), to this new species.

The diagnostic characters above which are used to identify the three mentioned nematode species are few and rather difficult to use. This is particularly true for *H. incurvum* and H. *corrugatum*. This is what prompted us to write a report on the morphometry and morphology of the nematodes found in swordfish and to include relevant photographs.

MATERIALS AND METHODS

The single swordfish (*Xiphias gladius* L.) individual examined was caught in 1982 in the Georges Bank fishing ground (NW Atlantic). The digestive tract (mainly the stomach) of the fish, which was dissected aboard the vessel, yielded a total of 103 nematodes. These were preserved in formalin. The population consisted of 72 females and 31 males. The nematodes, cleared in glycerin or laktophenol, were examined at the laboratory of the Department of Fish Diseases, Agricultural University of Szczecin. The nematode's intestine and spicules were dissected and measured. Measurements were made on the largest, smallest and medium-sized individuals, chosen at random. A total of 25 nematodes (13 females and 12 males) were measured, as were 30 eggs. Microphotographs were taken under Nomarsky interference phase contrast.

RESULTS

The nematodes were identified as *Hysterothylacium incurvum* (Rudolphi, 1819). The anterior part of the body is narrower than the posterior part. Females are much larger than males. Measurements of females and males and their organs are presented in Table 1.

The mouth is surrounded by three labia which are markedly narrowed at the base. The interlabia are elongated, each showing a deep, longitudinal groove (Fig. 1). The buccal cavity is connected to a long, muscular esophagus that opens into a small, heart-shaped ventriculus provided with a very thin, elongated, posteriorly directed ventricular appendage (Figs 2 and 5). The ventriculus is connected to the intestine from which emerges an anteriorly pointing intestinal caecum. The tip of the caecum is located close to the nerve ring (Fig. 3). The intestinal caecum is very thick and two to three times as long as the ventricular appendage (Table 1; Fig. 2). The excretory pore opens at the level of the nerve ring (Fig. 3). The tail is strongly tapered, and the female tail (Fig. 4) is much longer than that of the male (Fig. 8). Some of the large female specimens studied possessed very fine, distinct spines on the tip of the tail.

The male has two long, thin, curved spicules (Fig. 8). The base of each spicule is slightly broadened and resembles a triangle; there are three or four spine-like protuberances posterior to it (Fig. 9). The spicules are tapered at their posterior end. The length of the spicules is from 7-11% of the body length. Four pairs of distal, one pair of double

Table 1. Measurements of adult *Hysterothylacium incurvum* (Rudolphi, 1819) [mm]

	Males			Females		
	range	*x*	*S*	range	*x*	*S*
Total length	32.50-66.10	53.74	9.93	51.10-151.20	116.83	34.88
Maximum width	0.71-1.79	1.29	0.55	0.92-4.03	2.38	0.83
Distance from anterior end to nerve ring	0.52-0.85	0.72	0.12	0.68-1.01	0.81	0.27
Length of esophagus	4.31-7.67	6.22	1.06	5.01-10.24	7.43	2.68
Ventriculus:						
length	0.22-0.49	0.33	0.09	0.31-0.58	0.41	0.16
width	0,16-0.31	0.21	0.04	0.18-0.30	0.24	0.08
Ventricular appendage length	1.45-3.26	2.44	0.66	1.85-3.09	2.46	0.93
Intestinal caecum length	3.85-7.16	5.59	1.02	4.31-9.24	6.59	2.39
Labia length	0.15-0.31	0.23	0.04	0.20-0.37	0.31	0.06
Tail length	0.17-0.28	0.22	0.03	0.60-2.01	1.39	0.62
Spicules	3.31-6.31	5.03	1.01			
Eggs:						
length				0.075-0.092	0.084	0.004
width				0.066-0.085	0.077	0.005

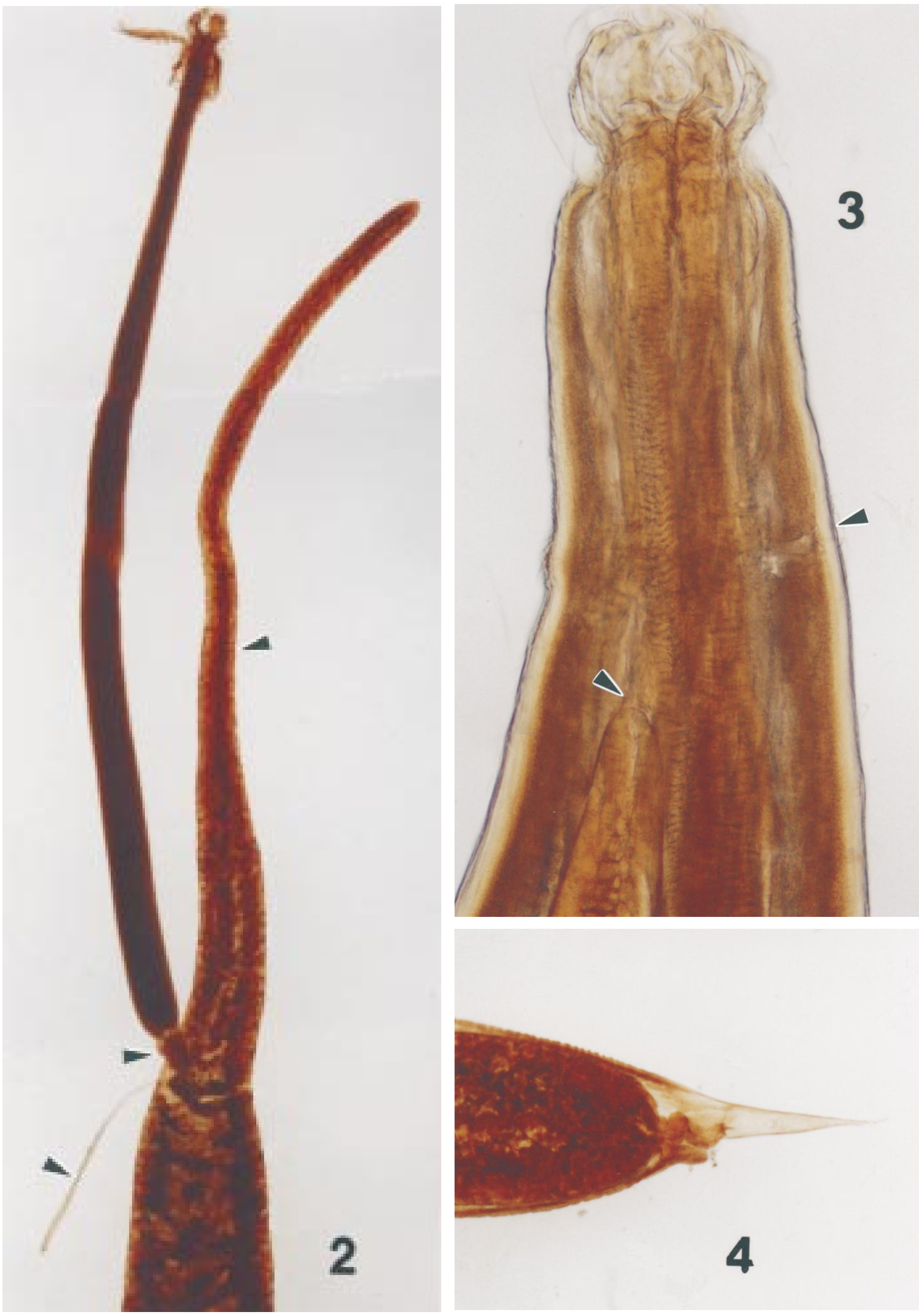
paracloacal, and up to 27 pairs of protimal papillae were observed, the latter was only clearly visible in some individuals. The phasmids were not clearly visible.

The gonopore of large females (121-151 mm in total length) is located at about one-third of the body length at a distance of 41-52 mm from the anterior end of the body. The vagina (Fig. 6) is 4 to 7 mm long. The biramous opisthodelphic uterus is filled with extremely numerous oval or spherical eggs. Each egg is surrounded by a thin, smooth membrane. The eggs were not yet embryonated (Fig. 7).

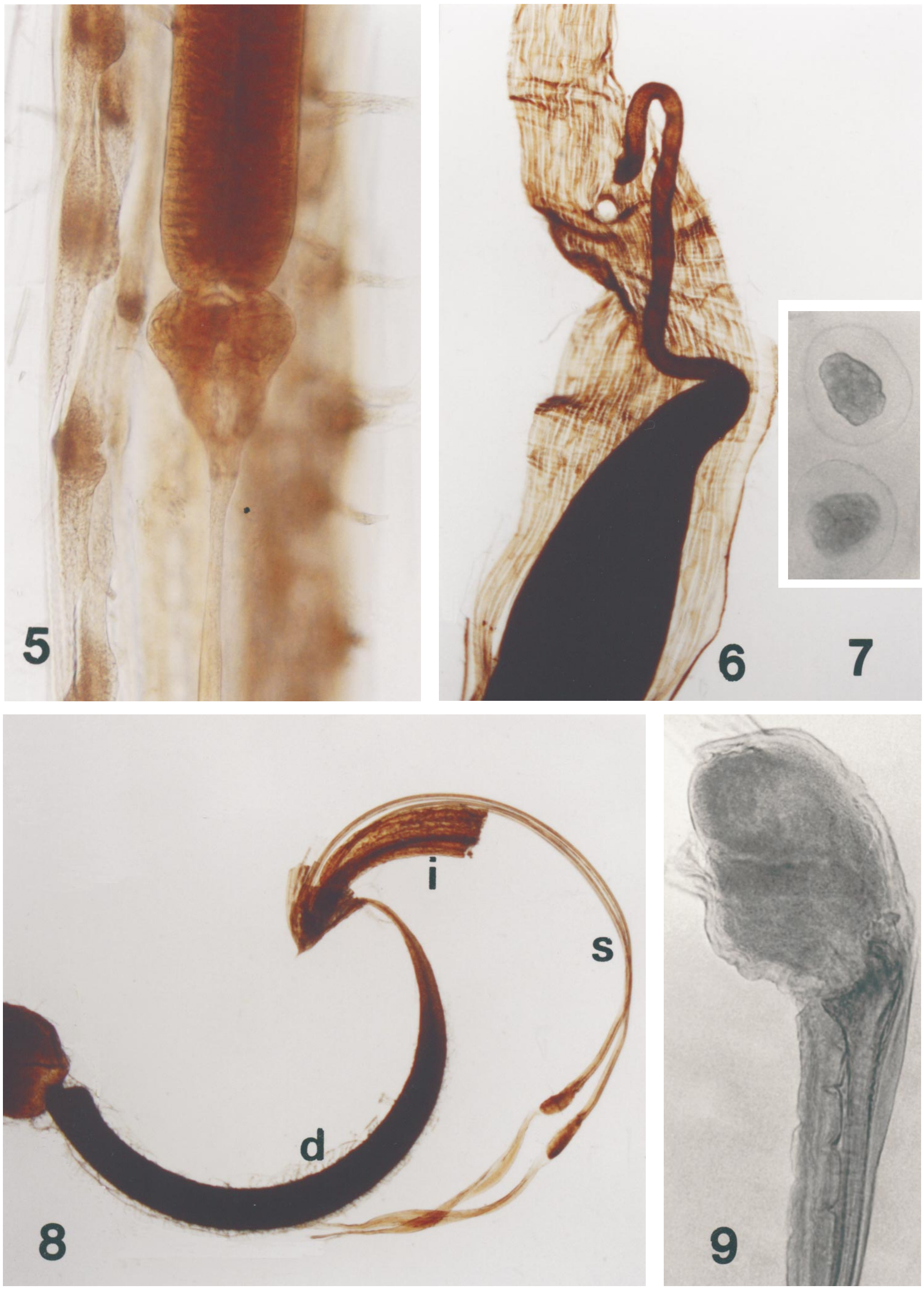
DISCUSSION

The morphology of the worms examined conforms to the descriptions of *H. incurvum* published by Hartwich (1975), Deardorff and Overstreet (1980) and Petter and Maillard (1987). Deardorff and Overstreet (1980) provided a detailed description of the nematode and supplied an identification key. According to Deardorff and Overstreet (1980), *H. incurvum* has, contrary to *H. corrugatum*, a deep interlabial groove. The copulatory spicule length is 12–25% of body length in *H. incurvum* and as little as 4-7% in *H. corrugatum*. The nematodes we examined showed the spicules to be from 4-11% of the male body length. This discrepancy might be related to size of the nematode. Deardorff and Overstreet (1980) examined males measuring 17-34 mm, while the males in our population were much larger (32.5-66.1 mm). On the other hand, Hartwich (1975) found the spicules of *H. incurvum* to reach 10-13% of the body length. Both our observations and the data reported by Hartwich (1975) demonstrate that the spicule length to body length ratio cannot be used as a diagnostic character to distinguish between the two nematode species in question.

Fig. 1. *Hysterothylacium incurvum:* interlabium with a visible groove (× 410).



Figs 2-4. *Hysterothylacium incurvum*: 2 – anterior part of intestine with stomach and processes (×15); 3 – anterior end of the body with the excretory pore and the intestinal caecum tip (×110); 4 – posterior end of a female (×15).



Figs 5-9. *Hysterothylacium incurvum*: 5 – ventriculus with the appendage (×110); 6 – vaginal region with the gonopore (×15); 7 – eggs (×210); 8 – posterior end of a male, with reproductive organs: s – spicules in pouches: d – ejaculatory duct; i – intestine (×15); 9 – anterior end of a spicule in a pouch (×120).

The labial and interlabial structure of the nematodes we examined concurred with the description provided by Deardorff and Overstreet (1980) and with the drawings of *H. incurvum* labia published by Hartwich (1975) and Petter and Maillard (1987). The labial morphology of *H. incurvum* is clearly different from that of *H. corrugatum* and is the major distinguishing character. According to Deardorff and Overstreet (1980), the labia of *H. corrugatum* are not narrowed at the base and lack the interlabial groove.

According to Hartwich (1975), the tip of the tail in male and female *H. incurvum* lacks any cuticular ornamental structures. Deardorff and Overstreet (1980) also failed to find any spines on the tip of the tail of the species, except in a single female. However some of the large females examined in the present study did show numerous fine spines on the tip of the tail.

Another character shown by *H. incurvum* in the description of Deardorff and Overstreet (1980) is the presence of lateral alae, which are bifurcated at the end. Petter and Maillard (1987) observed non-bifurcated alae in their nematodes, as did Dollfus (1935) (ref. Petter and Maillard, 1978). Our observations were not conclusive concerning this feature, and formalin preservation prevented us from examining the histology of the nematode.

Acknowledgement

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Primary productivity off western and southern Portuguese waters

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Abstract. Spatial and seasonal variations in phytoplankton productivity (PP) (measured with the ^{14}C method) and chlorophyll *a* (Chl *a*) were analysed using data obtained from several transects along the Portuguese coast during five cruises carried out in August and November 1985, January and March 1986 and April 1987. The variation of several parameters was examined, including surface and integrated chlorophyll *a*, surface and integrated primary productivity and assimilation number. The average values of PP and Chl *a* (integrated down to the 1% light level) along the coast were higher for inshore regions, values ranging from 4.1 to 8.3 mgC $m^{-2}h^{-1}$ and 9.5 to 30.1 mg m^{-2}, respectively, than for offshore regions where values ranged from 1.5 to 6.6 mgC $m^{-2}h^{-1}$ and 4.8 to 10.3 mg m^{-2}. No significant geographical differences were detected between the western and southern coast. However, variations of vertically integrated estimates of PP occurred over the study period. The highest photosynthetic production was measured in March inshore (27.2 mgC $m^{-2}h^{-1}$) and in April offshore (1.0 mgC $m^{-2}h^{-1}$), while the chlorophyll *a* maximum was attained in summer with values as high as 66.1 mg m^{-2} inshore and 2.9 mg m^{-2} offshore.

The assimilation numbers estimated along the coast were between 1.3 and 7.7 mgC mgChl $a^{-1}h^{-1}$. During most of the surveys the water column was nearly depleted of nutrients which indicated that conditions for algal growth were unfavourable. Significant positive correlations ($p < 0.01$) were found between integrated PP and surface Chl *a* on only two of the five cruises. Attempts were made to interpret these relationships by taking into account upwelling conditions. It was concluded that primary productivity and phytoplankton biomass measured along the Portuguese coast was within ranges reported for other regions of the Atlantic Ocean which are considered moderately productive.

Key words: primary productivity, ^{14}C method, assimilation number, Portuguese coastal waters

INTRODUCTION

Since 1952 when Steeman-Nielsen developed methodology for measuring primary productivity (PP) based on ^{14}C uptake, aquatic ecologists have been attempting to estimate phytoplankton productivity in the world's oceans.

Measurements of PP have been carried out in the Atlantic Ocean and along the Iberian coast. Extensive measurements have been made on the Galicia Coast and particularly in Rias Baixas. Moncoiffé *et al.* (2000) focused on determinations of PP in the Ria de Vigo during the upwelling season. Bode *et al.* (1993) presented one study which was carried out seasonally in three geographic areas of north-northwestern Spain during four periods; it was concluded that seasonallity was the major factor responsible for variations of chlorophyll *a* and primary production rates in the shelf area. These authors also refer to significant interaction between the seasonal and spatial variability of chlorophyll *a* and primary production. Few data relative to PP have, however, been reported for Portuguese oceanic and coastal waters (Pissarra *et al.* 1993, Cavaco *et al.* 1995) and ^{14}C measurements were carried out on Madeira Island waters for the first time in 1980 (Cavaco and Pissarra, in INIP 1982).

The Portuguese coast is strongly influenced by northern winds which promote upwelling processes. As a consequence, nutrient enrichment of surface waters occurs and eventually the impact of such events favours primary productivity.

The aim of this work was to determine primary production and phytoplankton biomass and to estimate photosynthetic capacity along the western and southern Portuguese coast as well as to establish relationships between primary production and hydrological, chemical and biological variables.

MATERIAL AND METHODS

The data set includes information obtained from five oceanographic cruises carried out aboard the research vessel NORUEGA along the Portuguese coast in August and November 1985, January and March 1986 and April 1987.

Sampling was conducted along the coast as shown in Fig.1 for the following parameters: temperature; salinity; dissolved oxygen; nutrients; pigments; primary production.

The Secchi disc (SD) was used to estimate the depth of light penetration. Sampling was carried out at five depths corresponding to predetermined light levels assessed by the relationship

$$Z = -\ln(\%\text{light}) * SD/K$$

(K is one experimental coefficient).

Water samples for salinity, chlorophyll *a*, nutrient and dissolved oxygen analysis were taken with Nansen bottles equipped with reversed thermometers from the surface to 300 meters. Niskin bottles were used to determine alkalinity and primary production from the sea surface and at light penetration depths of 50%, 15%, 5% and 1%.

Salinity was calculated from conductivity measurements taken with a Beckman RS9 salinometer. Water samples for nutrient analysis were stored at –20ºC and the determinations were performed with a Technicon AAII three channel autoanalyser according to the methods of the manufacturer Technicon Industrial Systems (1973, 1977a and 1977b). Dissolved oxy-

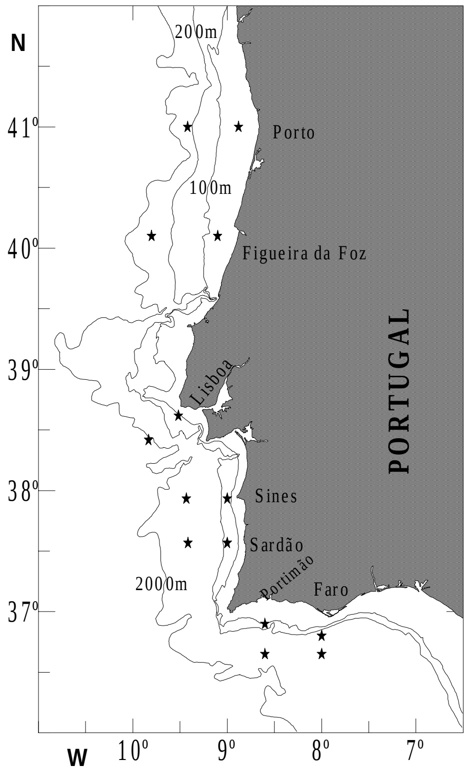

Fig. 1. Sampling sites along the Portuguese coast.

gen was measured by titration (Methröm-Herisau) using the Winkler method, following modifications by Carrit and Carpenter (1966). Chlorophyll *a* analysis was done by filtering 250 ml of sample through Sartorius filters (0.45 µ and Ø 47 mm) extracted with 90% acetone (24 h) and measured with a Perkin-Elmer fluorometer (Yentch and Menzel 1963).

Primary production was estimated from the uptake of radio-carbon. A set of three 125ml Pyrex bottles, two light bottles and one dark bottle (control) from each depth, were inoculated with 1ml of a solution of $NaH^{14}CO_3$ with 4 µCi of activity. These were incubated for four hours in an incubator illuminated with artificial light and under surface water circulation that simulated different light levels. The bottles were covered with filters of black nylon tissue corresponding to the respective light penetration levels from which the samples were taken. The filters were calibrated with a Khalsico photometer (Mod. 268WA310). A single filter corresponded to 50% light penetration, a double filter to 15%, a triple filter to 5% and a quadruple filter to 1%. After incubation, the samples were filtered through Sartorius filters (0.45 µ and Ø 25 mm), fumed in HCl to remove inorganic carbon and 10 ml of scintillation liquid (NE –250) was added to the filters. Readings were done with a scintillation counter (LSC–NE 6500).

Table 1. Values of temperature (^{o}C), dissolved oxygen (mg/l), and nutrients (μM) at surface and bottom of the euphotic zone on the sampling stations

		AUGUST 1985		NOVEMBER 1985		JANUARY 1986		MARCH 1986		APRIL 1987	
		Inshore	Offshore	Inshore	Offshore	Inshore	Offshore	Inshore	Offshore	Inshore	Offshore
		surf/bottom	surf/bottom	surf/bottom	surf/bottom	surf/bottom	surf/bottom	surf/bottom	surf/bottom	surf/bottom	surf/bottom
Porto	Temp.	15.86 / 14.18	18.14 / 17.03	15.45 / 15.62	16.24 / 16.10	13.08 / 14.37	14.08 / 14.17	13.07 / 12.83	13.29 / 13.28	15.50 / 13.60	16.16 / 15.15
	DO	9.23 / 8.51	8.39 / 8.78	8.36 / 8.25	8.18 / 8.19	9.23 / 8.03	8.56 / 8.39	9.36 / 8.95	9.43 / 9.19	8.64 /7.00	8.68 / 8.72
	NO_3	<0.2 / 1.0	<0.2	<0.2 / 0.2	<0.2	5.3 / 3.5	1.5 / 2.0	3.1 / 2.6	0.5 / 0.4	<0.2 / 5.3	<0.3
	PO_4	<0.04	?/0.10	0.16 / 0.09	0.05 / 0.07	0.28 / 0.30	0.21 / 0.29	0.13 / 0.20	0.82 / 0.19	0.45 / 1.09	0.04 / 0.07
	$Si(OH)_4$	<0.3 / 1.7	0.4 / 0.2	2.0 / 2.1	0.7 / 0.8	7.7 / 3.0	2.3 / 1.8	3.0 / 1.6	1.1 / 1.1	1.3 / 3.7	0.4 / 0.3
Figueira	Temp.		19.77 / 17.02		17.00 / 16.97	13.49 / 13.83	14.87	13.53 / 13.50	13.84 / 13.72		15.72 / 15.10
	DO		?/ 8.74	8.06 / 8.04	7.93 / 7.99	8.72 / 8.33	8.31	/ 8.83	8.93 / 8.99		8.69 / 8.67
	NO_3		<0.2	0.6 / 0.8	<0.2	2.4 / 4.5	1.5 / 1.6	3.3 / 2.5	<0.2		<0.3 / 0.3
	PO_4		0.06 / 0.13	0.11 / 0.15	0.11 / 0.17	0.54 / 0.43	0.20 / 0.23	0.27 / 0.29	0.65 / 0.11		0.31 / 0.32
	$Si(OH)_4$		0.4 / 0.6	1.3	0.9 / 0.8	3.7 / 4.8	1.5 / 1.7	2.7 / 2.2	1.3 / 1.1		0.9
Lisboa	Tem.p					14.25 / 14.30	15.05 / 14.90	14.02 / 13.54	14.31 / 14.19	16.88 / 15.17	17.25 / 15.31
	DO					8.30 / 8.28	8.31	8.60 / 8.16	9.04 / 9.06	8.86 / 8.70	8.32 / 8.34
	NO_3					3.3 / 3.4	1.1 / 1.2	7.6 / 9.6	<0.2	<0.3 / 0.3	<0.3
	PO_4					0.25 / 0.28	0.35 / 0.22	0.49 / 0.35	0.12 / 0.08	0.63 / 0.67	<0.03
	$Si(OH)_4$					2.2	1.3 / 1.5	3.9 / 4.6	0.7	1.1 / 1.2	0.6 / 0.8
Sines	Temp.	16.57 / 14.76				14.24 / 14.19	14.76	14.13 / 13.85	14.44 / 14.71	16.18 / 15.76	17.26 / 14.64
	DO	8.45 / 7.83				8.29	7.95 / 7.91	8.99 / 8.92	8.88 / 8.79	8.57 / 8.30	8.48 / 8.20
	NO_3	0.4 / 2.7				2.8 / 2.5	4.4 / 3.8	0.7 / 2.3	<0.2	<0.2 / 1.0	<0.2 / 1.1
	PO_4	0.17 / 0.32				0.26 / 0.43	0.65 / 0.41	0.14 / 0.25	1.18 / 1.78	0.40 / 0.29	0.27 / 0.33
	$Si(OH)_4$	0.8 / 1.3				1.7 / 2.5	2.5 / 2.2	1.5 / 1.8	1.5 / 2.2	1.0 / 1.0	0.6 / 1.0
Sardão	Temp.	16.11 / 14.62				13.78 / 13.80	14.76 / 14.77	14.49 / 13.91	14.81 / 14.84	16.68 / 16.67	17.59 / 15.90
	DO	8.08 / 7.40				8.02 / 8.06	7.95 / 7.91	8.76 / 9.33	8.88 / 8.79	8.40 / 8.45	8.36 / 8.48
	NO_3	1.3 / 6.3				5.1 / 6.3	4.4 / 3.8	2.3 / 2.2	<0.2	<0.3	<0.3
	PO_4	0.38 / 0.6				0.43 / 0.62	0.65 / 0.41	0.21 / 0.27	1.18 / 1.78	0.40 / 0.11	0.04 / 0.05
	$Si(OH)_4$	1.6 / 2.7				2.5 / 3.0	2.5 / 2.2	1.6 / 1.5	1.5 / 2.2	0.6 / 0.2	0.2 / 0.3
Portimão	Temp.	16.23 / 15.30	17.92 / 16.23	17.46 / 17.39	18.46 / 18.10	14.17 / 13.98	16.03 / 15.71	14.03 / 13.91	15.81 / 15.58	17.16 / 15.50	18.44 / 16.52
	DO	9.13 / 9.12	8.14 / 8.11	8.05 / 8.05	7.75 / 7.81	7.73 / 7.69	8.02 / 8.04	8.35 / 8.23	8.06 / 8.00	8.36 / 7.86	8.00 / 8.17
	NO_3	0.5 / 1.4	<0.2	<0.2	<0.2	5.2 / 6.3	0.6 / 1.2	5.5 / 6.0	1.9 / 2.0	<0.2 / 3.0	<0.4
	PO_4			0.10 / 0.07	<0.02	0.38 / 0.39	0.10 / 0.27	0.36 / 0.40	1.56 / 1.48	0.39 / 0.74	<0.2/ 0.3
	$Si(OH)_4$	0.4	0.4 / 0.8	0.6 / 0.8	1.0 / 0.8	2.6 / 2.8	1.0 / 1.2	2.8	2.4	1.0 / 2.0	0.6 / 0.8
Faro	Temp.	17.12 / 15.71	20.27 / 16.50	17.95 / 17.73	18.05 / 17.28	15.05 / 14.64	15.79 / 15.75	15.52 / 15.53	15.68 / 15.71		18.72 / 16.49
	DO	8.83 / 8.51	7.76 / 8.30	7.85 / 7.84	7.85 / 7.84	7.95 / 7.80	8.06 / 8.03	8.70 / 8.42	8.19 / 8.14		8.09 / 8.25
	NO_3	<0.2 / 1.3	<0.2	<0.2	<0.2 / 0.6	4.1 / 5.0	1.3 / 1.5	0.3 / 0.8	0.9 / 1.0		<0.3
	PO_4	0.12 / 0.33	0.09 / 0.15	<0.02	0.08 / 0.17	0.49 / 0.40	0.39 / 0.22	0.05 / 0.10	0.08 / 0.12		0.04 / 0.16
	$Si(OH)_4$	<0.2 / 0.5	0.4	0.7	0.9 / 1.3		1.5 / 1.4	1.3 / 2.3	1.7 / 1.6		0.6 / 0.7

RESULTS AND DISCUSSION

The main objective of the study undertaken along the Portuguese coast was to characterise the primary productivity of the coastal waters. This involved sampling fourteen stations, seven inshore and seven offshore, in 1985, 1986 and 1987 (Pissarra *et al.* 1993, Cavaco *et al.* 1995, Cavaco *et al.* 2000, Cavaco *et al.* 2001).

Hydrographic parameters

Table 1 shows the physical and chemical properties of the euphotic zone (up to 1% of light penetration) during the sampling periods at the inshore and offshore stations.

Analysis of the hydrographic parameters indicated that the euphotic zone is nutrient depleted most of the time. Nitrate and silicate and, to a minor degree, phosphate are replenished in the upper layers in winter and early spring (January and March) when the thermocline is absent. The approach based on comparisons between in situ nutrient concentrations and half-saturation constants for nutrient uptake K_m (Fisher *et al*. 1988) was used. The data indicates that there was nutrient-limited algal growth along the Portuguese coast during the study period, as K_m for dissolved inorganic nitrogen uptake was 1-2 µmol/l, for silicate uptake it was 1-5 µmol/l and the concentrations determined are often below or close to these values.

Primary productivity, phytoplankton biomass and assimilation number

The average depth of the euphotic zone at the sample stations was shallow in March reaching 25 meters, but it was deeper in April at up to approximately 40 meters.

Table 2 shows that the relationship between PP in the inshore and offshore regions is generally about twice as high in former than the latter, except in August when it was five-fold higher and in January when remained smaller than one. As a matter of fact, in general, higher rates of phytoplankton productivity were measured at inshore stations. Similar rela-

Table 2. Mean values of integrated PP (mgC $m^{-2} h^{-1}$), Chl *a* (mg m^{-2}) and depth of euphotic zone (meters) in different sampling periods

	August 1985		November 1985		January 1986		March 1986		April 1987	
	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
Inshore										
PP	7.3	3.2	5.5	0.9	5.5	1.9	8.3	9.4	4.1	2.6
Chl *a*	30.1	22.0	9.8	4.8	10.2	2.4	20.7	14.6	9.5	3.7
Depth EZ	24	4	31	6	26	6	25	13	36	11
Offshore										
PP	1.5	0.4	2.9	0.7	6.6	2.2	4.7	2.0	2.0	1.2
Chl *a*	4.8	2.1	5.9	1.6	9.3	1.4	10.3	3.8	6.6	4.2
Depth EZ	35	8	39	5	37	6	26	6	44	13

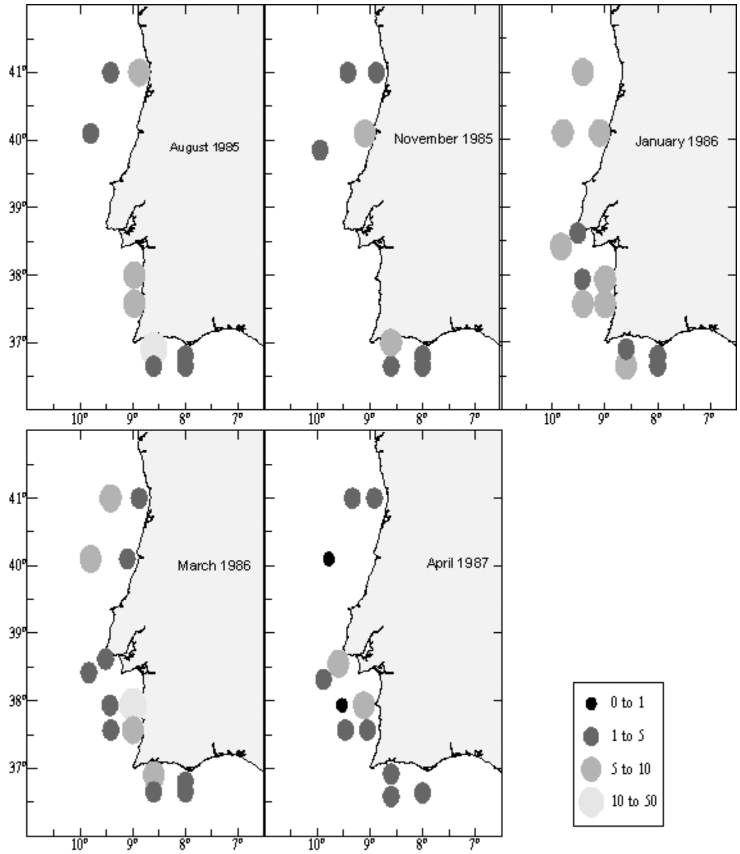

Fig. 2. Distribution of integrated primary production (mgC $m^{-2}h^{-1}$).

tionships were observed regarding to Chl *a*, which was six-fold higher inshore in August and approximately twice as high in the other months.

C fixation rates down to the 1% light level varied along the Portuguese coast during the study period between 0.95 mg m^{-2} h^{-1} (in April 87) and 27.17 mg m^{-2} h^{-1} (in March 86), while chlorophyll *a* ranged between 2.94 mg m^{-2} and 66.08 mg m^{-2} in August.

Figures 2 and 3 show the distribution of integrated primary production (mgC m^{-2} h^{-1}) and chlorophyll *a* (mg m^{-2}) along the Portuguese coast. In general, productivity and chlorophyll *a* reached higher values in the inshore region, although the opposite trend was observed in January.

The results also reveal that maximum values of PP were not reached at levels where phytoplankton biomass developed to a maximum (Table 3).

No clear pattern was depicted regarding the seasonality of primary productivity. However, a slight trend showing higher rates of C fixation in winter was observed.

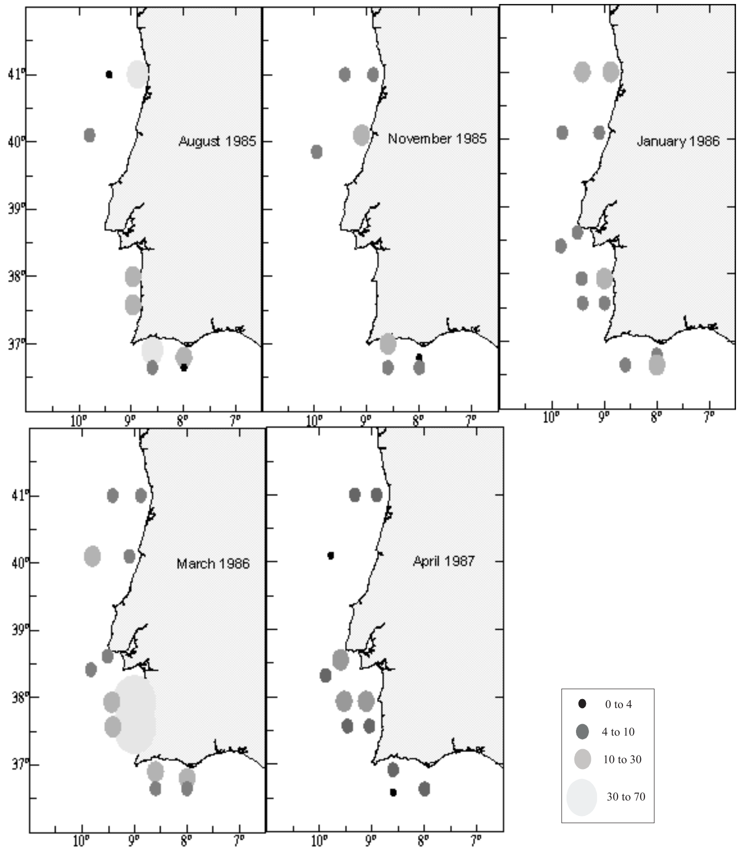

Fig. 3. Distribution of integrated chlorophyll *a* (mg m^{-2}).

Table 3. Overall means and standard deviations of P^B_{max} (maximum productivity in the euphotic zone), P^B_{DCM} (maximum productivity in deep chlorophyll maximum) and P/B (integrated primary production/integrated chlorophyll *a*) during the sampling periods

	P^B max mg C m^{-3} h^{-1}		P^B DCM mg C m^{-3} h^{-1}		P/B	
Cruise	Mean/(Depth)	Stdev	Mean/(Depth)	Stdev	Mean	Stdev
Aug-85	1.41 / (0)	1.39	0.63 / (21)	1.19	0.35	0.22
Nov-85	0.73 / (0)	0.48	0.15/ (18)	0.18	0.59	0.28
Jan-86	1.51 / (0)	0.73	0.11 / (11)	0.10	0.67	0.24
Mar-86	2.31 / (0)	3.28	0.26 / (16)	0.61	0.43	0.19
Apr-87	0.42 / (0)	0.53	0.48 / (32)	0.56	0.41	0.24

Relationships between parameters

A relatively high temperature gradient between the inshore and offshore regions was observed during summer ($\Delta \geq 1.7$ºC) as a consequence of intense upwelling. This might have been responsible for the development of larger phytoplankton populations near the coast which were reflected in the Chl *a* values. Sampling in autumn was carried out after the upwelling period, therefore the inshore-offshore temperature gradient was smaller ($\Delta \leq 1$ºC). The Chl *a* values were also higher near the coast, especially on Cabo de São Vicente. The temperature gradients in winter were below 1ºC nearly everywhere, and concentrations of chlorophyll *a* determined inshore and offshore were similar.

In spring, when the upwelling episodes were more persistent, a larger inshore-offshore temperature gradient was observed ($\Delta > 1$ºC), and higher levels of chlorophyll *a* and rates of primary productivity were observed in the southwest and Portimão area.

The only significant correlation between these parameters was noted in August 85 and March 86 between integrated PP and surface Chl *a* (Fig. 4).

Only when upwelling episodes were more persistent in August and March, was a significant relationship noted between the integrated values of primary production and the surface values of chlorophyll *a*. As suggested by Hayward and Venrick (1982), in this type of environment surface chlorophyll *a* appears to be an index of major changes in the biological state of the system.

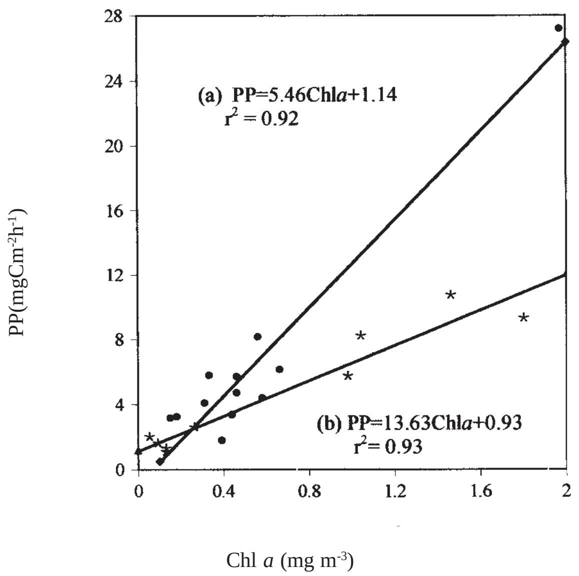

Fig. 4. Integrated primary productivity versus surface chlorophyll *a* in(a) August 1985 and (b) March 1986.

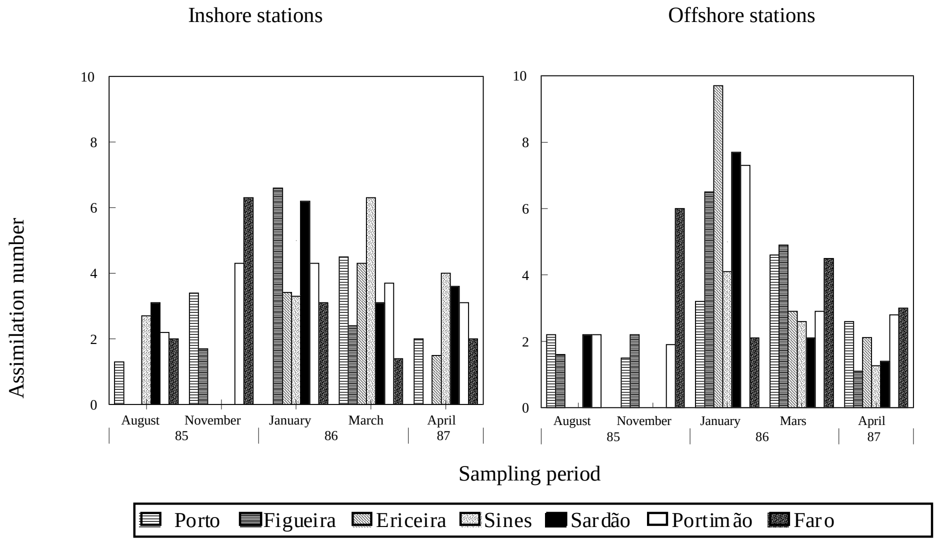

Fig. 5. Assimilation numbers (mgC mg Chl $\alpha^{-1}h^{-1}$) at the surface along the coast during the study period.

Assimilation numbers

According to Harrison and Platt (1980), the assimilation number estimated as the primary production/chlorophyll *a* ratio is used as an index to compare various biological and environmental factors. No correlation was found in the present study between temperature, DCM (Depth of Maximum Chlorophyll *a*) and nitracline. The estimated assimilation numbers along the coast ranged from 1.3 mgC mg Chl$a^{-1}h^{-1}$ in summer to 7.7 mgC mg Chl$a^{-1}h^{-1}$in January; the maximum values were estimated for surface waters in winter at both inshore and offshore stations (Fig. 5).

The estimated assimilation numbers indicated nutrient deficiency, as did the comparision of nutrients measured *in situ* with the half saturation constants for nutrient uptake. This also induced limited algal growth due to nutrients during most of the study period.

Comparison of primary productivity along the Portuguese coast with other regions

Table 4 displays values of PP in the Atlantic Ocean and Mediterranean Sea. The reported ranges of rates of carbon fixation are rather close in the Atlantic. In Iceland, however, the lowest values were significantly higher (PP>4.3 mgC $m^{-3}h^{-1}$) than those measured in other regions of the Atlantic. The highest values of PP on the eastern coast of the Atlantic were determined in the inshore region of the Portuguese coast (PP = 12.47 mgC $m^{-3}h^{-1}$). In the

Table 4. Primary productivity in the Atlantic Ocean and Mediterranean Sea

Geographic area	mgC $m^{-3} h^{-1}$	mgC $m^{-2} h^{-1}$	Reference
Iceland	4.3-9.2		Gudmundsson, 1998
Bay of Biscay-Guipúzcoa	8.6 (March)		Flos, 1982
	0.07 (June)		
Cantabrian Sea	>10 (Coastal) (Ap-Sept)		Fernandez & Bode,1991
	<0.1 (Oceanic)		
Catalano-Balearic Sea		17.4-83.6 (July-June)	Estrada *et al.* 1993
Canarias	2.54 (Coastal) Feb		Braun *et al.* 1985
	1.38 (Oceanic) Feb		
Portuguese coast			
Inshore	0.18-12.47 (April-March)	4.1 - 8.3	This study
Offshore	0.09-2.73 (April-March)	1.5 - 6.6	This study

Mediterranean, specifically in the Catalano-Balearic Sea, much higher rates of phytoplankton productivity were reported.

Values of PP measured along the Portuguese coast between 1985 and 1987 are within the ranges reported for oceanic regions which are considered moderately productive.

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Hydrological conditions of the southern Baltic waters in autumn 2002 and spring 2003

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Abstract. The main hydrological parameters – seawater temperature, salinity, oxygen content – measured during four research surveys, conducted in October-November 2002 and February -March 2003 aboard the r/v Baltica in the Polish EEZ, constitute the research materials analyzed by the authors. The basic aim of this article is to evaluate recent changes in the hydrological conditions of southern Baltic waters. The significant changes observed in water temperature and salinity between October 2002 and spring 2003 may have an impact on the effectiveness of cod spawning in 2003. In February 2003 a relatively heavy inflow of water with a salinity of 19.2 PSU was registered in the Bornholm Deep. The current inflow is regarded as cold as the water temperature in the near-bottom layer in the Bornholm Deep was 3.44°C lower than the long-term February mean (1950-2002). Recent observations indicate that the inflow waters are continuing to spread to the eastern parts of the southern Baltic.

Key words: seawater temperature, salinity, oxygen content, upper and bottom water layers, autumn 2002, winter-spring 2003, southern Baltic

INTRODUCTION

Baltic Sea environmental conditions and their variability are strongly linked to meteorological and hydrological processes and their interaction. All these processes influence temperature and ice conditions, inflows of fresh water from rivers and exchanges of water between the Baltic basins and the Skagerrak-Kattegat system. The climate and hydrology of the Baltic Sea region is influenced by the winter intensity of the North Atlantic Oscillation – NAO (Hänninen *et al.* 2000, Johansson *et al*. 2001, Anon. 2002b, Lehmann *et al*. 2002). The NAO for the winter of 2002-2003 was lower than in recent years (Anon. 2003).

The strong stratification of waters observed in the Baltic is related to the highly differentiated thermohaline regime in this sea and to the circumstances of the exchange of waters with the ocean (Majewski 1987). The most complicated vertical distribution of waters appears in the western parts of the Baltic Sea, which are strongly influenced by inflows from the North Sea (Matthäus 1975, Majewski 1987). Changes of hydrological conditions in the deep waters are strictly dependent on periodical inflows which occur irregularly and are a random phenomenon (Wojewódzki 1991). The inflows, even if not large, play a major role in shaping long-term changes in the deep layer and in improving oxygen conditions in the bottom waters (Majewski 1987, Wojewódzki 1991, Dahlin *et al*. 1993).

These so-called major inflows are very small compared with the total volume of the Baltic waters (0.1-0.5% of the total volume; Anon. 2003), but their effects may be very significant to the food web, species distribution, fish spawning and abundance of early life stages. Grauman (1973, 1974), Westin and Nissling (1991), Nissling and Westin (1991), Wieland and Zuzarte (1991), Waller *et al*. (1993), Bagge *et al*. (1994), Zezera and Zezera (1997) and Wieland *et al*. (2000) described the possible impact of hydrological regime variation on cod spawning conditions in the Baltic.

Recent international investigations in the Baltic Sea region have indicated that winter 2002-2003 and spring 2003 were colder than most in the 1990s (Anon. 2003). Moreover, a strong, new inflow was recorded for the first time on 16-25 January 2003 at the autonomous Darss Sill measuring platform (Anon. 2003). Previous effective major inflows into the Baltic Sea occurred in 1976, 1983 and 1993 (Dahlin *et al*. 1993, Matthäus 1995, Zazera and Zazera 1997).

The goal of this article is to evaluate recent (autumn 2002-winter/spring 2003) changes in the hydrological conditions (temperature, salinity, oxygen content) of southern Baltic waters (within the Polish EEZ), taking into account the differences in vertical (in upper- and bottom-layer) and horizontal profiles. Hydrological data collected by the authors during four research surveys (October and November 2002, February and March 2003) aboard the r/v BALTICA allows for the observation of seasonal changes which take place in the area of investigations. The Sea Fisheries Institute in Gdynia (SFI) organized the surveys and the ICES Baltic International Fish Survey Working Group (BIFSWG) coordinated these activities (Anon. 2002a).

MATERIALS AND METHODS

The seawater temperature (*T* in °C), salinity (*S* in PSU) and oxygen content (O_2 in ml/l) were measured during research surveys aboard the r/v BALTICA in October 11-28, 2002, November 5-9, 2002, February 18-28, 2003 and March 19-28, 2003.

Measurements of hydrological parameters were carried out in the southern parts of ICES sub-divisions 24, 25 and 26 (within the Polish EEZ) at varied fish control haul locations and at fixed hydrographic stations (Fig. 1). Three of these stations were arbitrarily designated as representative for the description of hydrological conditions in the Bornholm Deep, the Słupsk Furrow and the Gdańsk Deep. The stations are – IBY5 (55º14´N, 15º59´E), RS2 (55º14´N, 17º20´E) and G2 (54º50´N, 19º20´E).

Research material was collected within the framework of a hydroacoustic survey program (October 2002) at 23 haul locations and at an additional 7 stations along the hydrological profile of the southern Baltic (Fig. 1.A). The profile extends through the Bornholm Deep, the Słupsk Furrow, the Gotland Deep and the Gdańsk Deep. The second survey mentioned above was realized within the framework of the Baltic International Trawl Surveys (BITS) program and research materials were collected at 13 haul locations

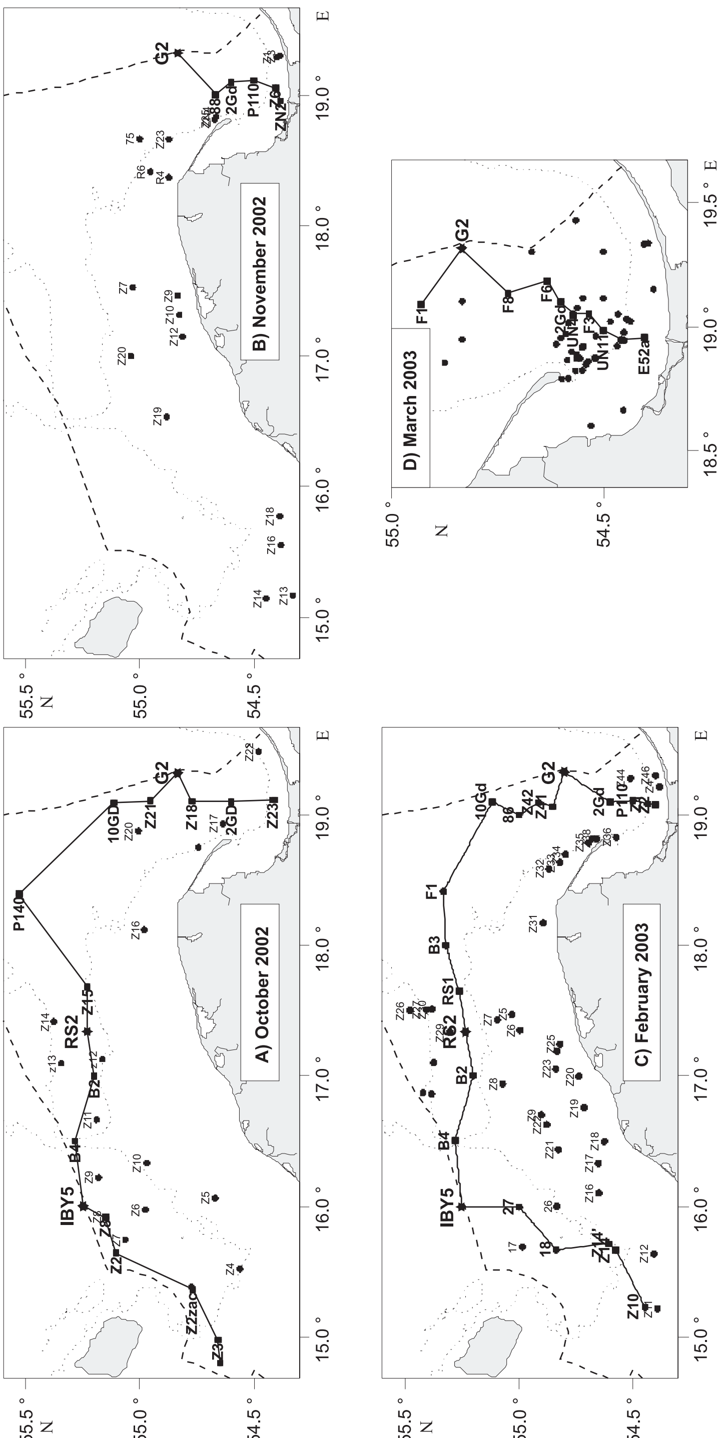

Fig. 1. Geographical distribution of hydrological measurements conducted at fish control haul locations (marked Z) and hydrological stations (marked by letters other than Z) during the hydroacoustic survey (11-28.10.2002; part A), BITS surveys (05-09.11.2002 – part B, 18-28.02.2003 – part C) and hydrological survey (19-28.03.2003; part D) on the r/v BALTICA in the Polish EEZ; the continuous line represents the hydrological profile.

and at an additional 9 hydrographic stations on the transect which extends from the Gdańsk Deep to the Vistula River mouth (Fig. 1.B). Hydrological measurements were also conducted in February 2003 during the third survey (BITS type) at 47 fish catch locations and at 19 hydrographic stations (Fig. 1.C). A hydrological profile was designated which extended from the Bornholm Deep, through the Słupsk Furrow, the Gdańsk Deep to the Vistula River mouth. During the hydrological survey in March 2003, measurements were taken at 67 hydrographic stations located in the Gdańsk Deep and the Gulf of Gdańsk (Fig. 1.D).

Stratified measurements of the seawater temperature, salinity and oxygen content (Winkler method) were taken from the surface to the bottom at isobath intervals of 2.5 m with a CTD Neil-Brown probe supplemented with a bathometer rosette. The data collected during the recent surveys were compared with the monthly results from 1996-2002 and with the long-term mean for particular months in the 1946-1996 period based on the Sea Fisheries Institute data.

RESULTS

Hydrological conditions in October 2002

The water temperature in October 2002 was exceptionally high and was up to 13, 11 and 9.5ºC in the surface layer of the western, central and eastern parts of the southern Baltic, respectively (Fig. 2). The lack of a normal thermal gradient in the deeper layers was registered (Figs. 2 and 5). The mean water temperature in the investigated areas of ICES Sub-division 24 at depths of 19-33 m from the surface (location of fish control catches) was 12.58ºC, in Sub-division 25 at depths of 24-41 m it was 10.69ºC and in Sub-division 26 at depths of 39-56 m it was 8.74ºC. The ranges of the average salinity and oxygen content in waters at the fish catch depths mentioned previously were relatively narrow at 7.36-7.75 PSU and 6.42-6.91 ml/l, respectively.

The water temperature in the near-bottom layer in the Bornholm Deep (station IBY5; Figs. 2 and 5) was 10.08°C, which was 3.01°C higher than in October 2001 and 3.41°C higher than the long-term October mean for the 1946-1996 period. The water salinity was 15.46 PSU, which was 0.29 PSU lower than that reported in October 2001 and 0.72 PSU lower than the long-term mean. The oxygen content in waters was very low – 0.09 ml/l, while in 1998-2001 hydrogen sulfide was recorded near the bottom in October surveys.

During the 1996-2002 period the highest water temperature (10.32°C) near the bottom of the Słupsk Furrow (station RS2) was recorded in 2002, and this was also 3.98°C higher than the long-term October mean for the 1950-1996 period (Figs. 2 and 5). In October 2002 salinity was 13.11 PSU, which was 0.42 PSU higher than in October 2001 and 0.59 PSU higher than the long-term mean. Oxygen content was 1.78 ml/l, which was 1.00 ml/l lower than in October 2001 and 0.98 ml/l lower than the long-term mean. In 1996-2002 hydrogen sulfide was not recorded in the bottom layers of the Słupsk Furrow during measurements taken in October.

The water temperature near the bottom of the Gdańsk Deep (station G2) was 8.64°C, which was 3.11°C higher than in October 2001 and 3.44°C higher than the long-term mean

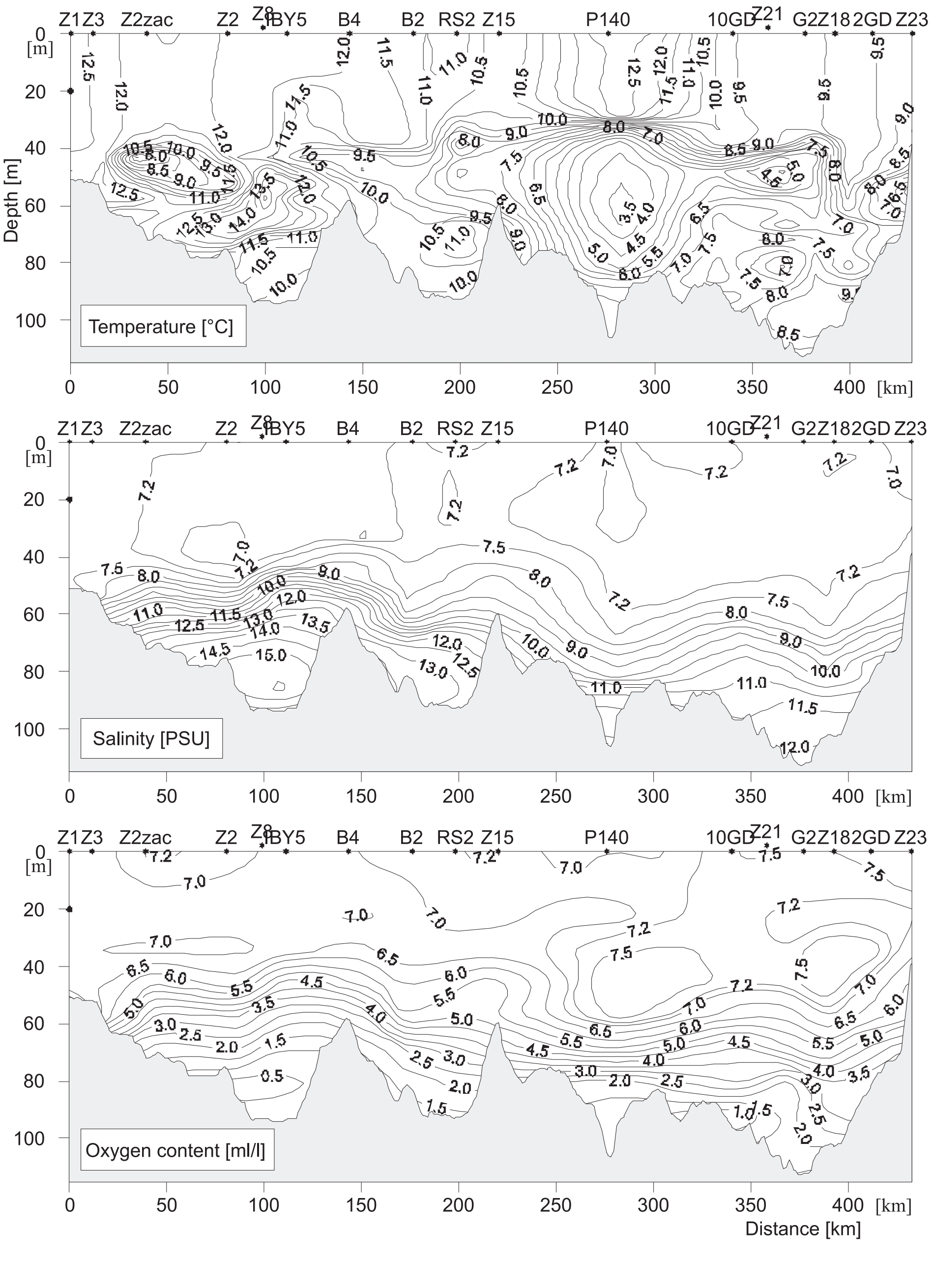

Fig. 2. Vertical distributions of seawater temperature, salinity and oxygen content along the hydrological profile of the southern Baltic in October 2002.

for 1946-1996. Salinity was 11.77 PSU, which was 0.75 PSU higher than in October 2001 and only 0.06 PSU higher than the long-term mean. Oxygen content was 2.18 ml/l, which was 1.77 ml/l higher than in October 2001 and 1.58 ml/l higher than the long-term mean. On the other hand, the appearance of hydrogen sulfide near the bottom was noted in the 1998-2000 October surveys.

The values of the hydrological parameters in the near-bottom layer in the studied area indicate the improvement of oxygen conditions in the Gdańsk Basin which was caused by the "dissolution" of the halocline. This facilitated the diffusion processes, i.e., it was easier for surface waters with high oxygen content to penetrate the lower layers (Fig. 2). The long-term lack of water inflow caused stagnant conditions in the southern Baltic.

Hydrological conditions in November 2002

Atmospheric processes shaped the thermal conditions of the upper seawater layer in the survey area. During the survey the air temperature was relatively low and ranged from –1.5ºC to 6.2ºC. In the autumn of 2002 a temperature decrease to approximately 9.0°C in the upper seawater layer and water mixing in the layer reaching 40 m were recorded (Fig. 4). The hydrological conditions on the surface and near the bottom in the vast survey area were similar, with exception of the Vistula River mouth and Kołobrzeg regions.

The impact of the Vistula River was evident in surface waters with a salinity range of 6.5-6.8 PSU which extended for up to 20 km from the river mouth. An upwelling was observed near Kołobrzeg and was manifested by the presence of near-bottom water with a salinity range of 7.8-8.5 PSU and temperatures of 10.5-10.9°C. In the near-bottom water layer with higher salinity, the oxygen content decreased to 5.5 ml/l, while in the adjacent bottom areas it varied from 7.0 to 7.9 ml/l.

No significant amounts of typical seawaters reached the Gulf of Gdańsk after 1997. This was particularly evident in the salinity distribution on the hydrological profile (Figs. 1.B and 3). In the first ten days of November 2002 the water salinity was 11.6 PSU, which was slightly lower than the long-term mean value (11.82 PSU) for 1948-1996. The water temperature throughout most of the Gulf of Gdańsk area varied from 8.5 to 9.5°C up to the halocline.

In the center of the Gdańsk Deep the winter waters from the previous year were still present, and their temperature varied from 5.5 to 7.5°C. The temperature of the deep waters was similar to that of the surface waters and in the Gulf of Gdańsk they were thermally uniform to a depth of 80-90 m (Fig. 3). The deep waters in the Gulf of Gdańsk were characterized by a significant oxygen content of approximately 2.5 ml/l, while the long-term mean for 1948-1996 for the Gdańsk Deep was 1.44 ml/l. In the Gulf of Gdańsk oxygen content varied from 5.5 to 2.5 ml/l from 60 m to the bottom (Fig. 3). This was most likely due to the weak halocline.

Hydrological conditions in February 2003

The vertical mixing of waters both during stormy winds and convective mixing during periods of low temperatures resulted in the significant decrease of temperature in the surface layer to a depth of 60 m e.g. to 1.7ºC in the Gulf of Gdańsk (Figs. 4 and 5). The winter of

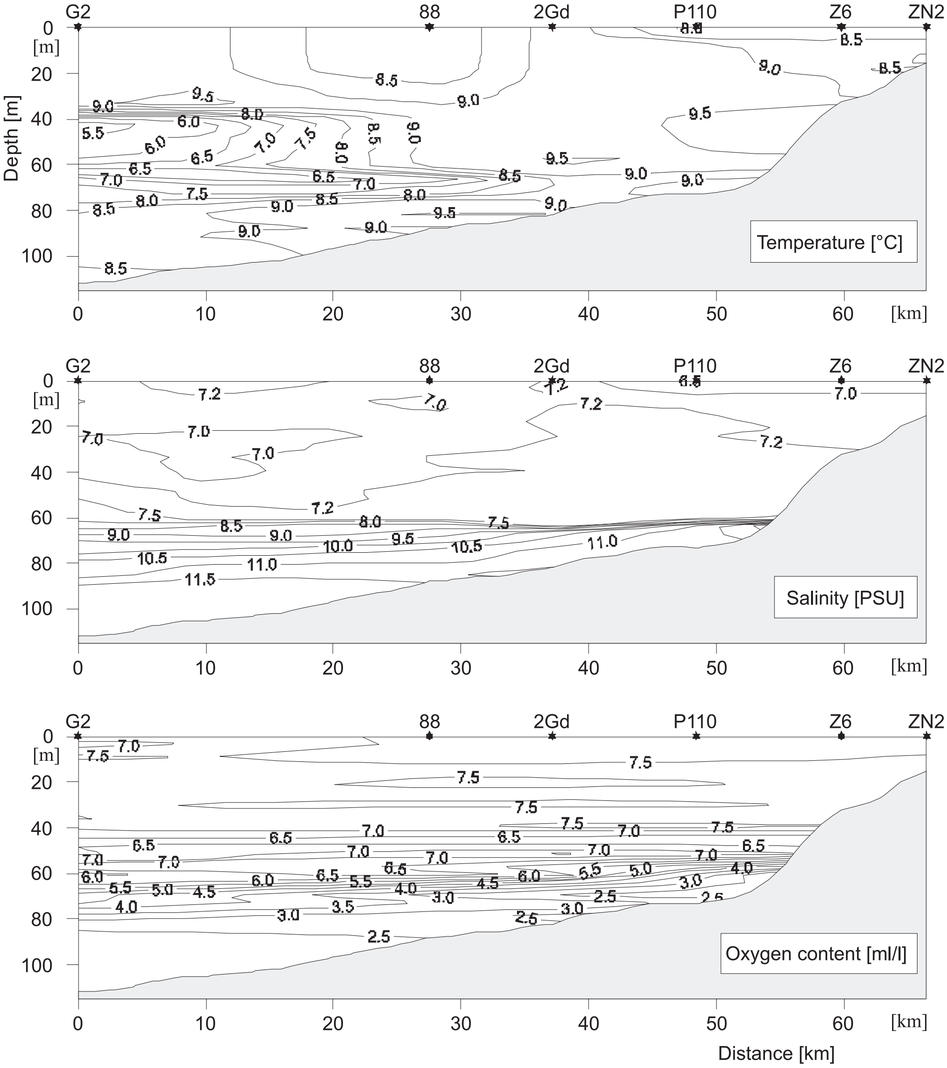

Fig. 3. Vertical distributions of seawater temperature, salinity and oxygen content along the hydrological profile of the Gdańsk Basin in November 2002.

2002-2003 was the first cold winter in fourteen years in the investigated area. The long-term (February 1988-2002) mean of water temperature at a depth of 0-50 m in the Gulf of Gdańsk was 3.1ºC (unpublished data by SFI – Gdynia). The previous low water temperature of 0.3ºC was recorded in this area in February 1987.

The thickness of the surface layer in the Bornholm Deep, which was mixed in terms of temperature and salinity, was approximately 45 m (Figs. 4 and 5). In the mixed layer the water temperature, which varied from 12ºC (October 2002) to 2ºC (February 2003), indicates that the value of this parameter strongly diminished during the last winter.

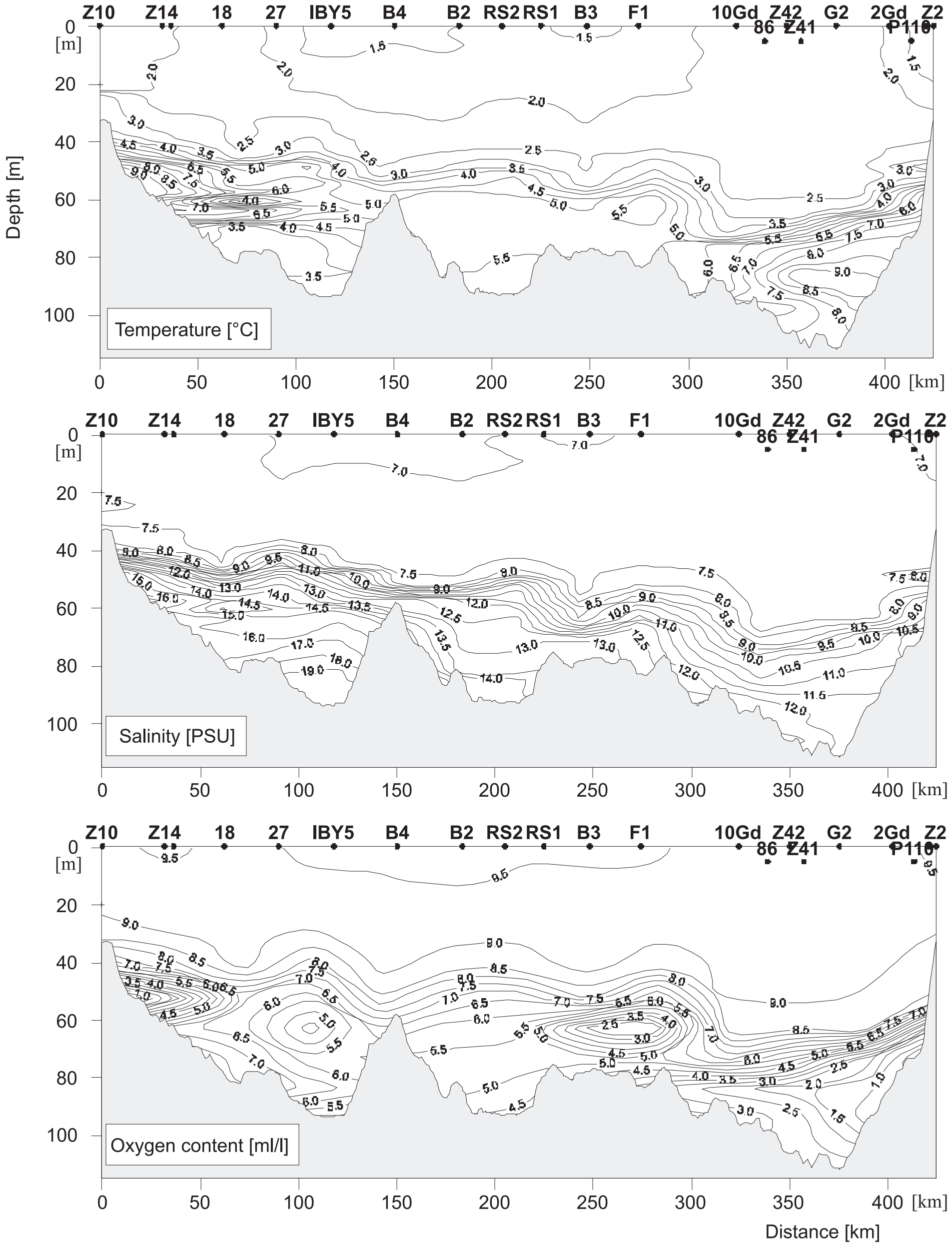

Fig. 4. Vertical distributions of seawater temperature, salinity and oxygen content along the hydrological profile of the southern Baltic in February 2003.

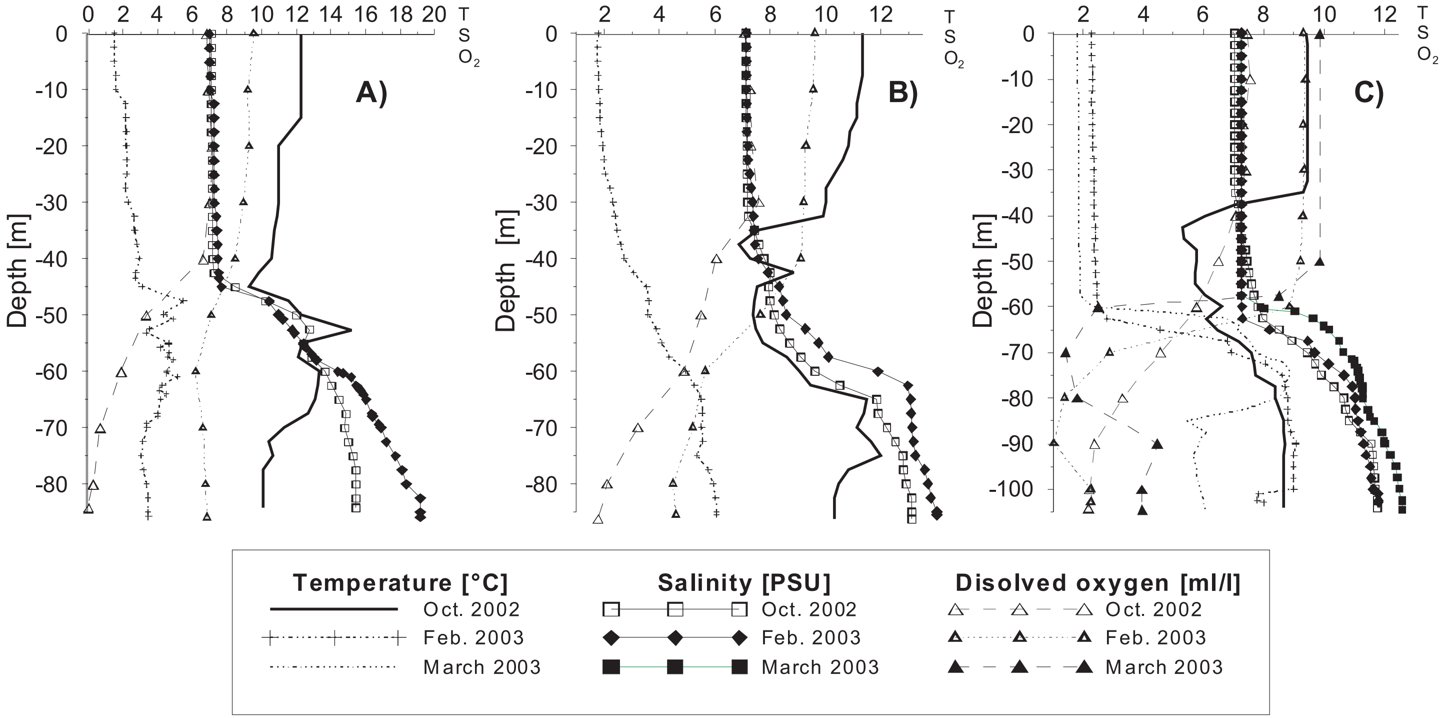

Fig. 5. Vertical distributions of seawater temperature, salinity and oxygen content at the Bornholm Deep (station IBY5; part A), the Słupsk Furrow (station RS2; part B) and the Gdańsk Deep (station G2; part C) in October 2002, February and March 2003.

The values of temperature, salinity and oxygen content measurements above the sea bottom confirmed that there had been a heavy inflow into the Bornholm Deep. The salinity of 19.2 PSU is the fourth highest figure recorded over the past 57 years in surveys conducted by the SFI (Gdynia). Such high salinity will replenish stores of "cod waters". The oxygen content at station IBY5 of 6.94 ml/l and of 7.2-7.4 ml/l (Figs. 4 and 5) at two other stations at depths of 80 m near Bornholm allows for the prediction that in 2003 the deep waters in the majority of the southern Baltic will be well oxygenated. The long-term (1950-1996) mean of oxygen content for February in the near-bottom waters of the Bornholm Deep was 2.48 ml/l. In February 2003 the mean temperature in these waters was 3.46ºC and was 3.44ºC lower than the long-term mean. This allows us to characterize the observed inflow as very cold.

In the Słupsk Furrow the surface waters and the transformed waters of the new inflow were 5.5ºC colder than the deep waters in October 2002. In February 2003 the water temperature in the near-bottom layer of the Słupsk Furrow (at station RS2; Figs. 4 and 5) was 5.45ºC and was 2.61ºC lower than in February 2002 and 1.32ºC lower than the long-term mean for the 1953-1996 period. Salinity was 14.02 PSU and was 1.24 PSU higher than in February 2002 and 1.42 PSU higher than the long-term mean. Oxygen content was 4.59 ml/l and was 1.86 ml/l higher than in February 2002 and 1.16 ml/l higher than the long-term mean. The distribution of hydrological parameters above the bottom indicates that in February 2003 the majority of inflow waters in the Słupsk Furrow were located in the northern part.

Water temperature above the bottom in the Gdańsk Deep (station G2; Figs. 4 and 5) was 8.01ºC, which was 0.75ºC higher than in February 2002 and 1.87ºC higher than the long-term mean for 1950-1996. Water salinity was 11.81 PSU, which was 0.26 PSU higher than in 2002, and slightly (0.05 PSU) lower than the long-term mean. Oxygen content was 2.25 ml/l, which was 0.65 ml/l higher than in the previous year and 0.25 ml/l higher than the long-term mean. Three other measurements in this region proved that in the near-bottom layer the water temperature was 2.2ºC lower and the oxygen content was 1.2 ml/l higher than at adjacent, shallower levels. These data indicate that the inflow water filling process in the central part of the Gdańsk Deep has begun.

The eight-meter thick „new water" layer above the bottom, which was observed in the area to the north-west of station G2 indicated the presence of inflow waters in the Gdańsk Deep (Fig. 5). A twenty-meter thick water layer rested on top of this layer; the temperature of it was approximately 2ºC higher and the oxygen content was minimal – at some places it was as low as 0.9 ml/l (Figs. 4 and 5).

Efficient catches of the main Baltic fish species were made in locations where there was a several-meter thick layer of new, well-oxygenated inflow water under the existing, oxygen-poor deep waters. This usually occurred at depths of 60 m in the Bornholm Deep, 70-75 m in the Słupsk Furrow and 70-90 m in the Gdańsk Deep. Well-mixed cold surface waters with temperatures from 1.8 to 2.4ºC and with an oxygen content of 9.5-10.5 ml/l (February 2003) are known as "winter waters". These waters will be a source of well-oxygenated water at depths from 30 to 60 m in the summer. The highly saline (above 19 PSU) inflow water that was observed in the Bornholm Deep will refresh deep waters throughout the Polish EEZ and will replenish the body of well oxygenated "cod water".

Hydrological conditions in March 2003

The inflow waters in the Gdańsk Deep spread farther in comparison with the observations made in February 2003. This was noted near the eastern border of the Polish EEZ (Fig. 6). Since the maximum salinity value of deep waters in the Gdańsk Deep was 11.8 PSU in November 2002, it was assumed arbitrarily that waters with salinity equal to or higher than 12.0 PSU are the result of the progressing inflow. These waters were further analyzed to determine the thickness of this layer.

Figure 6A presents the thickness of deep-water layer with a salinity ≥ 12 PSU, which varied from 5 to 17 m. The oxygen content in this water layer varied from 3.5 to 4.8 ml/l (Fig. 6B). Figure 6C presents the dependence of temperature on salinity in the water layer from the surface to the bottom (up to a maximum depth of 105 m). The distribution of oxygen content dependent on salinity in the same water layers is also illustrated in this figure. The vertical lines denote the salinity range registered in deep waters from the time period before the inflow (Fig. 6C).

Our observations indicate that the mean water temperature in the surface layer at station G2 (Gdańsk Deep; Fig. 5) was 1.80ºC, which was 1.54ºC lower than in March 2002 and 0.17ºC lower than the long-term mean for 1948-1996. In March 2003 the mean salinity as well as oxygen content in these waters was nearly the same as in March 2002. In March 2003 the temperature near the bottom of the Gdańsk Deep was 6.07°C (Fig. 5), which was 1.19°C lower than in March 2002 and 0.12°C lower than the long-term mean for 1948-1996. The mean salinity in this area was 12.60 PSU, which was 1.05 PSU higher than in March 2002 and 0.78 PSU higher than the long-term mean. Oxygen content was very high at 3.97 ml/l and was 2.37 ml/l higher than in March 2002 and 2.12 ml/l higher than the long-term mean. In 1998-2000 the oxygen content in the near-bottom waters of the Gdańsk Deep was very low (below 0.70 ml/l) and the appearance of hydrogen sulfide was noted in March 2001.

The thickness of the surface layer in the Gdańsk Deep, which was mixed in terms of temperature and salinity, was approximately 60 m. Results of measurements also show that the layer of old deep waters contained minimum oxygen (about 1 ml/l) and had maximum temperatures (6.5-8.9°C). The water parameters listed above were registered at depths from 60 to 80 m (Fig. 5). Oxygen content below this layer increased from 1.0 to 4.1 ml/l.

Deep waters with typical values of temperature (8.4-8.7°C) and salinity (10.7-11.8 PSU) for autumn 2002, which were registered in November (Fig. 3) at depth stratums of 80-105 m, were in the 70 to 90 m layer in February 2003 and in the 60-80 m layer in March 2003 (Fig. 5C). These data indicate that during the process of deep water transformation, which occurred in spring 2003 in the Gulf of Gdańsk, the water layer with minimum oxygen content will move close to the picnocline.

DISCUSSION

Qualitative and quantitative characteristics of seawater temperature, salinity, oxygen content and the thickness of reproductive volumes (RV – water layer favorable for fish spawning; Westin and Nissling 1991) are indispensable hydrological investigations which are applied

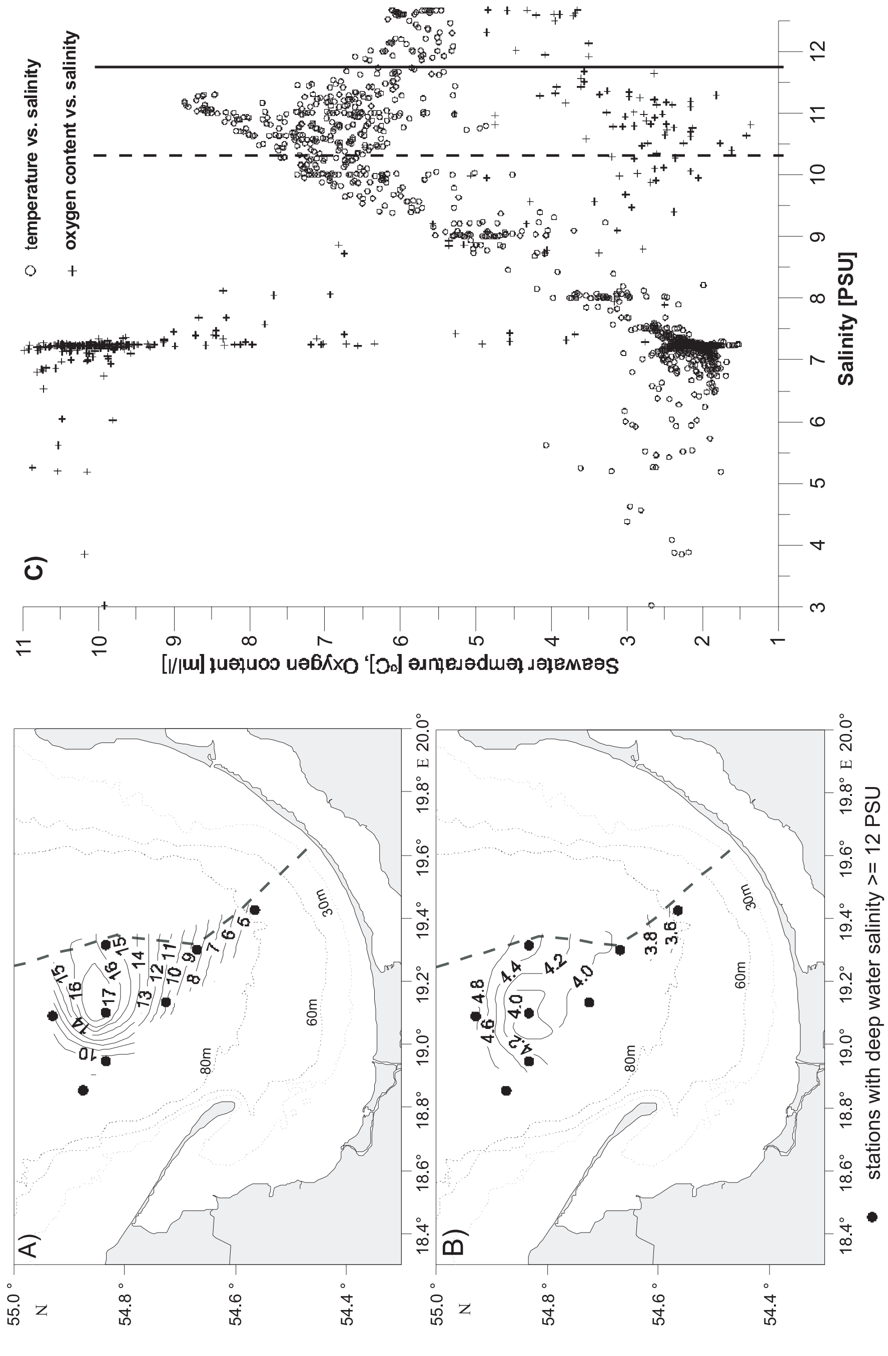

Fig. 6. The thickness (in m) of the deep-water layer with salinity >=12 PSU (part A) and oxygen content (in ml/l) in this water layer (part B), and the dependence between temperature and salinity and between oxygen content and salinity (part C) in all stratums and stations of the Gulf of Gdańsk and the Gdańsk Deep (within the Polish EEZ) in March 2003; dashed and solid lines refer to minimum and maximum, respectively, salinity in the deep waters in the period before the inflow into the Baltic Sea.

directly in the evaluation of the fish spawning process as well as in the preliminary assessment of new year-class abundance (Grauman 1973, 1974, Nissling and Westin 1991, Wieland and Zuzarte 1991, Waller *et al.* 1993, Bagge *et al.* 1994, Zezera and Zezera 1997, Wieland *et al*. 2000). These authors describe the possible hydrological regime variation's impact on cod spawning conditions in the Baltic. The following conditions determine the success of cod spawning in the Gdańsk Basin: salinity >11 PSU, oxygen content >2 ml/l and temperature >1.5ºC.

Investigations conducted by Westin and Nissling (1991) revealed that a minimum salinity of 11 PSU is necessary for the successful fertilization and egg development of Baltic cod. Further investigation showed that no hatching of cod occurred at a salinity of 5 PSU, while, in contrast, mortality during hatching was comparatively low at a salinity of 10 and 15 PSU (Nissling and Westin 1991). Grauman (1973, 1974) concluded that the thickness of the spawning layer, i.e., the layer with favorable salinity and oxygen conditions for normal egg development, is the most significant factor for Baltic cod egg survival. Other authors (Wieland *et al.* 2000) stated that water temperature during the period of gonad maturation is one of three key factors governing the timing of Baltic cod spawning. According to Bagge *et al.* (1994), salinity combined with oxygen content (both of which are determined by the frequency of inflows) are the most important factors which determine the mortality of Baltic cod eggs. The minimum oxygen content for successful cod egg development is 2.3 ml/l; the lethal oxygen level was assumed to be approximately 1.6 ml/l (Wieland and Zuzarte 1991, Waller *et al.* 1993).

A long period of sunny, warm, calm weather conditions in late summer 2002 and the long-term lack of water inflow caused the oxygen situation in the near-bottom waters to deteriorate rapidly, mostly in the west and south-west parts of the Baltic. In these areas oxygen levels fell to the limit of detection and there was hydrogen sulfide production (Anon. 2003). The result was a wide-ranging depletion of bottom fauna in Danish and German waters, and there were reports of fish kills over wide areas of the western Baltic. The affected areas were larger than had ever been observed before and covered an area between Kattegat and the Mecklenburg Bight (Anon. 2003). Investigations conducted abroad the r/v BALTICA indicated that the temperature at depths of about 30-45 m from the surface (the location of fish control catches) was higher in October 2002 than in October 2000 by an average of 3.72ºC, 4.20ºC and 3.57ºC in ICES sub-divisions 24, 25 and 26, respectively. Stronger winds in early autumn, however, led to slight improvement in this situation.

The results obtained by the authors indicate that oxygen conditions improved in the near-bottom layer in the Gdańsk Basin in October 2002, but in the Bornholm Deep the oxygen content was still very low (0.09 ml/l). The next survey of the r/v BALTICA confirmed improved oxygen conditions in the deep waters of the Gulf of Gdańsk – in November 2002 it was 2.5 ml/l on average, while the long-term mean for 1948-1996 was 1.44 ml/l. The hydrological conditions in the deep waters of the Gotland Basin in 2002-2003 are characterized by a continuing stagnation period (Anon. 2003).

In the second half of January 2003 a large, new inflow from the Kattegat into the Baltic basins was first recorded (Anon. 2003). One the main reason for the occurrence of this phenomenon was the relatively low water level in the Baltic, e.g. about 20-30 cm below mean at Stockholm, due to stable high air pressure over Scandinavia and the associated north-easterly winds (unpublished data from the Swedish Meteorological and Hydrographical Institute – Anon. 2003). In February 2003 the Swedish r/v ARGOS reported an inflow through the Sound with a volume of 40 km^3, which is normally around one-third of the total inflow through both the Sound and the Belt Sea (Anon. 2003). This inflow is estimated to have a volume of between 120-180 km^3, and calculations indicate that it may have been a strong one comparable with that from 1993. The average velocity of the inflowing waters in 1993 was 9 cm/s (Dahlin *et al*. 1993).

The salinity of 19.2 PSU, which was registered in February 2003 during the survey of the r/v BALTICA in the Polish part of the Bornholm Deep, is the fourth highest figure recorded in the past 57 years. The present inflow has to be regarded as a very cold; the water temperature in the near-bottom layer in the Bornholm Deep was 3.44ºC lower than the long-term mean for 1950-1996. The oxygen content range from 6.9 to 7.4 ml/l (in the Bornholm area) and the well-mixed cold surface waters (with temperatures of 1-2ºC and an oxygen content of 9.5 ml/l – so-called "winter waters") will be the source of well-oxygenated waters below the picnocline and at depths of 30-60 m in summer 2003.

The latest results of the Polish survey, in comparison with data from February 2003, indicate that in March 2003 inflow waters were continuing to spread to the eastern parts of the southern Baltic. Oxygen content in the water layer below depths of 60-80 m in the Gdańsk Deep increased from 1.0 to 4.1 ml/l. A number of recent surveys carried out by various institutes from around the Baltic Sea have also provided evidence that the inflow improved considerably the hydrological situation in the Bornholm Basin and adjacent waters. The inflow waters will refresh deep waters in the majority of the southern Baltic region and will replenish the body of well oxygenated "cod waters".

The largest inflow into the Baltic observed to date occurred in 1951/1952 (Wyrtki 1954), when about 200 km^3 of waters with a salinity of 22 PSU were introduced into this sea (in June 1952 salinity in the Bornholm Deep was 20.8 PSU). The volume of average inflows is usually between 30-50 km^3; smaller inflows do not reach to central basins of the Baltic (Majewski 1987). After 1951 the next highest salinity values in the southern Baltic were recorded in September 1953 (20.43 PSU) and August 1954 (19.38 PSU). One of the last effective inflows into the Baltic Proper occurred in 1993 (Dahlin *et al*. 1993, Matthäus 1995, Zazera and Zazera 1997, Anon. 2003). In the Öresund and in the Belt Sea in January 1993 the temperature of the inflowing waters was below 5ºC; this contrasts with the inflow in 1976-1977 which brought unusually warm water into the Gotland Deep (>7ºC; Dahlin *et al*. 1993). In 1993 the average salinity of the inflow waters in the Bornholm Basin was slightly higher than 18 PSU, and the volume of all inflow waters was about 300 km^3 (Dahlin *et al*. 1993, Matthäus 1993). In April-May 1994, following the inflow from 1993, the reproductive volumes for cod spawning in the Gdańsk Basin increased significantly to 95.4 km^3 (in 1992 this figure was 15.1 km^3; Zazera and Zazera 1997).

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Piscicola pojmanskae Bielecki 1994 (Piscicolidae, Hirudinea) reported in a new location in central Pomerania

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Abstract. The leech *Piscicola pojmanskae* was found in the brackish Lake Gardno for the first time. This is the second report of this leech occurring in lakes.

Key words: brackish waters, *Piscicola pojmanskae*, Hirudinea

Leeches are typical components of reservoir fauna in the Polish climatic zone. The phylum is comprised of six families which include predatory and parasitic species. The majority of the representatives of the Piscicolidae family are fish parasites. Only two or three species from this family (Timm 1999, Kołodziejczyk and Koperski 2000) are mentioned in the most widely available guidebooks. However, 21 species of Piscicolidae leech have been recorded in Poland alone (Bielecki 1994). The most common is the fish parasite *Piscicola geometra* (L.). Detailed morphological and anatomical analysis allowed Bielecki to distinguish a number of species from this group, including *Piscicola pojmanskae* (Bielecki 1994) – Photograph 1. To date, *Piscicola pojmanskae* has been recorded in numerous

Phot. 1. *Piscicola pojmanskae* – ventral view.
1. Interior sucker small or very small, its greatest diameter is not wider than the greatest width of the trachelosome.
2. Posterior sucker small too, its greatest diameter is not wider than the greatest width of the urosome.

fishing ponds and dam reservoirs (Bielecki 1997), although only one publication reported the occurrence of this species in lakes, namely lakes Ukiel and Wulpińskie which belong to a group of lakes situated near Olsztyn (Bielecki and Dzika 2000). The author of the current article found *Piscicola pojmanskae* in Lake Gardno, a brackish water coastal lake located on the central Baltic coast. According to the available literature, this is the first time this species has been recorded in such a lake. Lake Gardno is a ß-oligohaline lake, and during the studied period the chloride ion concentration ranged from 20 to 4425 mg Cl dm^{-3} and was 0.5 ‰, on average. It follows that it is possible that *Piscicola pojmanskae*, like *Piscicola geometra*, is a euryhaline species that occurs in freshwater as well as brackish water Baltic estuaries.

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