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CONTENTS

Scientific papers

NATALIA KRASOVSKAYA

Spawning of the Baltic herring in the Vistula Lagoon:
effects of environmental conditions and stock parameters 3

KORDIAN TRELLA

Fecundity of walleye pollock (*Theragra chalcogramma* Pallas)
from the southwest region of Kamchatka (Sea of Okhotsk) 27

Short communications

ZBIGNIEW DOBRZAŃSKI, PIOTR BYKOWSKI, ZBIGNIEW IWANIUK,

ZYGMUNT USYDUS, HELENA GÓRECKA and TADEUSZ TRZISZKA

Evaluation of the chemical composition of fish oil: a by-product from fish processing plants
in the southern Baltic Sea 39

DARIUSZ P. FEY

Length correction of larval and early-juvenile herring (*Clupea harengus* L.)
and smelt (*Osmerus eperlanus* L.) after preservation in formalin and alcohol 47

SVAJŪNAS STANKUS

Growth, sex structure and commercial significance
of turbot (*Scophthalmus maximus* L.) in the Lithuanian EEZ 53

NORBERT WOLNOMIEJSKI and IRENA GRYGIEL

Food of common bream (*Abramis brama* L.) in the Szczecin Lagoon (Great Lagoon) 61

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Spawning of Baltic herring in the Vistula Lagoon: effects of environmental conditions and stock parameters

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Abstract. The Vistula Lagoon is one of the main spawning grounds of Baltic herring (*Clupea harengus membras* L.) in the southeastern Baltic Sea. Coastal spring spawners constitute from 94 to 98% of the total herring catches in the lagoon. Using data from 1950-2000, the high amplitude of inter-annual variability of spawning timing of the Baltic herring was shown within a wide range of environmental conditions and stock characteristics. The principal factors which have a prevalent effect on spawning timing included the time of ice breakup and clearing from the lagoon, which is related to the severity of the preceding winter, further warming processes and water salinity values. In spite of the inter-annual diversity of spawning time, abiotic conditions, stock size etc., a noticeable constancy was observed in the spawning run (changes in CPUE, age composition, mean weight-at-age of herring during the spawning period). The trend towards milder winters and the early occurrence of spring should be mentioned, and the distinct shift of herring spawning in the Vistula Lagoon towards an earlier time and at lower temperatures was observed in spite of the positive trend of mean water temperature in spring.

Key words: Vistula Lagoon, Baltic herring, timing of spawning, duration of spawning, water temperature, water salinity, stage of maturity.

INTRODUCTION

Reproduction in a wide range of environments is one of the principal abilities that ensures the success of herring populations (Blaxter 1985). It is essential to know the timing and duration of the spawning season in response to biotic and abiotic factors for fishery management purposes, and especially investigations of temporal fluctuations in the year class strength, racial discrimination of stocks, growth rate and migration patterns.

The Vistula Lagoon is of special interest for several reasons. It is a large reproduction area for spring spawning coastal herring from the southeastern Baltic Sea. Autumn herring spawning observed in the lagoon is insignificant due to its low abundance. Herring migrate into the Vistula Lagoon only to spawn and leave immediately after spawning for offshore feeding grounds. Using preliminary data divided into assessment units reported by Feldman and Gasjukov *et al.* (1998), the share of the Vistula Lagoon in total catches of coastal herring in SD26 is about

30%. However, its role in herring reproduction is evidently more important due to the close fry-recruitment relationship (Birjukov and Shapiro 1971, Krasovskaya 1992) and the high density of larvae which in some years exceeds 9×10^{10} ind. The proportion of herring belonging to other populations is low. Otolith studies indicated that only about 2% (0.2 - 5.4%) of fishes caught in the Vistula Lagoon are open sea herring. The percentage of herring infested by *Anisakis* nematode larvae, noted in the lagoon from 1985 (Gaevskaia and Krasovskaya 1986), varies within the range of 0.0-5.3% (1.5%, on average). According to Reimer (1970), Grabda (1974) and Friess (1977), this infestation is considered as a natural tag of herring feeding on euphausiids in the North Sea, Kattegat, Skagerrak areas and spawning in the southwestern Baltic Sea (so-called Rugen herring). Therefore, the spring spawning coastal herring of the southeastern Baltic make up at least 90% of the annual catch in the Vistula Lagoon. In general, herring catch fluctuations in the Vistula Lagoon from the 1950s correspond well with reports by Seletskaya (1962) and Popiel and Strzyżewska (1971) for the southeastern part of the Baltic Sea. The literature which attempts to define the status of this spawning stock as a distinct population is not in consensus. Birjukov (1970), Elwertowski (1982) and Ojaveer (1988) considered this to be the same population as that of coastal herring in the Gulf of Gdansk. Strzyżewska (1969, 1979), meanwhile, examined some of the morphological structures of Baltic herring and noted significant differences between the populations in the Vistula Lagoon and in other spawning grounds in the southern Baltic Sea. Considering the close relationship between fry abundance and spawning stock recruitment of herring in the lagoon, Shapiro and Shemina (1975) concluded that it comprised one distinct population, although the high variation of herring morphological features was emphasized (Gaevskaia and Shapiro 1981). However, unlike the summarized fisheries assessment for ICES Sub-divisions 25-29 and 32 (including the Gulf of Riga) performed by the ICES Working Group from 1990, the spawning stock state in the Vistula Lagoon may characterize the general situation of the spring spawning coastal herring of the southeastern Baltic. The assessment unit 25-29 and 32 was created in 1990 as a combination of several stock components with different growth rates and patterns of year-class fluctuation. In accordance with the 1997 and 1998 Working Group on the assessment of Baltic Pelagic Stocks, the perception of this herring stock development was quite different when considering number and biomass (Anon. 1997, 1998). It was noted that the declining trend of stock biomass was caused by drastic changes in the mean weight of herring. In terms of number, the stock size estimation was even higher than the 1982-1991 average level. The most recent assessment revealed that both the biomass and abundance of herring (ICES Sub-divisions 25-29, 32) is at a historically low level (Anon 2000, 2001). The results obtained in the Vistula Lagoon have shown that besides the mean weight-at-age decrease, a sharp decline of herring spawning stock began in 1994-1995 owing to fair recruitment (Krasovskaya 1999).

The aim of this work is to review the long term monitoring data which characterizes the Baltic herring spawning activity in the Vistula Lagoon from 1950 to 2000 and which provides a rather precise picture of its seasonal and inter-annual variability.

MATERIALS AND METHODS

The Vistula Lagoon ($54^{\circ}15' - 54^{\circ}43' \text{ N}$, $20^{\circ}13' - 19^{\circ}25' \text{ E}$) is a semi-enclosed, shallow, brackish-water basin situated in the southeastern part of the Baltic Sea (Fig. 1). The lagoon is divided by the Russian – Polish border. The total area of the lagoon is 838 km² (Russian part – 473 km²).

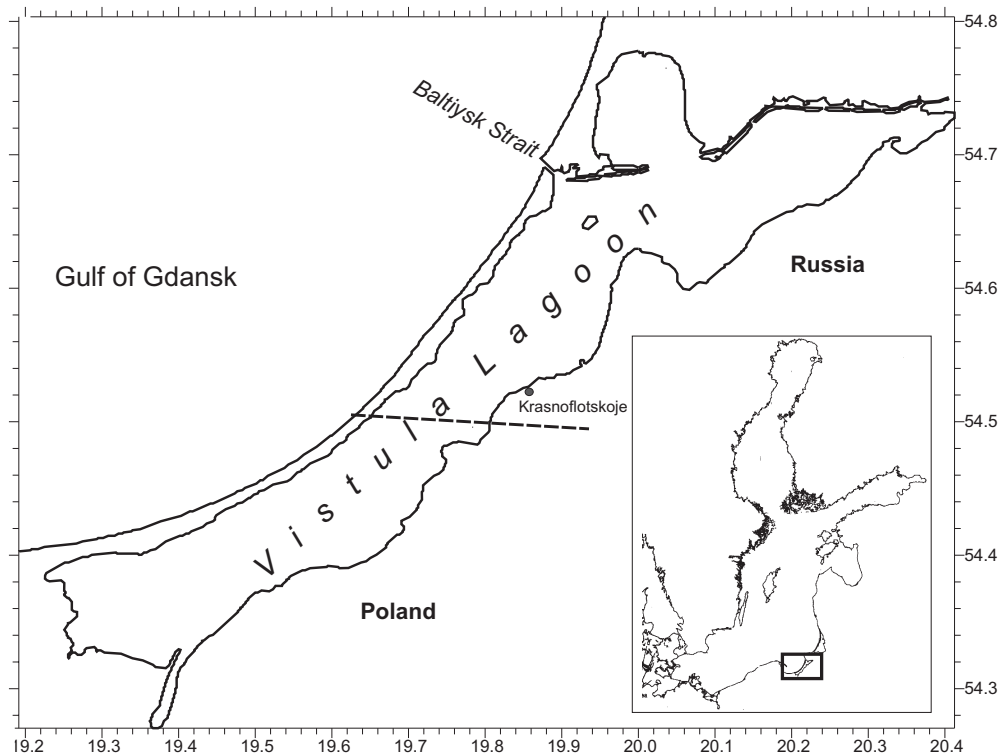


Fig. 1 The location of the Vistula Lagoon.

The mean depth is 2.6 m, and the water salinity varies from 1 to about 5‰ in the central part of the basin. The Baltiysk Strait, which connects the lagoon with the Baltic Sea in the Russian part, is 400 m wide and about 9 m deep. The basin is practically uniform in thermal structure. The pattern of water temperature is determined by solar heating and fully correlates with changes of air temperature (Anon. 1971, Chubarenko 1999).

The Vistula Lagoon was a freshwater basin by the early 1920s. Changes in current characteristics were observed in the lagoon after the removal of a drain from one of the branches of the Vistula from the lagoon into the Gulf of Gdansk and the artificial deepening of the Baltiysk Strait. Water exchange with the Baltic Sea became the main factor in the water balance resulting in an increase of water salinity (Anon. 1971). These changes in the hydrological regime created new ecological conditions in the basin and caused significant alterations in the ecosystem.

The timing of herring spawning was investigated on the basis of commercial catch data. Herring fishery in the Russian part of the Vistula Lagoon is conducted throughout the spawning season using passive fishing gears only. The same kind of pound nets were used throughout the investigation period, and their number, location and catch values were monitored. Herring spawning migrations are possible only through the Baltiysk Strait in the Russian part of the lagoon. The first appearance of herring schools was recorded on the basis of catches taken by nets often set in spring before the basin was free of ice.

Two sets of herring stock assessment data which included the Vistula Lagoon were available only from the 1970s for SD 25-29 and 32 (and the Gulf of Riga) (Anon. 2001) and for the Vistula Lagoon spawning stock, in particular (Shemina 1977, Krasovskaya 1992); however, there were no comparable estimations for the whole study period from the 1950s. Thus, variations in total catch and catch per pound net in the Vistula Lagoon were used as an index of herring stock dynamics. Daily information on catches and the number of pound nets, as well as sample data collected during the spawning period since the 1950s were used. Two or three random samples per week of 100 fish each, i.e. 10-25 samples per spawning season, were examined. The total length and total weight of the fishes was measured and recorded, and the sexual maturity stage was determined. Otoliths were used for reading age. Differentiating the herring of different origin was based on typical features of the otolith structure. The timing of herring spawning was defined with the relatively small error of about 3-5 days. The date of spawning completion was the most difficult to determine. Data provided by local fishermen who catch eel with eel traps in the Vistula Lagoon and herring samples obtained from the eel traps were used to determine the latest date of the herring's presence in the lagoon.

The staging of maturity was based on a six-point scale (Alekseev and Alekseeva 1996). As mentioned, the Vistula Lagoon is a spawning ground, therefore there are adult herring in maturing (III), mature (IV), ripe (V) and spent (VI) maturity stages. In this case, stages III and IV are considered to be pre-spawning and stage V is running, when flowing roe and milt occurs. These maturity stages correspond approximately to the maturing (IV), mature (V), ripe (VI) and spent (VII) stages of the Maier scale (Anon. 1965).

The onset of spawning was determined when the proportion of fishes in stages V and VI (VI and VII in the Maier scale) constituted more than 30% of the catches. Mass spawning was defined as the period when the percentage of these stages exceeded 70%, and, additionally, the catches per pound net approached the mean seasonal value. Specimens in stage V were noted throughout the period when herring were present in the lagoon, but these single events were not considered to indicate the onset of spawning. The problem of age/length at first maturity is not discussed in the current work because the Vistula Lagoon is a spawning ground only and all herring entering the basin are either in the pre-spawning and running stages of maturity.

The dates of the Vistula Lagoon's release from ice, the average daily water temperature and salinity values recorded by the Kaliningrad hydrometeorological observatory were used. Water temperature data presented characterize the thermal conditions for the Baltiysk Strait and the central part of the basin (Krasnoflotskoje). The classification of winters from the 1950s to the 1970s by degree of severity was taken from Antonov (1964), Birjukov (1970), Sergeeva (1983) and Anon. (1994). In more recent years, it was based on the mean monthly air temperature in Kaliningrad during the winter season (Table 1). The results obtained correspond well with those reported by Kalejs and Ojaveer (1989).

In order to compare spawning timing in different environmental conditions, the following variables were grouped: first spawning wave dates (early, average, late); mean water temperature in spring in the Baltiysk Strait (warm, average, cold); water salinity in the Vistula Lagoon (high, average, low). The values $\bar{x} \pm \sigma/2$ as the borderlines of intervals were used to distinguish the above mentioned groups of observations after the verification of the assumption of normality with Chi-square goodness of fit test was performed (Table 2).

Table 1. Data characterizing the herring spawning period in the Vistula Lagoon (1951-2000)

Year	Prior winter severity	Mean water temperature in spring [°C]	Total catches [t]	Clearing the lagoon of ice	First spawning wave	Onset of spawning	End of spawning	Onset of mass spawning	End of mass spawning	Onset of age 2 spawning	Mean water temperature[°C]				Water salinity during first spawning wave [psu]
											during spawning	during mass spawning	during spawning age 2	at the end of spawning	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1951	moderate	6.9	16,200	5 IV	5 IV	20 IV	20 VI	25 IV	25 V	15 V	13.8	12.2	16.1	18.3	
1952	mild	7.0	12,660	14 IV	10 IV	14 IV	25 VI	25 IV	20 V	5 V	13.3	12.3	15.4	17.0	
1953	moderate	8.5	8,015	28 III	29 III	2 IV	19 VI	15 IV	15 V	5 V	13.6	11.6	16.2	19.4	
1954	severe	6.3	10,662	12 IV	11 IV	11 IV	16 VI	10 V	30 V	10 V	12.4	13.5	16.1	19.6	
1955	moderate	5.4	4,248	12 IV	11 IV	14 IV	16 VI	15 IV	15 V	10 V	10.9	7.9	13.8	15.8	
1956	severe	5.9	1,804		17 IV	23 IV	17 VI	5 V	25 V	25 IV	14.1	13.9	14.5	19.4	
1957	mild	7.7	770		29 III	2 IV	4 VI	10 V	30 V	10 V	10.8	13.2	13.2	13.2	
1958	moderate	5.9	800	24 IV	20 IV	20 IV	30 V	25 IV	30 V	1 V	11	11.9	13.6	13.6	
1959	mild	9.2	400		27 III	5 IV	27 V	25 IV	25 V	10 V	12.1	13.9	15.9	16.0	
1960	moderate	7.1	242		11 IV	11 IV	1 VI	25 IV	25 V	15 V	12.5	13.1	16.2	16.2	1.97
1961	mild	8.9	280		1 IV	10 IV	1 VI	25 IV	25 V	15 V	12.5	12.9	15.4	17.4	2.66
1962	moderate	5.8	411	14 IV	13 IV	14 IV	6 VI	12 V	25 V		11.4	12.9		14.4	1.23
1963	severe	6.8	520	17 IV	17 IV	17 IV	1 VI	5 V	20 V	5 V	13.8	14.4	16.6	19.6	2.18
1964	severe	6.6	705	14 IV	20 IV	20 IV	5 VI	25 IV	15 V	1 V	14.1	11.4	15.7	19.6	1.47
1965	moderate	6.0	1,225	4 IV	4 IV	15 IV	4 VI	20 IV	25 V	2 V	11	10.6	12.7	15.2	3.74
1966	moderate	7.4	1,790		1 IV	15 IV	1 VI	20 IV	25 V	20 IV	12.2	12.8	13.1	15.1	2.84
1967	moderate	8.9	3,499		17 III	25 III	30 V	25 III	20 V	25 III	10.5	9.7	10.5	15.6	2.28
1968	moderate	8.3	4,357		25 III	25 III	5 VI	30 III	10 V	20 IV	11.4	10.3	13.9	16.4	3.18
1969	severe	6.6	4,473	17 IV	20 IV	20 IV	10 VI	20 IV	1 VI	20 IV	13.3	12.8	13.3	15.5	3.23
1970	severe	5.9	2,611	21 IV	25 IV	25 IV	5 VI	25 IV	25 V	5 V	13.0	12.3	14.5	15.1	2.80
1971	mild	8.2	5,755	25 III	25 III	5 IV	21 V	5 IV	15 V	5 IV	11.2	10.2	11.2	17.9	2.98
1972	moderate	7.3	5,743	28 III	28 III	1 IV	5 VI	5 IV	15 V	15 IV	10.7	9.2	11.9	15.3	4.22
1973	mild	7.9	10,230	15 II	23 II	10 III	30 V	25 III	1 V	15 III	8.5	7.1	9.3	15.5	3.89
1974	mild	7.6	12,841	10 III	10 III	10 III	22 V	20 III	25 IV	20 III	7.8	7.0	8.7	14.6	4.61
1975	mild	8.6	12,019		10 II	10 III	15 V	10 III	30 IV	25 III	7.7	5.9	8.6	15.8	3.35

Table I, continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1976	moderate	6.7	10,675	2 IV	5 IV	5 IV	2 VI	5 IV	15 V	15 IV	10.6	8.8	11.5	13.9	2.01
1977	moderate	7.2	9,613	17 III	19 III	19 III	15 V	19 III	10 V	25 IV	7.6	6.9	12.2	13.8	2.58
1978	moderate	7.6	10,205	12 III	17 III	1 IV	15 V	1 IV	25 IV	5 IV	8.2	7.2	8.2	9.6	3.80
1979	severe	7.2	8,018	7 IV	10 IV	10 IV	8 V	15 IV	8 V	1 V	8.5	8.7	9.6	9.6	1.86
1980	severe	5.3	8,088	16 IV	15 IV	15 IV	1 VI	15 IV	10 V	20 IV	10.2	7.8	10.8	13.8	3.83
1981	mild	7.9	7,452	25 III	20 III	27 III	25 V	1 IV	15 V	1 IV	9.8	8.5	10.3	18.5	2.53
1982	severe	7.1	6,671	23 III	20 III	25 III	20 V	1 IV	5 V	1 IV	7.9	6.7	8.4	13.6	2.22
1983	mild	8.9	12,611	13 III	16 III	20 III	31 V	20 III	10 V	5 IV	10.9	8.2	12.6	18.9	3.82
1984	mild	7.9	11,367	17 III	16 III	25 III	31 V	25 III	15 V	17 IV	10.7	8.7	13.0	17.4	4.93
1985	severe	7.4	9,527	1 IV	6 IV	10 IV	15 V	10 IV	10 V	20 IV	9.5	8.4	10.4	14.9	2.80
1986	severe	7.6	10,100	5 IV	1 IV	15 IV	30 V	15 IV	11 V	22 IV	13.3	8.9	14.7	16.4	1.47
1987	severe	5.7	9,799	15 IV	10 IV	15 IV	30 V	15 IV	5 V	5 V	10.3	8.7	11.9	13.0	2.42
1988	mild	8.0	12,104	25 III	20 III	1 IV	15 V	1 IV	20 IV	5 IV	9.8	7.4	10.3	15.8	3.49
1989	mild	9.6	11,873		1 II	25 II	25 IV	1 III	5 IV	10 IV	6.2	4.6	10.2	9.6	4.47
1990	mild	10.5	9,558	28 I	12 II	12 II	25 IV	12 II	15 IV	25 III	6.8	5.9	9.56	12.3	3.77
1991	moderate	7.8	7,310	10 III	18 III	18 III	30 V	18 III	15 IV	5 IV	9.3	6.7	10.5	12.5	4.23
1992	mild	8.1	6,858	5 III	1 III	2 III	25 IV	5 III	10 IV	15 III	4.7	4.3	5.61	6.0	4.44
1993	mild	8.6	6,220	19 III	22 III	22 III	20 V	25 III	1 V	25 III	9.8	6.9	10.0	17.4	4.48
1994	moderate	8.1	7,652	17 III	26 III	26 III	15 V	26 III	25 IV	15 IV	9.6	6.8	12.2	15.5	4.46
1995	moderate	7.7	4,922	6 II	23 II	1 III	31 V	5 III	25 IV	10 IV	7.7	4.6	11.1	16.4	4.39
1996	severe	5.9	2,338	19 IV	18 IV	18 IV	20 V	18 IV	20 V	5 V	11.5	11.5	13.2	15.5	4.36
1997	moderate	7.8	2,645	25 II	9 III	15 III	16 V	15 III	5 V	25 IV	7.0	5.6	11	14.3	3.22
1998	mild	8.5	2,136	15 II	16 II	20 II	15 V	10 III	1 V	10 IV	6.8	5.9	11.3	14.7	3.50
1999	mild	8.5	2,520	6 III	15 III	15 III	31 V	20 III	10 V	1 IV	9.9	9.0	11.6	17.4	3.76
2000	mild	8.4	3,105	6 II	13 II	1 III	7 V	10 III	1 V	10 IV	6.2	5.9	11.5	14.2	4.23

Table 2. The borderlines of variable intervals which were used to distinguish the observation groups after verifying the assumption of normality with the Chi-square goodness of fit test

Parameters	First spawning wave date	Mean water temperature [°C]	Mean water salinity [‰]
Chi-square tab.	5.56	2.55	0.46
Chi-square st.	11.07	5.99	5.99
Mean value	March 24	5.98	3.26
$\sigma/2$	10	0.55	0.49
Borderlines	March 4-April 4	5.43-6.53	2.77-3.75

RESULTS

Herring spawning fishery in the Vistula Lagoon

The historical data of herring catches in this area are presented in Fig. 2. It reflects the state of the spring spawning coastal herring stock in SD 26. The catch in the Vistula Lagoon approached its long-term peak level in the early 1950s. This period is characterized by the highest fishing rate in the Russian part of the lagoon (up to 230 pound nets), followed by a collapse of this spawning stock and a 10-year low in stock abundance. The total catch decreased from about 17 000 t to 242 t. The stock began to recover in the mid 1960s. The next 20 years were characterized by a quasi-stable period of high fish abundance. A sharp decline in the spawning biomass and catches has occurred over the last decade.

Some distinct periods with opposite tendencies in herring growth changes in the Vistula Lagoon can be distinguished from the 1950s onward (Fig. 2C). From 1950 to the mid 1960s, the mean size was relatively low, while high growth rates were observed from the mid 1960s through the next 20 years. An appreciable, sustained trend of decrease occurred from the 1980s up to the mid-1990s. A similar trend was observed in other Baltic herring stocks. This was discussed in Cardinale and Arrhenius (2000) in connection with changes of biotic and abiotic factors.

The fisheries dynamics in the Polish part of the Vistula Lagoon are varied. Herring has constituted a significant share of the catches only from the 1970s (Birjukov 1970, Skóra 1996). Despite a considerable decrease in the spawning biomass, over the last decade Poland's portion of the total catches was generally more than 30% (Fig. 2A). A review of the long-term data indicates a relationship between Polish catches and the total catch level, the fishing rate in the Russian part of the basin and hydrological conditions during spawning time (Fig. 3). Significant changes in biotic and abiotic factors within the period under consideration have caused an alteration in the spatial distribution of herring in the lagoon and the extension of migration toward its southwestern part. The most important of these changes have been:

- spawning stock stabilization at a high level by the mid 1970s;
- restriction efforts in the Russian part of the Vistula Lagoon (from 230 to 60-80 pound nets);
- the shift of the herring spawning period to an earlier time and lower temperatures which has caused a longer spawning period;
- a pronounced positive trend in water salinity with the highest indices recorded during the most recent decade. In the southwestern part of the lagoon, which is distant from the Baltijsk Strait, water salinity is lower and in spring it approaches its minimum level (Fig. 4).

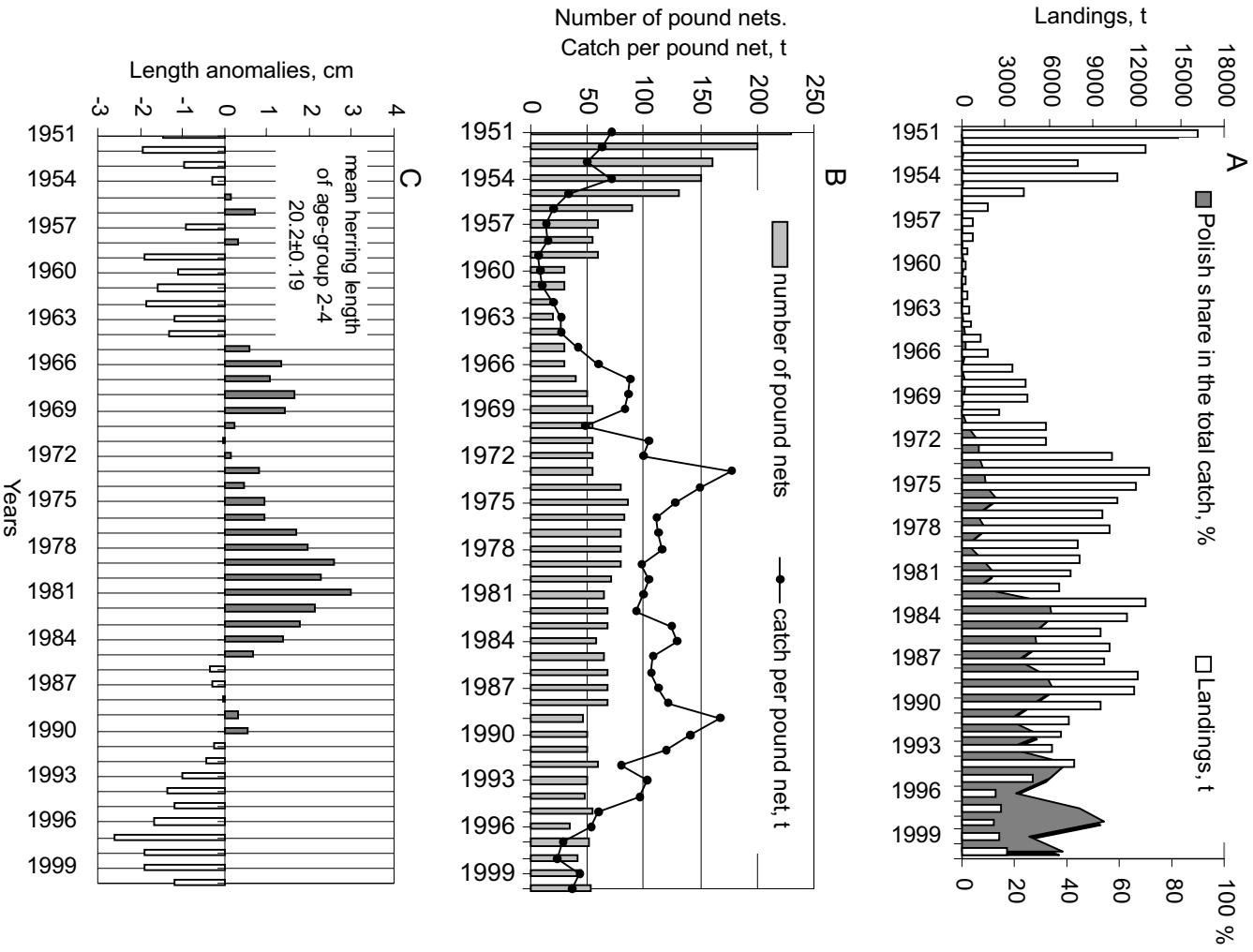


Fig. 2. Historical data of the Baltic herring fishery in the Vistula Lagoon (number of pound nets and catches per pound net data (B) represent the Russian part of the basin).

Fig. 3. Polish catch percentage of the total herring catches in the Vistula Lagoon dependent on total catches, fishing effort in the Russian part of the basin and hydrological conditions.

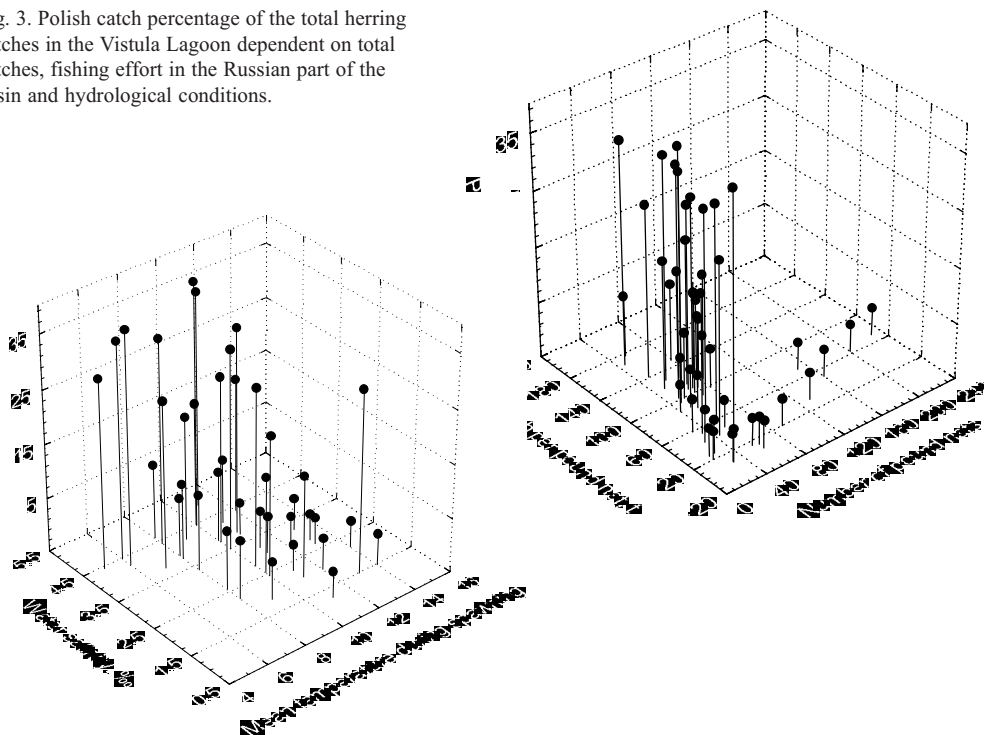


Table 3. Variability of time, duration and hydrological conditions of the herring spawning period in the Vistula Lagoon in 1951-2000

Characteristics	Mean value (1951-2000)	Range		Standard deviation	Coefficient of variation [%]
Date					
the first spawning wave	24 III	1 II	25 IV	20.6	38.7
onset of spawning	31 III	12 II	25 IV	17.8	30.3
ending of spawning	27 V	25 IV	25 VI	13.5	11.6
onset of mass spawning	6 IV	12 II	12 V	20.2	31.3
ending of mass spawning	11 V	5 IV	1 VI	13.9	13.9
onset of age-group 2 spawning	18 IV	15 III	15 V	17.0	22.0
Duration [days]					
herring presence in the Lagoon	70	34	104	15.8	22.5
spawning period	57	28	90	13.6	23.8
mass spawning period	35	13	63	11.6	33.7
Mean water temperature [°C]					
during spawning period	10.3	7.7	14.1	2.4	22.8
during mass spawning period	9.3	4.3	14.4	2.9	30.9
during spawning period of age-group 2	12.2	5.6	16.6	2.6	20.9
at the ending of spawning	15.3	6.0	19.6	2.8	14.2
at the ending of mass spawning	12.2	5.1	17.5	2.8	22.6
Water salinity during first spawning wave [psu]	3.26	1.23	4.93	0.99	30.4

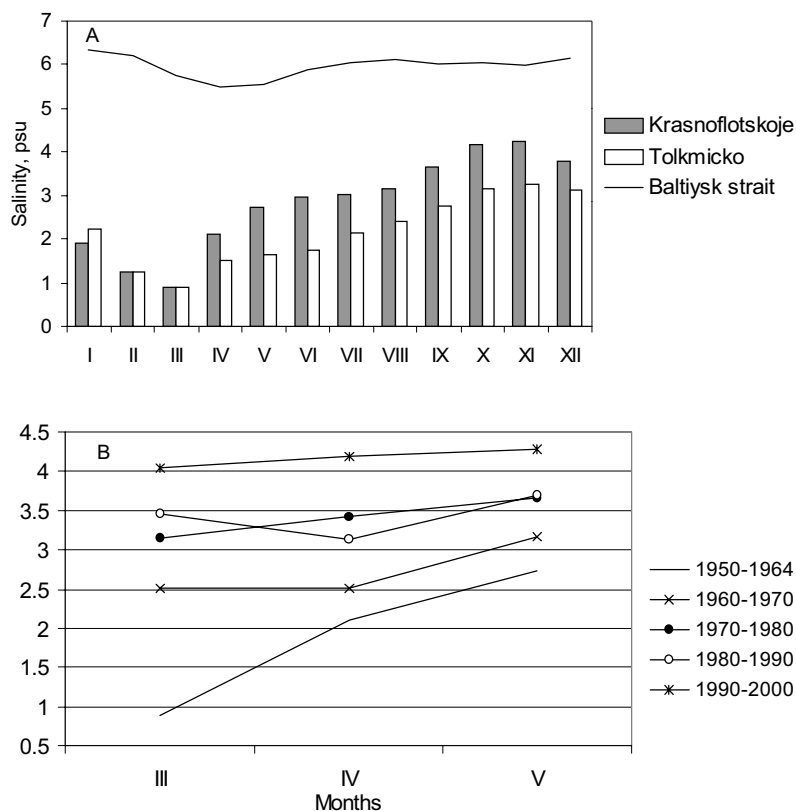


Fig. 4. Salinity conditions in the Vistula Lagoon. Monthly means for 1950-1964 (Anon 1971) (A) and inter-annual changes in spring by decades (B).

Inter annual variability of spawning in relation to environmental conditions and the state of stocks

The timing and duration of herring spawning and the hydrological conditions in the Vistula Lagoon are remarkably variable (Table 2). Range of variables, standard deviation values and coefficients of variation are presented in Table 3. The presence of herring schools in the lagoon varied from 34 to 104 days throughout the period under consideration. The spawning event extends from February 12 to June 25 in different years (March 24-May 27, on average). Within this period, spawning and mass spawning can take place during 57 (28-90) and 35 (13-63) days, respectively. The difference in the spawning season exceeds two months from year to year with April 25 being the boundary between the end of the earliest spawning and onset of the latest one. Mean water temperature within the spawning period varied from 7.7 to 14.1°C and can rise rather quickly from about 1°C when the first herring enter the lagoon to more than 19°C during the last spawning waves. It should be noted that Baltic herring are very tolerant to low salinity. In the Vistula Lagoon, herring spawn at a value of 1.23-4.93 psu. The data presented are characterized by high CV, in the range of 11.6-38.7%, with minimum values at the end of the herring spawning period (Table 3). Water temperature and salinity as well as the time when the first herring entered the lagoon had a significant impact on the timing and duration of spawning (Table 4).

Table 4. Timing (date) and duration (days) of herring spawning period in the Vistula Lagoon under different environmental conditions: one-way ANOVA results (r^2 – coefficient of determination)

Factors		Onset of spawning	Onset of mass spawning	Onset of age-group 2 spawning	Ending of spawning	Ending of mass spawning	Duration of herring presence in the lagoon	Duration of spawning	Duration of mass spawning	Mean water temperature during spawning period
Winter	mild	17 III	26 III	9 IV	21 V	5 V	79	64	39	9.2
	moderate	1 IV	7 IV	22 IV	1 VI	12 V	71	59	35	10.5
	severe	15 IV	19 IV	27 IV	31 V	16 V	54	45	26	11.7
	<i>F, p</i>	15.25 ^c	7.62 ^b	6.14 ^b	3.48 ^a	3.27 ^a	14.32 ^c	10.52 ^c	6.65 ^b	4.87 ^a
	r^2 [%]	38.2	24.9	18.2	9.8	11.0	45.2	25.3	21.6	16.7
Spring	warm	15 III	21 III	9 IV	18 V	30.IV	79	64	40	8.8
	average	1 IV	7 IV	17 IV	28 V	13 V	70	57	36	10.6
	cold	13 IV	21 IV	29 IV	122	19 V	59	50	28	11.6
	<i>F, p</i>	22.49 ^c	16.10 ^c	8.05 ^b	6.43 ^b	11.29 ^c	11.11 ^c	6.30 ^b	5.94 ^b	8.54 ^c
	r^2 [%]	46.6	38.3	24.5	21.8	29.2	29.3	18.8	17.5	25.4
Salinity	low	9 IV	20 IV	26 IV	4 VI	18 V	65	54	29	11.6
	average	31 III	4 IV	17 IV	24 V	12 V	69	54	38	10.3
	high	17 III	20 III	8 IV	20 V	29 IV	75	63	39	8.8
	<i>F, p</i>	11.05 ^c	17.2 ^c	13.71 ^c	6.44 ^b	15.18 ^c	ns	ns	5.03 ^a	9.19 ^c
	r^2 [%]	35.6	45.0	42.7	20.1	41.1			14.8	30.3
First entrance of herring	early	2 III	8 III	1 IV	12 V	23 IV	87	71	46	6.9
	average	30 III	5 IV	16 IV	27 V	11 V	71	58	36	10.6
	late	16 IV	24 IV	3 V	4 VI	20 V	57	48	26	12.0
	<i>F, p</i>	101.00 ^c	46.03 ^c	19.29 ^c	13.02 ^c	19.91 ^c	21.09 ^c	12.56 ^c	14.81 ^c	34.18 ^c
	r^2 [%]	77.9	64.4	44.3	35.1	41.6	45.2	32.5	37.1	54.0

Effects are significant at ^a $p < 0.05$, ^b $p < 0.01$, ^c $p < 0.001$

Table 5. Duration of herring spawning season in the Vistula Lagoon by periods of different stock abundance

Period	Total herring catches [t]	Catch per pound net [t]	Stock abundance	Duration of herring presence in the lagoon [days]	Duration of mass spawning [days]
1951-1954	11884	162	High	81	26
1955-1966	1100	19	Low	62	26
1967-1994	8472	131	High	69	37
1995-2000	2944	31	Low	81	47

On the contrary, changes in factors related to the spawning stock state did not cause very noticeable changes in the spawning pattern. Alternating periods of high and low stock abundance in the Vistula Lagoon are clearly determined (Fig. 2). When the data are summarized taking into account all the years until 2000, the results (Table 5) indicate either weak or insignificant relationships despite significant changes in stock abundance. The same should be noted concerning age composition and growth rate changes. The current results confirmed the prevalent effect of abiotic factors on the herring spawning pattern in the Vistula Lagoon.

The first spawning wave

As follows from Table 4, the timing and duration of spawning are closely connected to the date the first spawning wave appeared. When the herring arrival is earlier, spawning begins and ends earlier, but the duration of the reproduction period is longer. The first herring onset in the lagoon takes place from February 1 (1989) to April 25 (1970) at a mean water temperature of 0.5-8.0°C. The difference between the dates is up to 80 days. This is associated with the time of the ice breakup and clearing from the lagoon. The correlation is remarkably close (Fig. 5). The role of further temperature changes should be emphasized. A typical feature of the hydrological regime of the Vistula Lagoon is the unstable ice coverage; several ice breakups are observed in 50% of the cases in winter and spring (Sergeeva 1983). However, the arrival of the herring schools occurs only with the commencement of steady water heating. If a standard period for

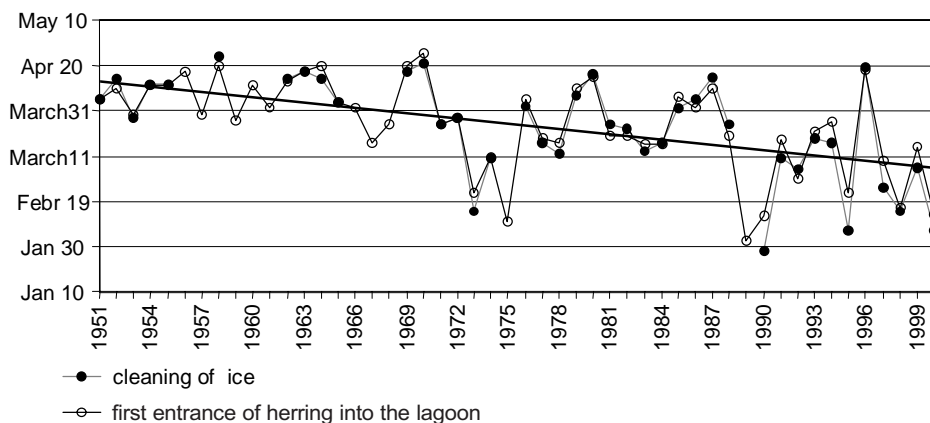


Fig. 5. Links between the dates of the herring first entrance into the lagoon and cleaning of ice ($r^2 = 96.0\%$, $p < 0.001$).

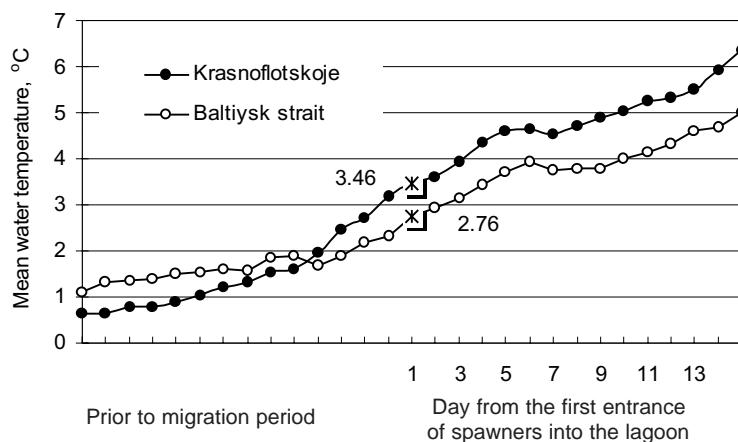


Fig. 6. Temperature conditions in the Baltiysk Strait and central part of the Vistula Lagoon (Krasnoflotskoje) at the beginning of the first spawning migration of herring into the lagoon.

the first herring school appearance in the Vistula Lagoon is considered, instead of specific dates, it is evident that it takes place from about a week after the water temperature in the lagoon permanently exceeds the temperature in the coastal zone. Owing to its shallow depths, the lagoon waters warm faster than the sea surface following increases in air temperature. This period is shown in Fig. 6 where the thermal conditions in the central part of the lagoon are described by Krasnoflotskoje data and those in the sea coastal zone by Baltiysk Strait data. The herring enter the spawning area as they move towards the water mass with the higher temperature.

Clearing the lagoon of ice is attributed to the severity of the preceding winter (Anon. 1971; Sergeeva 1983), and onset of herring reproduction processes shows a similar relationship ($r = 0.68$, $p < 0.05$).

Spawning pattern

The herring entering the spawning grounds in the Vistula Lagoon are in maturation stages III, IV, V (IV, V, VI on the Maier scale). The majority of reproductive fish constituting the earliest wave is not fully ripe and they require time in the lagoon to become fully mature before spawning (Fig. 7). When the ice breakup occurs late and there is a subsequent sharp increase in heating, large schools in approximately the running maturation stage “wait” for 5-15 days in the Baltiysk Strait area for suitable conditions (probably the clearing of the lagoon of ice). Spawning begins immediately when they enter the lagoon.

The mean water temperature at the beginning of mass herring spawning changes from 0.8 to 9.3°C (4.9°C, on average). The minimum water temperature corresponds to years with the earliest ice breakups, while the maximum is observed when the ice breakup is the latest and the rapid increase in air temperature causes intensive water warming before the clearing of lagoon ice.

The first schools of herring enter the Vistula Lagoon and stay for 0 to 30 days before the onset of mass spawning depending on water warming (Fig. 8). The interval of about 30 days which is observed only in the early spring at lower water temperatures may be considered as the maximum duration of the pre-spawning stay in the lagoon.

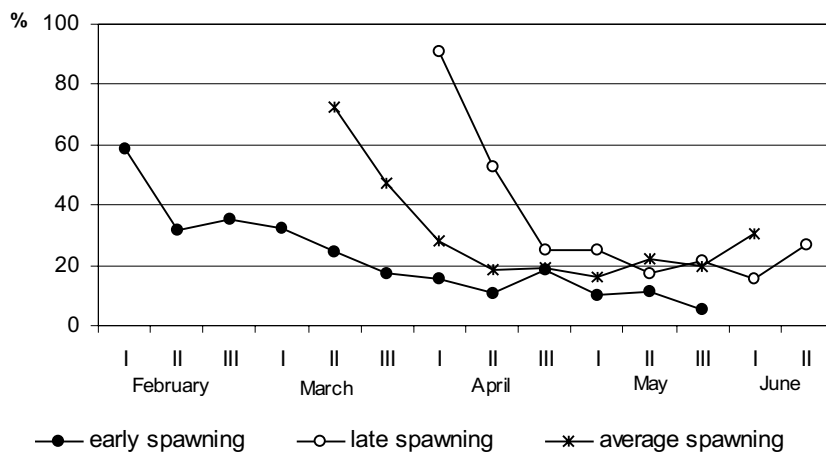


Fig. 7. Percentage of herring at maturity stages III, IV (IV and V of Maier scale) in the Vistula Lagoon. Changes by 10-day periods within the early, average and late spawning periods.

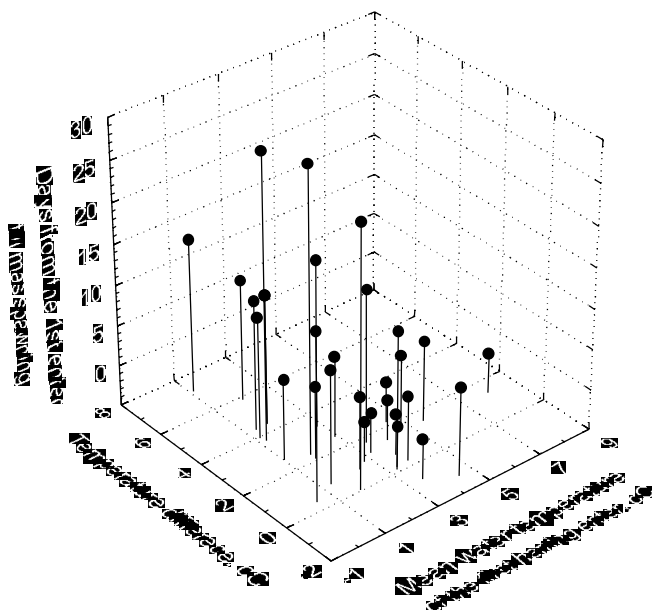


Fig. 8. Time interval between the first herring entering the Lagoon and the start of mass spawning in relation to thermal conditions – mean water temperature and temperature difference between both mentioned periods (1970-2000).

In general, herring arrive at spawning areas in “waves”. Older fish begin maturation earlier and reach the high stages of maturity more rapidly (Iles 1964); this is the reason for the trend of larger and older specimens dominating at the beginning of the spawning period. Changes in maturity stage ratios, CPUE and age composition of the schools during the late, early and average spawning season in the Vistula Lagoon are presented in Figs. 7, 9-10. Typically, three “waves” are observed. The first one consists of age groups 3 and older, three-year-old fishes

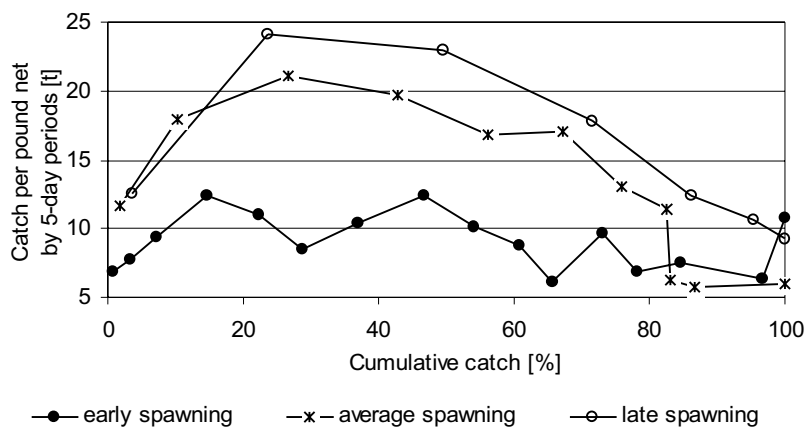


Fig. 9. CPUE dynamics within early, average and late herring spawning period in the Vistula Lagoon by 5-day periods in relation to the cumulative catch.

constitute the bulk of the second one and they often dominate throughout the spawning period. Age group 2 (recruits) spawning is usually observed later when water temperatures are higher (Tables 3, 4; Fig. 10). The available data suggest that the fish of the consecutive “waves” stay in the lagoon no longer than 5-10 days before migrating to the Baltic Sea immediately after spawning. In the case of early spawning onset, more than three “waves” can be detected. Less abundant schools gradually enter the lagoon at intervals of a few days, but the succession of age composition changes remains the same. In the case of late spawning, herring schools replace each other uninterruptedly (Fig. 9). As spawning progresses, the fishes undergo final maturation prior to entering the lagoon where spawning occurs continuously and the ripe stage dominates (Fig. 8). The size of fish within age groups usually decreases towards the end of breeding. Mean length values at ages 2 to 6 fall by 3.7-5.9% and mean weight values by 19.4 - 22.4%. Based on the long reproduction period and spatial distribution of herring schools as well as early larvae concentrations, it is assumed that repeated spawning occurs in the same locations at different times.

Long term trend in herring spawning time in the Vistula Lagoon

The trend towards more frequent mild winters and the early occurrence of spring, especially in the last decade, should be mentioned when studying the period since the 1950s. These climate changes effectively advance reproductive processes through both physiological and environmental conditions. A large proportion of fish spend the over-wintering season in stage III (IV on the Maier scale) (Iles 1964, Butskaja and Kuznietsov 1977). Higher temperature accelerate gonad growth and the achievement of a higher maturity stage. At the same time, mild winters cause ice to clear earlier and water warming to commence in the inshore spawning areas. A distinct shift towards an earlier herring spawning time (Figs. 11 and 12) at lower temperatures was observed in the Vistula Lagoon in spite of the positive trend of mean water temperature in spring (Figs. 13, Tab. 5).

The first half of the 1950s differ significantly from among the years under consideration. The annual catches in this period were at the highest level (Fig. 2, Table 5). The arrival of

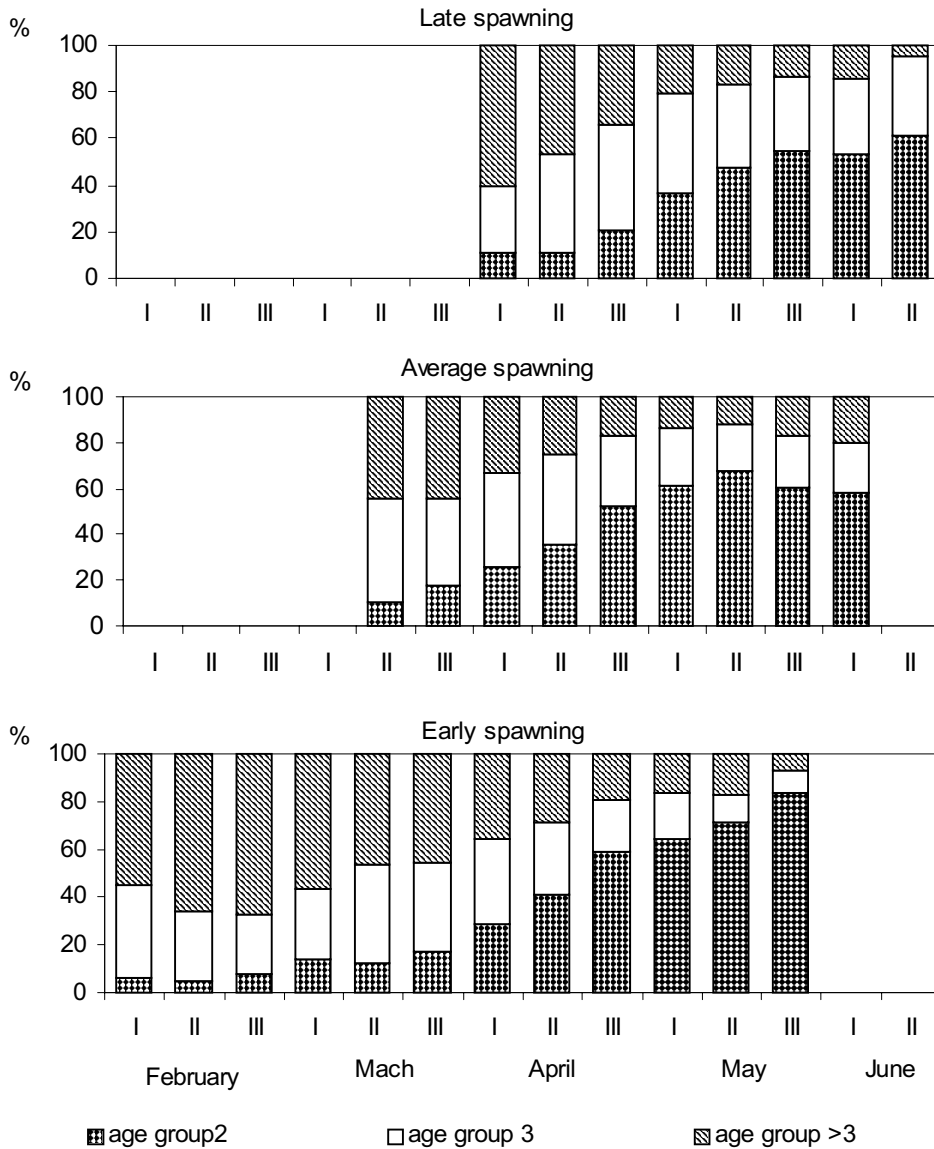


Fig. 10. Changes of herring age composition in the Vistula Lagoon by 10-day periods within the early, average and late spawning periods.

herring at the spawning grounds was observed later due to the late ice breakup in the Vistula Lagoon (Table 2). Further, a rapid increase in air temperature caused intensive water warming; thus the mean water temperature in the 1951-1954 spawning period (13.3°C) exceeded the average level (10.3°C). According to the current results, such thermal conditions cause mass herring spawning to begin immediately and occur continuously, despite herring schools replacing each other. The ripe stage dominates throughout the period which herring are present in the lagoon. In opposition to the first half of the 1950s, the average interval between the first spawn-

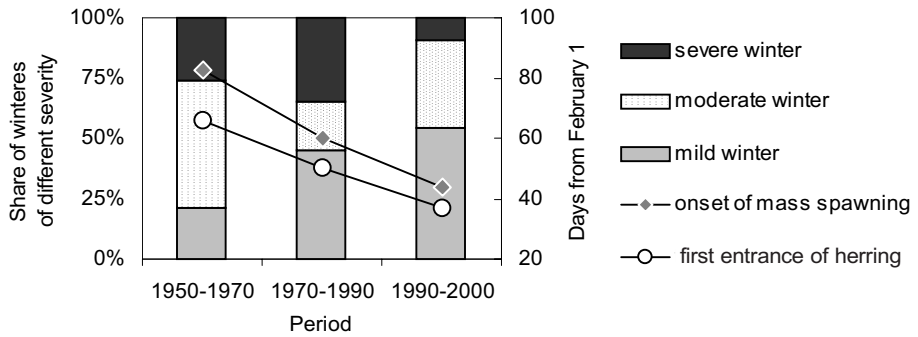


Fig. 11. Long-term changes in timing of the first spawning wave and herring mass spawning onset in the Vistula Lagoon by periods with different severity of previous winters.

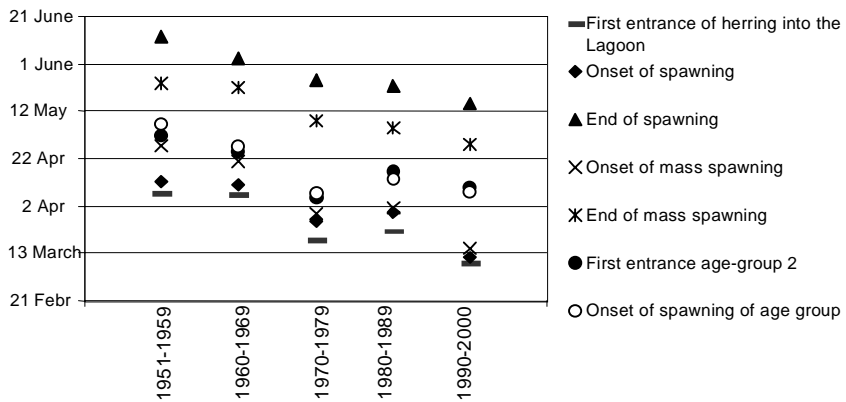


Fig. 12. Shift of herring reproduction timing in the Vistula Lagoon from 1951 to 2000 in 10-years periods.

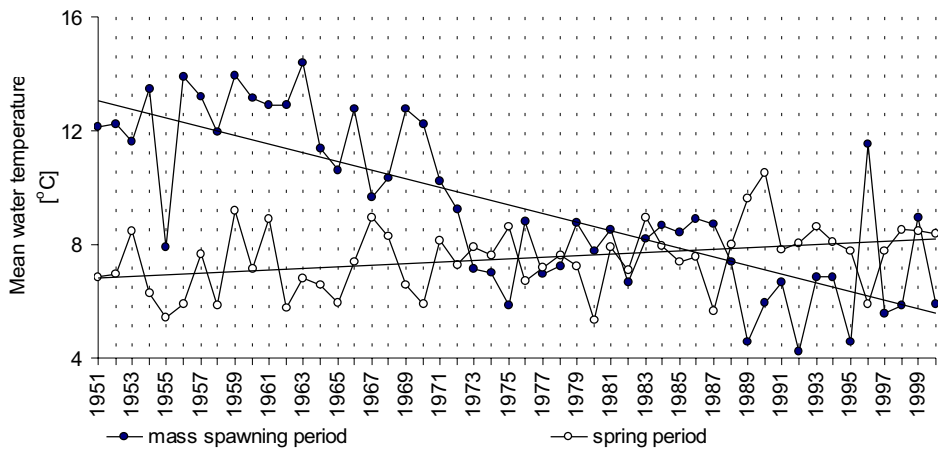


Fig. 13. Trends in the spring temperature conditions in the Vistula Lagoon and mean water temperature within the mass spawning period of herring ($r^2 = 16\%$, $p < 0.05$)

Table 6. Some characteristics of the herring spawning in the Vistula Lagoon in 1951-2000 by periods

Period	Mean water temperature during mass spawning [°C]	Interval between the first entrance and onset of mass spawning [days]	Duration of herring presence in the lagoon [days]	Share of mass spawning in total presence period [%]	Share of herring in pre-spawning stages [%]
1951-1954	12.4	20	81	32.3	51.9
1955-1959	12.2	19	65	43.8	41.5
1960-1969	12.1	14	64	48.3	30.6
1970-1979	8.4	11	69	55.8	19.0
1980-1989	7.8	8	67	49.2	21.7
1990-2000	6.6	9	75	59.1	15.7

ing “wave” and the onset of mass spawning was a maximum one. The share of herring in pre-spawning stages of maturity in the total catches reached more than 50%, on average, i.e. it was maximum as compared to other periods (Table 6), as if the large schools migrated into the lagoon and stayed there in pre-spawning condition for more than 30 days at water temperature corresponding to mass spawning during subsequent years. The mass spawning period constituted only 32.3% of the entire period that herring were in the lagoon, while in other periods under consideration it exceeded 44%. This scenario hardly seems probable, and it is very likely that much of the fish were subjected to heavy exploitation in the Russian part of the lagoon immediately after their arrival and prior to breeding. These speculations are supported by the previously cited differences between catch dynamics in the Russian and Polish parts of the Vistula Lagoon.

DISCUSSION

The presence of Baltic herring in the Vistula Lagoon has been documented since the earliest times (Filuk 1968), but according to Seletskaya (1956), catches of it were either insignificant or, in some cases, not recorded at all in the total catches. Only since the end of the 1920s has the mass influx of herring occurred. Evidently, the increase in water salinity from the 1920s, which occurred after a drain from one of the branches of the Vistula from the lagoon into the Gulf of Gdańsk was removed and the Baltiysk Strait was artificially deepened, created new ecological conditions which enhanced the intensity of the herring spawning migration into the lagoon. Thus, shallow water, rapid warming in spring, good aeration, high production and an acceptable salinity level became favorable to herring reproduction.

The present review indicates that there is high amplitude in the inter-annual variability of spawning timing of Baltic herring in the Vistula Lagoon within a wide range of environmental conditions and stock characteristics.

Berenbeim and Shapiro (1977) investigated the influence of environmental conditions on herring catches in the Vistula Lagoon during the 1950s and 1960s. They reported a positive correlation between the timing and duration of spawning and catch per pound net values. If the period until 2000 is considered, the results are different with regard to the influence of spawning stock levels. Environmental factors appear to have a prevalent effect on spawning timing.

The principal factors identified were the time of ice breakup and clearing ice from the lagoon, both of which are related to the severity of the preceding winter, further warming processes and water salinity values. The same dependence of spawning time on ice conditions was reported by Oulasvirta (1985), by Klinkhardt (1996) for Baltic herring as well as by Barton and Weststad (1980) for Bering Sea herring. Evtjukhova and Berzinsh (1983) documented the influence of the severity of the preceding winter on the herring spawning timing in the Gulf of Riga highlighting the role of temperature on maturation rate.

It was found that spawners move into the spawning ground in the Vistula Lagoon towards higher water temperatures. This supports the opinion that within the pre-spawning period higher temperatures are required to intensify metabolism to promote rapid gonad ripening and the onset of spawning (Krivobok and Tarkovskaja 1962). However, spawning might not follow immediately after the fishes reach physiological maturity, as spawning requires both physiological readiness and the appropriate ecological cues (Hay 1985). Thus, the role of local hydrological conditions should be emphasized especially in consideration of the fact that spring spawning coastal herring from the southeastern Baltic do not undertake long migrations during the summer feeding and over-wintering seasons (Birjukov 1956, 1970, Seletskaya 1961). Due to changes in mean water temperature just prior to the onset of spawning, there is an essential difference in the time between the stage when gonad growth is virtually completed and spawning itself begins. The results of the current observations show that the first schools of herring stay for 0 to 30 days before the onset of mass spawning depending on water warming.

It is commonly accepted that fish spawning is associated with water temperature, although the optimal range of this factor is rather wide (Haegele and Schweigert 1985). The temperature dependence of Baltic herring spawning is discussed by Berenbeim (1971) and Evtjukhova and Berzinsh (1983). Antonov (1964) developed some equations to forecast the spawning onset of some species, including the Baltic herring in the Vistula Lagoon. He used several complex indices of air and water thermal conditions in the Gulf of Gdańsk, Vistula Lagoon and Kaliningrad area. In all cases, the higher the temperature in winter and spring, the earlier spawning occurred and vice versa. The results presented here indicate that spawning at the earlier time occurs at lower temperatures of a rather wide range (Table 4).

Despite the inter-annual diversity of spawning time, abiotic conditions, stock size etc., a noticeable constancy was observed in spawning runs. Fluctuations of year class abundance primarily affect age composition as a whole. However, similar changes during the spawning period occurred in the age composition as well as in the ratio of maturity stages and the size at age of herring under different environmental conditions either when the total catch exceeded 16 000 t or when it was below 500 t. The type of spawning run described above appears to be common among herring populations; it was documented in Pacific herring (Spratt 1981, Haegele and Schweigert 1985) and in Atlantic herring (Blaxter and Holliday 1963). It has been reported in the Baltic Sea by Popiel (1955), Ranna (1970), Ojaveer (1988) and Klinkhardt (1996) for most local stocks.

Baltic herring exhibits a south to north cline in spawning times. The earliest spawning occurs in the southwestern and southern areas and lasts from March to May at a minimum water temperature of 4°C and a salinity of 4 psu (Klinkhardt 1996). In the northern part of the Hano Bight, spawning takes place during April-May at temperatures of 5.5-15°C (Elmer 1983). Evtjukhova and Berzinsh (1983) and Kornilovs (1994) reported the highest spawning activity in the Gulf of Riga from late May to early June at water temperatures of 9.5-16.9°C. In the Asko Archipelago (SD29), spawning dominates during May-June (Aneer 1989) at water temperatures of 4-15°C. Herring start to spawn in Finnish waters in May and spawning lasts until

mid summer at average water temperatures of 6-7°C (Oulasvirta *et al.* 1985). In the Bothnian Bay located in the northernmost part of the Baltic Sea, spawning begins one month later and sometimes takes place in July. The major spawning event occurs at water temperatures ranging from 3-4 to 15-16°C (6-7°C, on average). Berenbeim and Evtjuchova (1986) studied herring reproduction timing in different areas of the Baltic Sea under the assumption that they were functions of latitude. They argued it was possible to forecast the onset of spawning in the northern spawning grounds based on results obtained earlier in the southern areas. Hence, the above-mentioned shift to an earlier spawning time in the Vistula Lagoon must be reflected in other spawning areas of the Baltic Sea.

The current results suggested that repeated spawning in the Vistula Lagoon occurs in the same locations at different times. This concurs with observations made by Aneer (1983) in the northern Baltic proper, by Oulasvirta (1985) in the Gulf of Finland and by Kornilovs (1994) in the Gulf of Riga.

The spawning pattern causes year class variations particularly under such erratic conditions as those observed in the Vistula Lagoon in spring (Anon. 1971, Sergeeva 1983). It is likely that conditions within a protracted spawning period are so variable that occasionally only part of the season provides for high embryonic and larval survival. Thus, a prolonged and discrete spawning period ensures that either multiple cohorts or a successful one, whose development coincides with favorable conditions, contribute to recruitment (Cushing 1982).

Historical data on herring fishery in the Vistula Lagoon have shown the vulnerability of the spawning stock to heavy exploitation during the breeding period, and examples of clupeid collapse and the following stock recovery are well documented (Lasker 1985, Jakobsson 1985, Ojaveer 1988), although the reasons for such events are not always evident. High fishery mortality in the Vistula Lagoon in the 1950s caused recruitment failure by reducing the mass spawning time and the capture of a significant part of the spawners in the premature stages just before breeding. These types of changes in the spawning run coupled with high fishery pressure probably led to the decreased survival of embryonic stages (Birjukov and Shapiro 1971, Shapiro 1975), and caused a drastic decline of spring spawning coastal herring in the southeastern Baltic.

In consideration of the importance of this spawning area to herring and the real probability of overfishing during the spawning season, the catch value and number of pound nets in the Russian part of the Vistula Lagoon have been limited since the mid 1970s.

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Fecundity of walleye pollock (*Theragra chalcogramma* Pallas) from the southwest region of Kamchatka (Sea of Okhotsk)

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Abstract. This paper presents an estimate of the fecundity of walleye pollock from spawning grounds located off of the southwest coast of Kamchatka. The individual fecundity of females ranged from 67.7 to 724.5 thousand eggs, and was dependent principally on fork length and specimen weight. This dependence was described with regression equations: length – fecundity: $F = 0.27L^{3.5708}$; weight – fecundity: $F = 396.456W - 36255.7$.

Male walleye pollock reach 50% sexual maturity at a fork length of 33.5 cm, while females do so at a fork length of 37.4 cm.

When the results of the present walleye pollock fecundity studies conducted in 2000 were compared with previous results presented by other authors, it was confirmed that changes which occurred in the ecosystem of the northern region of the Sea of Okhotsk in the mid 1990s did not impact the fecundity of this species.

Key words: walleye pollock, *Theragra chalcogramma*, fecundity, Sea of Okhotsk, southwest Kamchatka.

INTRODUCTION

Walleye pollock inhabit the North Pacific and its adjacent seas from California to the Bering Sea, the Sea of Okhotsk, the Sea of Japan and Bay of Korea (Phillips 1942, 1943, Hart 1973, Bailey *et al.* 1999). Many walleye pollock spawning grounds are located in this vast region from the west coast of Canada and the USA (Pedersen and DiDonato 1982, Davis 1986, Matthews 1987, Palsson *et al.* 1997), where dense spawning concentrations of walleye pollock have been observed, to those in the Asian region of the North Pacific and its adjacent seas where Bakkala *et al.* (1986) identified 13 spawning grounds; two of them were located in the Sea of Okhotsk off of the west coast of Kamchatka and in the Bay of Terpeniya on the west coast of Sakhalin. Kitano (1972) reports that walleye pollock spawn from mid March to the end of May in the waters west of the Kamchatka region, while to the east of the peninsula they spawn from early April until the end of May. Kotenev *et al.* (1998) identified five walleye pollock spawning groups in the Sea of Okhotsk which differed as to the spawning place and time. Three of these groups spawned in winter, and two in spring.

Studies of the fecundity of walleye pollock have been conducted in every region where spawning grounds are located. As a result, the literature on this topic is quite rich. The bulk of the publications, however, refer to the fecundity of walleye pollock in the Bering Sea (Balykin 1986, Hinckley 1987, Teshima *et al.* 1989), the regions of the eastern Pacific (Thompson 1981, Mason 1985, Miller *et al.* 1986, Shaw and McFarlane 1986), and the Sea of Japan (Zverkova 1977, Kendall and Nakatani 1992, Hamatsu *et al.* 1993). Papers which address the reproduction and fecundity of walleye pollock from the region southwest of Kamchatka are few. Zverkova (1969) reports that this topic was discussed in the following publications: Kaganovskaja (1950) described the spawning process of walleye pollock in May and June; Rass (1953) investigated the distribution of spawn concentrations; Gorbunova (1954) analyzed the embryonic and post-embryonic development of walleye pollock, their spawning process and the distribution of eggs off the coast of Kamchatka. Zverkova (1987) also studied the spatial structure of spawning grounds in the northern areas of the Sea of Okhotsk.

Walleye pollock is one of the most intensely exploited fish species in the Sea of Okhotsk. As a result, the biomass of this species has fallen from 9 million tons in 1991-1994 (Janusz and Horbowy 1997) to 7.5 million ton in 1995 (Zverkova and Oktyabrski 1996). Later Russian research detected changes in the ecosystem of the northern parts of the Sea of Okhotsk (Shuntov 1998) which caused a rise in herring biomass at the cost of the walleye pollock biomass. The cause of these changes has yet to be identified.

The aim of this paper was to estimate the absolute fecundity of the walleye pollock found near the southwest region of Kamchatka based on materials collected during Polish commercial fishing conducted in 2000. This project was initiated in response to changes in the Sea of Okhotsk which occurred in the mid 1990s (Shuntov 1998) and intense fisheries pressure (about 1.8 million tons annually (Temnykh 1991) may have an impact on the fecundity of this species.

MATERIALS AND METHODS

The material used to study the fecundity of walleye pollock was collected during commercial fishing conducted by the m/t AMAREL from 11 February to 31 March 2000. Fork length measurements (rounding down to the nearest cm) were taken on a total of 16,835 specimens according to sex. Fork length is commonly applied by the Bering Sea Convention. A sample of 1,224 fish were selected from all the length classes for detailed biological analysis. Each fish was measured and weighed to the nearest 5 g, and the sex and gonad maturity stage, according to the eight-stage Maier scale (FAO, 1965), were estimated. The age of fish was determined from otoliths. From 8-14 March, 102 female gonads in maturity stage IV were collected and used to analyze individual fecundity. The gonads were frozen at a temperature of -35°C aboard the vessel, and then were defrosted in the laboratory following the cruise. The gonads were preserved in an 80% ethanol solution for 24 hours and then dried at a temperature of 42°C . The fecundity was estimated using the dry weight method (Brylińska and Bryliński 1972). The samples were weighed to the nearest 10^{-4} g, the eggs were counted and the number of them was calculated to the nearest 10^{-3} g for the whole of the dry mass of the gonad. The dependencies of fecundity on specimen characters (length, weight and age) mentioned above were described with the appropriate regression equations. The mutual correlation between these characters was determined using a multiple regression model.

Maturity ogives were determined for males and females separately based on the percentage of fish which reached sexual maturity in each length class. The dependency between length and the frequency of mature fish was described by the following logistic curve equation (Rickey 1995):

$$Y = \frac{1}{(1 + e^{-(a+bL)})}$$

where: Y – percentage of mature fish;

L – fish length (in cm);

a and b – equation coefficients;

from which, the fork length at which 50% of the fish reach sexual maturity was described with the equation (Seber 1982):

$$L_{50\%} = \frac{-a}{b}$$

RESULTS

In February and March 2000, walleye pollock formed dense pre-spawning concentrations off of the southwest coast of Kamchatka at depths from 450 to 520 m (Fig. 1). Individuals from 21 to 76 cm in length and from 2 to 23 years of age occurred in the samples. In February and March the female percentage of the catches was 61.4 and 63.9%, respectively. Approximately 75% of both male and female fish caught were aged from 5 to 7. The length distribution and age structure of the fish caught is presented in Fig. 2.

The systematic increase in the number of specimens with either maturing or mature gonads was observed between February and March. This was especially apparent in walleye pollock males; in February 67.0% of them had gonads in maturity stages IV and V, while 64.4% had gonads in stages V and VI in March. No females in maturity stage VI (spawning) were observed in the catches; however, there was a clear increase in the number of specimens with gonads in maturity stage IV from 44.5 to 71.5% (Fig. 3).

A close correlation between length and the frequency of mature fish as described by the logistic curve equation was found. The correlation coefficient (R^2) of these equations for males and females was 0.987 and 0.997, respectively. It was determined that 50% of the males were ready for spawning after they attained a length of 33.5 cm, while 50% of the females did so at a length of 37.4 cm (Fig. 4). The smallest mature males were 30 cm long and the smallest females were 33 cm long.

Absolute fecundity ranged from 67.7 to 724.5 thousand eggs and, in general, it increased with walleye pollock specimen length (Table 1), weight (Table 2) and age (Table 3). The regression equations that were devised for the various dependencies, including the correlation coefficients, can be found in Table 4.

The specimen weight-fecundity and age-fecundity dependencies were linear, while the length-fecundity dependence was expressed by a power function. The values of the coefficients of walleye pollock fecundity that were obtained indicated that it was most dependent on specimen weight, followed by fork length. The dependence between age and fecundity had a rather high correlation coefficient at $R^2 = 0.51$ (Table 5). However, the value of this result is lowered

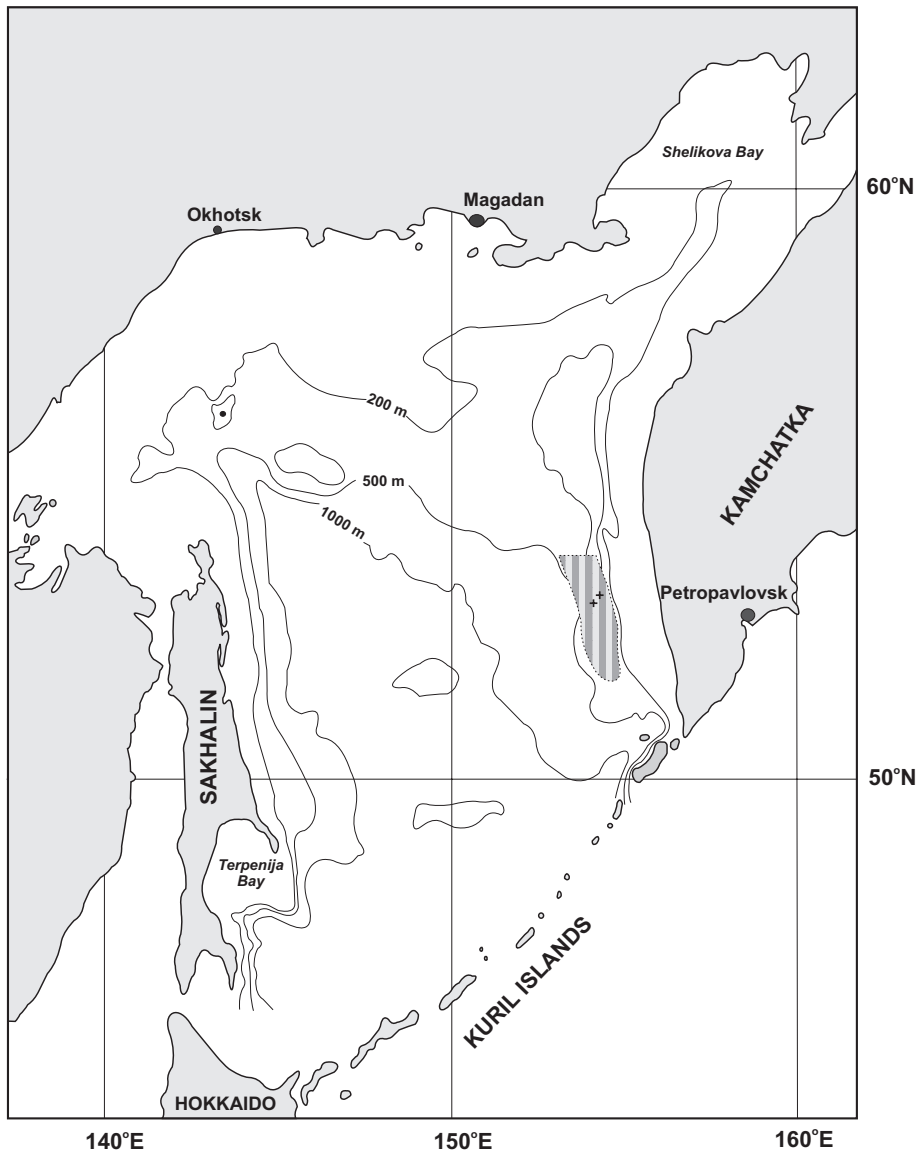


Fig. 1. Sea of Okhotsk. Walleye pollock study region in February and March 2000 (dotted line). Sites where samples for fecundity studies were collected (crosses).

by the fact that more than 77% of the studied gonads came from fish aged from 5 to 11 years, i.e. older fish were poorly represented (Table 4). The multiple regression model indicated that the value of the correlation coefficients calculated for the length-fecundity dependency ($R^2 = 0.85$) and for the specimen weight-fecundity dependency ($R^2 = 0.88$) were higher than the analogous age-fecundity dependence ($R^2 = 0.51$), which confirms the secondary importance of the influence of age on fecundity.

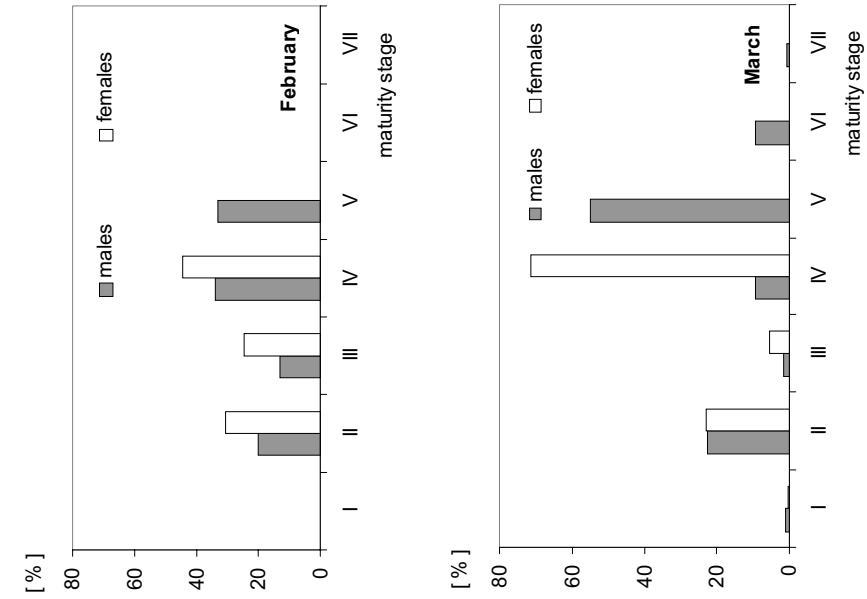


Fig. 3. Gonad maturity of walleye pollock males and females in February and March 2000 according to the Maier scale.

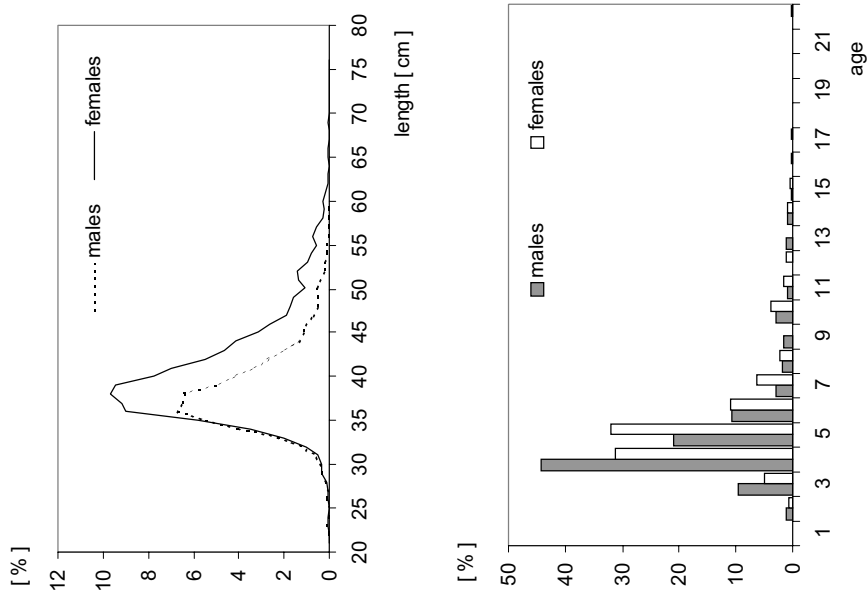


Fig. 2. Length distribution and age structure of walleye pollock males and females from the waters to the southwest of Kamchatka in February and March 2000.

Table 1. Walleye pollock fecundity by length classes (in thousands of eggs)

Length class [cm]	N	Range min–max	Average
35	2	67.7–67.8	67.7
36	1		71.8
37	1		132.7
38	5	54.3–110.2	96.7
39	7	87.9–156.0	129.1
40	6	105.9–184.2	136.0
41	6	55.4–188.0	120.8
42	6	106.4–220.2	156.0
43	5	135.5–206.8	180.2
44	5	92.4–327.5	177.5
45	3	79.0–193.6	137.6
46	6	191.0–292.1	245.8
47	6	239.0–321.8	282.8
48	4	239.7–311.2	274.7
49	7	220.7–370.9	293.8
50	4	246.9–410.7	351.3
51	3	285.3–352.9	315.7
52	2	406.7–492.3	449.5
53	5	344.0–477.5	424.0
54	4	452.9–563.2	484.8
55	2	263.7–390.6	327.1
56	2	360.2–516.0	438.1
57	3	424.3–550.0	482.6
58	2	450.2–564.8	507.5
59	3	527.7–688.3	630.9
62	1		675.3
66	1		724.5
Total	102		

Table 2. Walleye pollock fecundity by weight classes (in thousands of eggs)

Specimen weight class [cm]	N	Range min–max	Average
250–300	2	67.7–67.8	67.7
301–350	2	54.3–71.8	63.0
351–400	10	87.9–156.0	123.5
401–450	9	55.4–154.9	117.0
451–500	8	100.2–220.2	158.1
501–550	5	92.4–206.8	146.3
551–600	11	135.5–327.5	188.4
601–650	3	79.0–270.1	186.4
651–700	4	191.0–292.6	255.6
701–750	3	239.7–327.6	280.9
751–800	6	223.4–290.7	256.6
801–850	4	220.7–350.9	286.5
851–900	4	285.3–400.3	329.6
901–950	4	246.9–410.7	328.5
951–1000	2	370.9–399.1	385.0
1001–1050	5	344.0–492.3	391.2
1051–1100	3	263.7–477.5	402.9
1101–1150	4	424.3–516.0	462.1
1151–1200	1		471.9
1201–1250	3	427.8–563.2	488.1
1251–1300	1		390.6
1401–1450	1		550.0
1451–1500	2	450.2–676.7	563.5
1501–1550	1		564.8
> 1550	4	527.7–724.5	654.0
Total	102		

Table 3. Walleye pollock fecundity according by age groups (in thousands of eggs)

Age	N	Range min-max	Average
5	7	67.7–223.4	139.2
6	27	54.3–327.5	147.4
7	10	92.4–360.2	213.9
8	8	107.8–473.4	257.4
9	7	79.0–344.0	236.5
10	8	154.9–675.3	383.1
11	12	108.6–564.8	294.4
12	7	118.0–527.7	339.5
13	3	193.5–455.4	333.3
14	4	390.6–676.7	491.7
15	3	467.6–563.2	502.7
16	2	492.3–724.5	608.4
17	2	210.1–406.7	308.4
18	1		550.0
19			
20	1		688.3
Total	102		

Table 4. Correlation coefficient between selected specimen characters and absolute fecundity

Specimen character	Correlation equation	R ²
Fork length	$F = 0.27L^{3.5708}$	0.865
Specimen weight	$F = 396.456W - 36255.7$	0.881
Age	$F = 32954.0A - 33828.7$	0.510

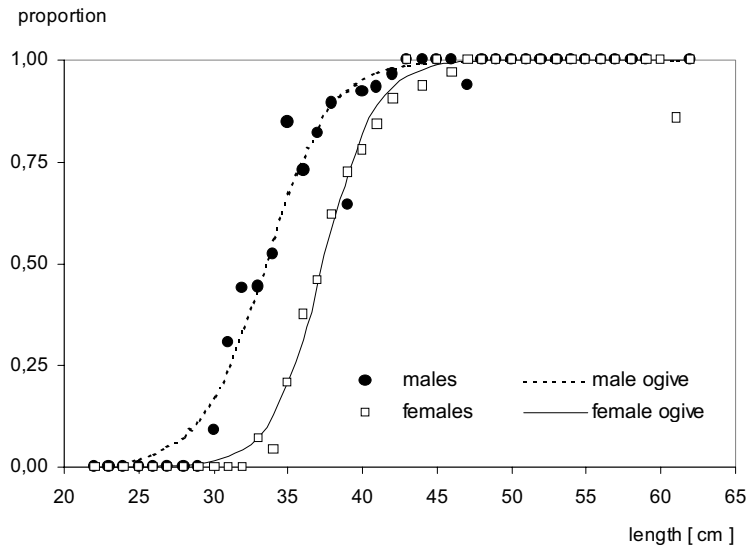


Fig. 4. Male and female walleye pollock maturity curves from empirical data.

DISCUSSION

Walleye pollock from the stock inhabiting the region southwest of Kamchatka spawn in batches from mid March to the end of May. Pre-spawning concentrations begin to form in late November and early December; they reach their maximum in late February and early March (Zverkova 1969). During this time, the walleye pollock gather in waters ranging from 400 to 500 m in depth (Fadeev 1995). As their gonads mature, they move from these depths to the spawning grounds located near the coast of Kamchatka at depths from 100-120 m. The data presented in this paper regarding the maturity stage of gonads are similar to those concerning pre-spawning walleye pollock concentrations presented in Gorbunova (1954) and Zverkova (1969). The spawning migration of walleye pollock in the waters of the Sea of Okhotsk (Fadeev 1995) explains the lack of mature females in the study region in February and March 2000.

The correlation between length and specimen weight and absolute fecundity is widely recognized and has been described by many authors for many species of fish. In publications concerning walleye pollock, authors have also paid particular attention to this subject and have developed an appropriate regression equation. The comparison of these dependencies with those of the walleye pollock population spawning in the Sea of Okhotsk off the southwestern coast of Kamchatka indicated that the latter were lower than those for walleye pollock from populations to the southeast of Kamchatka (Balykin 1986), in the Gulf of Alaska (Miller *et al.* 1986) and the Sea of Japan (Zverkova 1977). They were higher than those for the walleye pollock spawning in the central Bering Sea (Hinckley 1987). In comparison with the fecundity of the walleye pollock population spawning in the Kronotskiy Gulf (Balykin 1986), the fecundity of the present study population was higher for fish smaller than 52 cm in length and lower for longer fish. The opposite was noted for walleye pollock which spawn in the Aleutian Basin (Teshima *et al.* 1989) where fecundity was lower for fish measuring less than 46 cm in length and higher for larger fish (Fig. 5). Zverkova (1969) conducted fecundity studies of walleye pollock from the region to the southwest of Kamchatka; she reported the fecundity range of females measuring from 42 to 45 cm in length to be from 64 to 414 thousand eggs with an average of 198 thousand eggs per female. The results of the current study for analogous length classes showed a lower range (79-327 thousand eggs) and a lower average at 165.1 thousand eggs per female (Table 1). Since Zverkova (1969) did not provide a detailed description of the studied samples, it can be reservedly assumed that the results of her work are similar to those of the current study.

The length at which 50% of the fish achieve sexual maturity is a characteristic trait for a population being studied. This also indirectly indicates the age at which fish spawn for the first time. In comparison with results for walleye pollock populations inhabiting the North Pacific and its adjacent seas, it was determined that the fork length at which 50% of the males from the Sea of Okhotsk reach sexual maturity (33.5 cm) was lower than that of males from the spawning grounds off the coast of British Columbia where this figure ranged from 37.4 to 41.4 cm (Shaw and McFarlane 1986, Saunders *et al.* 1989). However, this figure was decidedly higher in comparison with data for males from the spawning grounds near the Strait of Georgia region which ranged from 27.1 to 32.1 cm (Shaw and McFarlane 1986, Shaw *et al.* 1986, Saunders *et al.* 1989). Similar results were obtained when data for the females was compared. In the spawning grounds off of British Columbia, 50% of the females attained sexual maturity at lengths of 38.8 to 43.5 cm (Shaw and McFarlane 1986, Saunders *et al.* 1989), and in the region of the Strait of Georgia this figure ranged from 30.2 to 35.6 cm (Shaw and McFarlane 1986, Shaw *et al.* 1986, Saunders *et al.* 1989). Females from the spawning grounds near the western region of

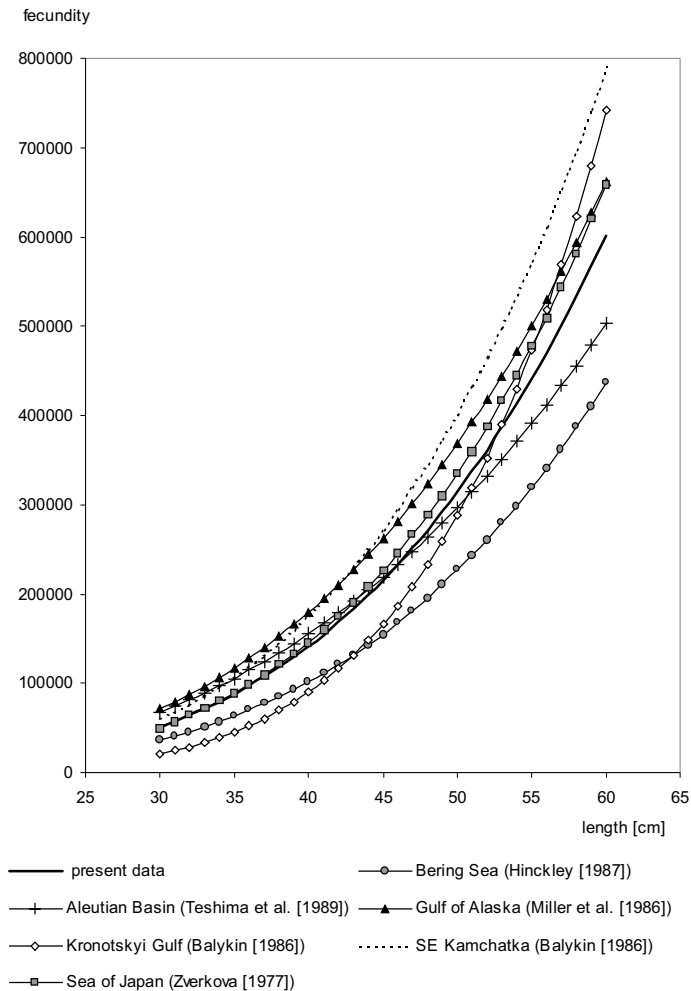


Fig. 5. Walleye pollock length-absolute maturity regression curves for selected regions of the North Pacific.

the Bering Sea and from the Kronotskiy Gulf were longer at 42.0 and 41.0 cm, respectively, when 50% of them achieved sexual maturity (Balykin 1986). In turn, the results of the current study were nearly identical with those recorded for females spawning off the eastern coast of Kamchatka at 37.0 cm (Balykin 1986).

The results presented by Shuntov (1998) indicate that in the mid 1990s a change occurred in the quality of the ecosystem of the northern region of the Sea of Okhotsk. The principal symptom of this was an increase in the biomass of herring at the cost of that of walleye pollock. Studies of the directions of walleye pollock migrations throughout the Sea of Okhotsk described by Fadeev (1995) and Kotenev *et al.* (1998) indicated that changes in patterns also affected the walleye pollock which spawn off the southwest coast of Kamchatka.

In light of the results of walleye pollock fecundity studies conducted in 2000 and those previously obtained by Zverkova (1969), it can be concluded that changes in the ecosystem of the Sea of Okhotsk has not affected the fecundity of walleye pollock.

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Evaluation of the chemical composition of fish oil: a by-product from fish processing plants

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Abstract. This study evaluated the chemical properties of fish oil derived from the fish processing industry. Its manufacturing technology was jointly developed by the Sea Fisheries Institute in Gdynia and Big-Fish Ltd. in Gniewino. The acid contents of this oil are as follows: unsaturated fatty acids – 82.72%; polyunsaturated fatty acids – 35.59%; omega-3 – 17.04%; Cl – 0.23%; Ca – 0.047. The following are also present (in mg/kg): Mg – 24.6; Na – 37.57; P – 51.8; Zn – 220; Fe – 15.33; Al – 14.43; Se – 7.62. Twenty other trace elements are found in this product. Vitamins are present in the following concentrations (in IU/g): A – 458; D₃ – 240; E – 1.21. The concentrations of organic chlorine pesticides, polychlorinated biphenyls and toxic metals (As, Cd, F, Hg, Pb) were within permissible ranges. This fish oil meets the general criteria for animal feed ingredients. It is, however, essential to determine its optimal nutritional rations.

Key words: fish oil, chemical composition, organic-inorganic contamination.

INTRODUCTION

Fish oil (FO) can be obtained from many species of marine fish. On an industrial scale, refined fish oil is produced from subcutaneous tissue and bones, whole fishes or muscular tissue and fish-liver oil (Bimbo and Crowther 1992). FO can also be gained from technological processes of consumption fish, i.e. from the thermal reflux from canned fish production (Konicka-Wocial *et al.* 1996). Therefore, the quality and chemical composition of fish oil may differ depending on the raw material used and the production technology.

Fish oil can also be used for preventive and therapeutic treatments (fish liver oil), as a food, in technical applications and as feed. The latter application could indirectly influence the quality of products of animal origin (milk, meat, eggs, fats), increasing the content of long-chain polyunsaturated fatty acids (L-PUFAs), mainly from the EPA and DHA families (Baer *et al.* 2001, Ponnampalam *et al.* 2001).

The aim of the study was to evaluate the chemical composition of the fish oils derived from the fish processing industry to determine whether the product meets the criteria for animal feed ingredients.

MATERIALS AND METHODS

Fish oil (FO) was derived from liquid by-products of the fish processing industry using technology developed by the Sea Fisheries Institute in Gdynia and Big-Fish Ltd. in Gniewino.

FO was obtained from protein and fat coagulates which are thickened using a special filtration press. The resulting products are fish oil, protein coagulate and wastewater. FO was then pasteurized at 70°C, and clarified mechanically in a centrifuge. To prevent oxidation processes, Termox Liquid F.G. (Kemin, Poland) was added in the amount of 1 l per 1000 l of oil. The resulting product was a clear, yellow oil with a density of 0.9 g/cm³, and a pH of approximately 5.2. Using this procedure, a typical fish processing factory is capable of producing approximately 800 l daily (Usydus and Bykowski 1998).

Laboratory analyses included:

- general physical and chemical properties;
- fatty acid composition;
- contents of elements (essential, trace, toxic);
- fat-soluble vitamins (A, D₃ and E);
- concentrations organic chlorine pesticides (OCP), polychlorinated biphenyls (PCB).

Analysis of the basic composition of FO was conducted using standard chemical methods in accordance with the AOAC (1990). The following parameters were determined:

- the color of the oil on the iodic scale;
- water content;
- acid number (AN);
- peroxide number (PN);
- petroleum benzene insoluble substances (PBIS) content;
- nitrogen content calculated as protein.

Standard laboratory procedures for evaluating feed fats were followed in compliance with standards NB -89/8186-01 and NB – 89/8189-07.

The fatty acids were determined using the classic gas chromatography method (Eder 1995) and a Philips chromatograph (type PU 4410) with a flame-ionization detector. An Rtx - 2330 column 105 m long – was used with Restek capillaries. The temperature in the spray chamber was 220°C, and in the detector it was 230°C. Helium (70 psi) was used as the carrier gas. All these tests were conducted in the analytical laboratories of the Agricultural University in Wrocław.

The contents of minerals and trace elements, including heavy metals, were determined by the ICP-MS method with a plasma spectrometer (Ultra Mass 700, Varian Australia Pty Ltd.). The mercury content was determined with an AMA-254 spectrometer, and an Orion Research EA-940 ion selective electrode was used to determine fluorine content. Samples were mineral-

ized using the microwave technique with an MDS-2000 (CEM) station according to the standard procedures of the Environmental Chemistry Laboratory (ICP certificate No. 01.04.15) for the Wrocław University of Technology (Górecka *et al.* 2001).

The levels of fat-soluble vitamins (A, D₃, E) were determined by particle chromatography using a liquid chromatograph HPLC (Merck/ Hitachi, type LaChrom HPLC Systeme) which was equipped with a fluorescence detector and a DAD (Diode Array Detector). This is the method applied in the Accredited Research Laboratory of the Sea Fisheries Institute in Gdynia (accreditation certificate No. L 17/4/99 conferred by the Polish Research and Certification Center) methodology instruction No. IM-24.

The levels of organic pesticides (OCPs) and polychlorinated biphenyls (PCBs) were determined using a method which was developed at the Accredited Research Laboratory at the Sea Fisheries Institute (research procedure No. PB-10). This method is based on extracting the compounds with hexane and then cleaning the extracts with sulfuric acid and 30% oleum. Capillary chromatography using a gas chromatograph (Fisons GC-8000, series 8160-00) with an electron capture detection was applied to analyze the compounds quantitatively.

The laboratory tests were conducted on fresh fish oil samples from several production runs ($n = 3.5$). Organic-chlorine contamination with OCPs and PCBs was analyzed in two series of tests ($n = 4.5$) due to the differences in the raw materials used to produce the oil. Additional tests of AN and PN were done for oil which had been stored for 30 days at an air temperature of 10-15°C without sunlight (normal storage conditions) or for 30 days at an air temperature of 21-26°C with sunlight (extreme storage conditions). In both tests the oil was stored in darkened containers made of a synthetic material.

The results were analyzed statistically using version 5.1 of the Statgraphics program.

RESULTS

Tables 1 and 2 present the results of the basic physical and chemical tests of fresh FO including color (on the iodine scale), water and protein content, PBIS content, acid number (AN) and peroxide number (PN). The last two indicators were also determined for FO which had been stored for 30 days under both normal and extreme climatic conditions.

The fatty acids content of FO is illustrated in Tables 3 and 4. Notice the high percentage of UFA (82.72%), including oleic (41.03%), linoleic (17.74%) and palmitic (11.74%). The

Table 1. Chemical characteristics of fish oil (FO)

Indicator	Unit	Mean \pm SD ($n = 5$)	Permissible value ^a
Color (iodine scale)	mg/100ml	84.5 \pm 14.6	up to 400
Water	%	0.4 \pm 0.33	up to 1.5
Acid number (AN)	mg KOH/g	18.5 \pm 7.8	up to 50
Peroxide number (PN)	meq O ₂ /kg	6.2 \pm 3.3	up to 20
Petroleum benzene insoluble substances (PBIS)	%	0.8 \pm 0.33	up to 1.5
Nitrogen (as protein, N x 6.25)	%	0.08 \pm 0.02	up to 2.0

^aaccording to industry standards NB-89/8186-01 and NB-89/8189-07

Table 2. Acid number (AN) and peroxide number (PN) of fish oil stored under different conditions

Indicator	Unit	Test I (<i>n</i> = 3)	Test II ^a (<i>n</i> = 3)	Test III ^b (<i>n</i> = 3)
		Fresh oil	Stored 30 days	Stored 30 days
AN	mg KOH/g	12.5	12.6	13.4
PN	meq O ₂ /kg	6.2	7.4	10.0

^astorage at air temp. 10-15°C without exposure to sunlight

^bstorage at air temp. 21-26°C with exposure to sunlight

Table 3. Fatty acids content (%) in fish oil (FO)

Fatty acid	Symbol	Mean (<i>n</i> = 3)	Range
Myristic	C ₁₄ : O	3.19	2.92-3.52
Myristoleic	C ₁₄ : 1	0.11	0.08-0.13
Pentadecanoic	C ₁₅ : O	0.20	0.16-0.22
Palmitic	C ₁₆ : O	11.74	10.66-12.04
Palmitoleic	C ₁₆ : 1 (<i>n</i> = 7)	2.14	1.96-2.32
Heptadecanoic	C ₁₇ : O	0.33	0.18-0.45
Margaric	C ₁₇ : 1	0.26	0.22-0.28
Stearic	C ₁₈ : O	1.82	1.66-2.02
Oleic	C ₁₈ : 1 (<i>n</i> = 9)	41.03	38.50-43.66
Vaccenic	C ₁₈ : 1 (<i>n</i> = 7)	1.95	1.69-2.33
Linoleic	C ₁₈ : 2 (<i>n</i> = 6)	17.74	17.02-19.11
γ-linolenic	C ₁₈ : 3 (<i>n</i> = 6)	0.29	0.26-0.32
α-linolenic	C ₁₈ : 3 (<i>n</i> = 3)	7.01	6.60-7.42
Eicosenoic	C ₂₀ : 1	1.64	1.59-1.69
Eicosadienoic	C ₂₀ : 2	0.29	0.24-0.33
Arachidonic	C ₂₀ : 4 (<i>n</i> = 6)	0.14	0.11-0.17
Eicosapentaenoic	C ₂₀ : 5 (<i>n</i> = 3)	3.98	3.59-4.36
Docosatetraenoic	C ₂₂ : 4 (<i>n</i> = 6)	0.08	0.06-0.10
Docosapentaenoic	C ₂₂ : 5 (<i>n</i> = 3)	0.17	0.14-0.22
Docosahexaenoic	C ₂₂ : 6 (<i>n</i> = 3)	5.88	4.96-6.84

content of EPA *n*-3 (omega) was 3.98%, and DHA *n*-3 was 5.88%, and total PUFA *n*-3 – 17.04%.

Tables 5 and 6 present the elemental composition of FO. The presence of 5 minerals and 25 trace elements was confirmed. Excluding Cl (0.23%) and Ca (0.047%), concentrations of Mg, Na and P as well as toxic elements (As, Cd, Hg, F i Pb) were all low.

The average values of fat-soluble vitamins were as follows (in IU/g of oil): A – 458; D₃ – 240; E – 1.21.

The results of OCP tests are presented in Table 7 and indicate that the concentrations of individual metabolites, i.e. DDD, DDE and DDMU, varied significantly. However, their sum (Σ DDT) did not exceed 0.35 in test I or 0.15 mg/kg in test II. The PCBs level was similar in both test series (Tab. 8) and did not exceed 0.20 mg/kg. Some congeners (for example, numbers 28, 52 and 180) occurred in very low concentrations (< 0.01 mg/kg).

Table 4. Characteristics of fatty acids in fish oil (FO)

Item	Percentage or ratio
Saturated fatty acids (SFA)	17.28%
Unsaturated fatty acids (UFA)	82.72%
Monounsaturated fatty acids (MUFA)	47.13%
Polyunsaturated fatty acids (PUFA)	35.59%
Total fatty acids	100%
PUFA/SFA	2.06
Omega - 6	18.25%
Omega - 3	17.04%
Omega - 6/ omega - 3	1.07

Table 5. Content of minerals and elements (mg/kg) in fish oil (FO)

Element	Symbol	Mean (<i>n</i> = 3)	Range
Mineral			
Calcium	Ca	465.70	416.3-500.5
Chlorine	Cl	2330.3	2060-2644.3
Magnesium	Mg	24.60	19.94-28.66
Sodium	Na	37.57	34.29-40.34
Phosphorous	P	51.80	47.25-60.33
Trace element			
Aluminum	Al	14.43	12.66-17.34
Barium	Ba	0.048	0.041-0.054
Chromium	Cr	7.27	6.94-7.58
Cobalt	Co	0.056	0.042-0.072
Copper	Cu	2.36	2.11-2.65
Iron	Fe	15.33	14.50-17.38
Manganese	Mn	12.84	9.93-15.42
Molybdenum	Mo	0.045	0.029-0.067
Nickel	Ni	< 0.005	< 0.005
Tin	Sn	< 0.005	< 0.005
Selenium	Se	7.62	6.35-9.21
Vanadium	V	1.68	1.59-1.74
Zinc	Zn	220.25	194.33-260.51
Other elements			
Silver	Ag	0.0573	0.0465-0.0692
Cesium	Cs	0.0002	0.0002
Indium	In	< 0.0005	< 0.0005
Lanthanum	La	0.0003	0.0002-0.0004
Niobium	Nb	0.0006	0.005-0.008
Platinum	Pt	0.0173	0.015-0.0214
Rhenium	Re	< 0.0005	< 0.0005
Antimony	Sb	0.0020	0.0016-0.0027
Tantalum	Ta	0.0187	0.0104-0.0325
Thallium	Tl	< 0.0005	< 0.0005
Tungsten	W	0.1493	0.0125-0.2037
Zirconium	Zr	0.0006	0.0004-0.0008

Table 6. Content of toxic elements (mg/kg) in fish oil (FO)

Element	Symbol	Mean (<i>n</i> = 3)	Range	Permissible content ^a
Arsenic	As	3.21	1.39-5.21	10
Cadmium	Cd	< 0.005	< 0.005	2.0
Fluorine	F	9.46	8.36-12.21	500
Mercury	Hg	0.045	0.029-0.062	0.5
Lead	Pb	< 0.005	< 0.005	10

^aaccording to the Council Directive No. 1999/29/EC

Table 7. Content (mg/kg) of organic chlorine pesticides (OCP) in fish oil (FO)

Pesticide or metabolite	Test I (<i>n</i> = 5)	Test II (<i>n</i> = 4)
α-HCH	0.0043 ± 0.0017	0.0035 ± 0.00006
HCB	0.0127 ± 0.0031	0.0110 ± 0.00012
β-HCH	0.0079 ± 0.00	0.0052 ± 0.00006
γ-HCH	0.0050 ± 0.0013	0.0064 ± 0.00006
heptachlorine	0.0018 ± 0.0004	0.0005 ± 0.00
pp'DDMU	0.0092 ± 0.0009	0.0005 ± 0.00012
pp'DDE	0.1740 ± 0.011	0.0834 ± 0.0027
pp'DDD	0.0880 ± 0.009	0.0038 ± 0.0017
pp'DDT	0.0350 ± 0.00	0.0230 ± 0.00042
Σ DDT	0.3379 ± 0.026	0.1373 ± 0.0048

Table 8. Content (mg/kg) of polychlorinated biphenyl (congeners) in fish oil (FO)

Congener	Test I (<i>n</i> = 5)	Test II (<i>n</i> = 5)
28	0.0027 ± 0.0002	0.0021 ± 0.00006
52	0.0082 ± 0.0003	0.0072 ± 0.0002
101	0.0293 ± 0.0014	0.0195 ± 0.0004
151	0.010 ± 0.0000	0.0058 ± 0.0002
118	0.027 ± 0.0003	0.0163 ± 0.0006
153	0.059 ± 0.005	0.0329 ± 0.001
138	0.051 ± 0.005	0.0249 ± 0.0009
180	0.0095 ± 0.0012	0.0042 ± 0.0001
Σ PCB ₈	0.1967 ± 0.0134	0.1129 ± 0.0035

DISCUSSION

The results of the basic physical and chemical tests on fresh FO indicate that all of the parameters such as color, water content, petroleum benzene insoluble substances (PBIS) and nitrogen (protein) were low and did not exceed permitted levels.

AN and PN, the most important parameters, both of which are indicators of impending hydrolytic, oxidative and polymeric transformations, also did not exceed the values prescribed by industry standards (NB 89/8186-01 and NB 89/8189-07).

The composition of FO was found to contain a high percentage of UFA (82.72%) and PUFA (35.59%). These FOs included fatty acids from the omega *n*-3 family and a beneficial *n*-6/*n*-3 ratio at 1.07. Ryś *et al.* (1998) reported that this ratio in Lyso fish oil was 0.1, while for mixed fish oil it was 0.16, which was the result of the high percentage of EPA *n*-3 and DHA *n*-3 acids.

Bakuła *et al.* (1999) reported a slightly different fatty acid composition for fish oil that is derived from thermal overflow during fish canning. These authors determined that 81.94% of the fatty acids were UFA, and that the levels of PUFA rose as high as 51.07%. This oil contained slightly less oleic acid, stearic acid, EPA and DHA, and had a higher AN value. The contents of palmitic and linoleic acids were similar. Values of these indicators will obviously vary as different marine, and even occasionally freshwater, fish are processed. Notable different fatty acids content was found in menhaden oil, where UFA was 68.23% and PUFA 45.04% (Judex *et al.* 2000).

The general composition of the fatty acids in FO seems to be nutritionally beneficial for feeding animals, especially with respect to the high values of *n*-3 PUFA.

Mineral compounds occur in FO. Chlorine (0.23%) and Ca (0.047%) are present in the largest amounts, while Mg, Na and P concentrations are considerably lower. Trace elements are present in the following amounts (in mg/kg): Zn – 220; Fe – 15; Mn – 12.84; Cu – 2.36; Se – 7.62; Al – 14.43; Cr – 7.27; V – 1.68; W – 0.149. Standards have been established for most of these elements in animal feed, as they play an important role in metabolic processes (Kabata-Pendias and Pendias 1999). The trace elements Ba, Co, Mo, Ag, Pt and Ta are below 0.10 mg/kg. The concentrations of the following were nearly below the sensitivity threshold of the detection method (0.005 mg/kg): Ni; Sn; Cs; In; La; Nb; Re; Sb; Tl; Zr. The biological role of most of these elements is still unknown. It should be mentioned that FO contains As, Cd, F, Hg and Pb. Cadmium and Pb, occurred at levels lower than 0.005 mg/kg. The remaining three elements did not pose any toxic threat according to the permissible levels described in Council Directive No. 1999/29/EC.

In general, FO is not a rich source of minerals, however, it can supplement some trace elements (Zn, Se) in the feed ration of livestock.

The contents of fat-soluble vitamins in FO were quite high. For the purpose of comparison, in 1 ml of cod liver oil there are 920 IU of vitamin A, 92 IU of vitamin D₃ and 0.28 IU of vitamin E. Even low dosages of FO would largely fulfil the daily requirement of ruminant and other animals for vitamin D₃ and to a lesser extent for vitamin A. Data from the literature (Anon. 1991) indicates that oil from dried fish contains other vitamins (mg/kg), choline (5000), vitamin B₁₂ (900), niacin (230), pantothenic acid (45), vitamin B₆ (10). It can be assumed that FO contains vitamins from the B group.

FO has been subjected to repeated chemical analyses to determine the levels of organic chlorine pesticides (OCP) and polychlorinated biphenyls (PCBs), as these are substances which are readily deposited in the fatty tissues of animals and which also pose a threat to human health. The total DDT did not exceed the permissible EU levels which were set by Council Directive No. 1999/29/EC; nor did the PCB level (8 congeners) exceed permissible levels. The sum of OCPs and PCBs did not exceed the permissible values set by the EU in Commission Decision No. 1999/449/EC.

In summary, fish oil feed is a good source of energy, fat and fat-soluble vitamins especially for monogastric animals. However, the challenge remains of determining the dosage to avoid a fish aftertaste in meat, fat, milk and eggs. This is a complex problem and research is

currently being conducted to determine the optimal dosage of both fish oil and meal for poultry, swine, cattle and sheep.

FO is currently being tested in the feed of broiler chickens, laying hens, dairy cows, growing-finishing pigs and sows in farrow. Some preliminary results are already in press (Korniewicz *et al.* 2002; Dobrzański *et al.* 2002).

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Length correction of larval and early-juvenile herring (*Clupea harengus* L.) and smelt (*Osmerus eperlanus* L.) after preservation in formalin and alcohol

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Abstract. The most significant changes in the length of larval and juvenile herring and smelt occurred after two days of preservation in 4% formaldehyde seawater solution. The larvae were then transferred to 96% alcohol, this was followed by additional shrinkage over the next eight days. The subsequent 90 days of preservation did not induce significant shrinkage. There were no differences in shrinkage between smelt and herring and the degree of shrinkage for both species was very much dependent on fish size, i.e. smaller specimens shrunk more (e.g. 12 mm *SL*: 8-18%) than larger ones (e.g. 28 mm *SL*: 0-2%). The live length of larvae and juveniles that were initially preserved in formalin and then transferred into alcohol can be back-calculated using an equation that describes the relationship between *SL* measured prior to and after 10 days of preservation ($SL_{\text{live}} = 0.910 SL_{\text{preserved}} + 2.695$; $n = 154$, $R^2 = 0.994$). This equation can be used for length correction of fish not larger than 30 mm in size when shrinkage is zero.

Key words: Shrinkage, herring, smelt, length correction.

INTRODUCTION

Larval and juvenile fish length measurements are used to calculate growth rate, condition, mortality, etc. However, one can expect considerable error in these estimates as a result of inaccurate length estimates due to shrinkage as high as 40% during fixation and preservation (Radtke 1989). It has already been shown that the degree of shrinkage depends on the type and strength of the preservative and specimen size and can vary depending on fish species (for review see Butler 1992, Fey 1999). Thus, any length correction should be made with formulas which take into consideration all these factors. The standard procedure for sample storage in many scientific groups and institutes worldwide is to preserve the samples in formalin onboard and to transfer them into alcohol after two to three days. Despite the significant number of papers regarding shrinkage that have already been published, there is no formula available to calculate the live length of larval smelt and herring preserved this way.

The goal of this study was to present a length correction formula, including preserved fish length as an independent variable, for larval and juvenile smelt and herring preserved for 100 days initially in 4% formaldehyde solution and transferred after two days into 96% alcohol.

MATERIALS AND METHODS

Larval and juvenile smelt and herring samples were collected between 15 and 29 May 2001 in the Polish part of the Vistula Lagoon, Baltic Sea using a neuston net with 2 m² opening and 500 µm mesh size. After 1-minute tows from a fishing boat sailing at a minimal speed (2-3 knots), the fish caught were placed in a cooler and transported to the harbor within ten minutes. Immediately after arriving at the harbor, the standard length, i.e. from the tip of the snout to the end of the notochord, of herring and smelt was measured to the nearest 0.1 mm with a pre-calibrated ocular micrometer; only live specimens were measured. Then, all the measured specimens were placed into separate vials filled with 4% formaldehyde seawater solution buffered with sodium borate to pH 8 to 9. After two days they were transferred to 96% ethyl alcohol. Fish length measurements were taken when they were transferred from the formalin to the alcohol, then 10 and 100 days after capture.

The shrinkage of larval and juvenile smelt and herring after two days of preservation was compared with that sustained after 10 and 100 days using the paired t-test (Zar 1984). The fish size-shrinkage magnitude relationship was described with a logarithmic function separately for smelt and herring and the slopes and intercepts were compared with ANCOVA (Zar 1984). The same statistics was used to compare the slopes and intercepts of regression lines which described the relationship between live and preserved length for both species.

RESULTS

The most significant changes in larval and juvenile herring and smelt length occurred within the first two days of preservation in formalin (Table 1). For both herring and smelt the increase in the percentage of shrinkage measured between the second day, when all the specimens were transferred from formalin into alcohol, and the tenth day after preservation was still statistically significant (paired t-test, $P < 0.001$). The additional 90 days of preservation did not induce additional shrinkage (paired t-test, *NS*) (Table 1).

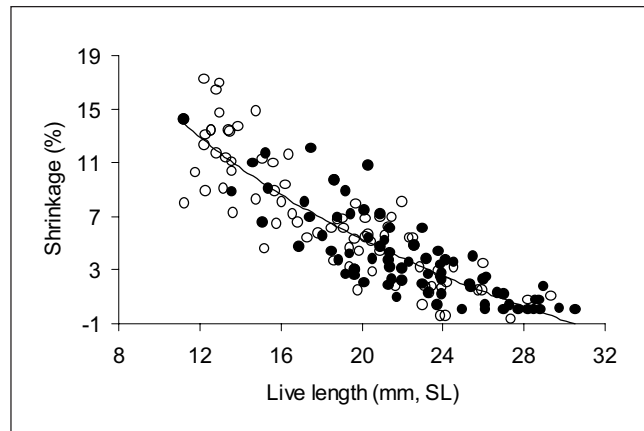
The amount of shrinkage was very much dependent on fish size; smaller specimens shrunk more (e.g. 12 mm *SL*: 8-18%) than larger ones (e.g. 28 mm *SL*: 0-2%) (Fig. 1). Thus, the differences in the average percentage of shrinkage between smelt and herring presented in Table 1 should not be used as an indication of interspecies variation since it was just the result of differences in size distribution between the two analyzed species. The shrinkage at fish length data were described separately for herring and smelt with logarithmic curves. Since there were no statistically significant differences in slopes or intercepts (after log-transformation) (ANCOVA, *NS*), one logarithmic curve was fitted to all the data pooled together (Fig. 1).

Table 1. Average percent shrinkage of larval and juvenile smelt and herring preserved initially with 4% formaldehyde seawater solution and transferred into 96% ethanol after two days of preservation

Species	<i>n</i>	Fish size [mm, <i>SL</i>]			Shrinkage [%]		
		average	min	max	2 days	10 days	100 days
Smelt	75	18.6	10.0	29.3	5.42	6.90	6.85 ^a
Herring	79	22.3	11.2	30.5	3.18	3.89	3.94 ^a

^aThe shrinkage increase/decrease between day 10 and 100 was not statistically significant (paired t-test, *NS*).

Fig 1. The effect of fish size on shrinkage magnitude after 10 days of preservation, initially in 4% formaldehyde seawater solution (two days) and then in alcohol (eight days), presented separately for larval smelt (open circles) and herring (closed circles). When all the data were pooled together, this relationship was described with a logarithmic equation ($y = -14.92 \ln x + 50.0$; $n = 154$, $R^2 = 0.762$).



The live length of larvae and juveniles that were initially preserved in formalin and then transferred to alcohol can be back-calculated using an equation describing the relationship between SL measured before and after 10 days of preservation. Here, as well, there were no statistically significant differences in slopes or intercepts (ANCOVA, NS) of regression lines fitted separately for herring and smelt. Finally, one linear equation was presented for the two analyzed species: $SL_{\text{live}} = 0.910 SL_{\text{preserved}} + 2.695$ ($n = 154$, $R^2 = 0.994$). The equation can be used for length correction of fish not larger than 30 mm in size when shrinkage is zero.

DISCUSSION

Most of the shrinkage took place during the first two days of preservation. This observation is concurrent with data presented by other authors who also report that the most shrinkage takes place during the first few days (Lockwood and Daly 1975, Fowler and Smith 1983, Fey 1999) or even hours (Farris 1963, Parker 1963, Rosenthal *et al.* 1978) of preservation.

The percentage of shrinkage decreases with increasing fish length; this was confirmed by this study, and was previously reported for herring (*Clupea harengus*) (Blaxter 1971, Hay 1981, 1982) and other fish species: *Pleuronectus americanus* (Hjörleifsson and Klein-MacPhee 1992); *Stizostedion vitreum* (Johnson and Mathias 1993); *Merluccius bilinearis* (Fowler and Smith 1993); *Gadus morhua* (Radtke and Waiwood 1980, Radtke 1989); *Sprattus sprattus* and *Enchelyopus cimbrius* (Fey 1999). This phenomenon is probably most closely related to the decrease in the water content of larval tissues as length increases (Ehrlich 1974). The fish size effect on shrinkage was the same for both analyzed species, and both smelt and herring shrank at the same rate. This probably resulted from the same body shape of the two species; it has already been shown that sprat, four-beard rockling and goby, fish larvae that have different types of body shape, exhibited a different degree of susceptibility to shrinkage due to preservation (Fey 1999).

Larval fish shrinkage can be a serious problem when studying the ecology and biology of early life stages of fish. It has been shown by Fey (1999) with sprat that preservation induced

shrinkage can be the cause of considerable growth rate over- or underestimation. Thus, length correction is necessary and can be done, for example, by using regression that describes the relationship between fresh length and otolith size (Leak 1986, Radtke 1989). However, it has been shown (Fey 1999) that higher accuracy is provided when the fresh length – preserved length relationship is used. Additionally, the otolith size – fish size relationship can be significantly affected by growth rate or temperature experienced by a given specimen (Fey 2001). Therefore, a linear equation describing the relationship between *SL* measured before and after 10 days of preservation is presented in this paper as a length correction method for early life stages of smelt and herring. It should be noted, however, that the equation was estimated for larvae which were alive prior to fixation. If the larvae were dead one should expect additional shrinkage related to damage while in the net. The degree of this shrinkage would depend on the duration and speed of the tow and the abundance of other planktonic organisms (Blaxter 1971, Theilacker 1980, Hay 1981, Jennings 1991).

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Growth, sex structure and commercial significance of turbot (*Scophthalmus maximus* L.) in the Lithuanian EEZ

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Abstract. The growth of turbot in length and weight is described using the modified von Bertalanffy equation on the basis of data obtained from back calculations. The study suggests differences in male and female growth rate in both length and weight. The rate of turbot length growth is the highest in age groups 1 and 2, while the difference between the male and female growth rate becomes more apparent in age group 3. The greatest weight increments of turbot females was observed in age group 8 and of males in age group 7. The range of turbot age groups caught in the 1998-2000 period was 1-16 for females and 1-11 for males. The amount of females in the coastal zone was on average from 1.4 to 1.9 times lower than that of males. Analysis of the turbot commercial catch age structure in different years showed a tendency towards a decline in the catch of fish from older age groups, females in particular. The CPUE index decreased from 20.3 kg per net in May 1995 to 2.1 kg per net in May 2001. Intensive turbot fishery in the coastal zone has influenced the abundance of juvenile fish.

Key words: turbot, growth, sex structure, catches, the Lithuanian EEZ.

INTRODUCTION

Turbot is one of the most valuable flatfish species in Lithuania. However, it is one of the least investigated Baltic fish species, and its name – *Rhombus*, *Scophthalmus*, *Psetta*, has been changed several times due to taxonomic disputes. The geographic range of turbot is rather wide, and it occurs in the European coastal waters of the Atlantic Ocean and in the Baltic and the Mediterranean seas. Turbot is abundant in the Lithuanian Baltic Sea coastal waters from April to July (Repechka *et al.* 1998).

Turbot biology has been most thoroughly studied in the North Sea. The relative proportions of turbot males and females from different ages groups in this area was studied by Rae and Devlin (1972). Studies on turbot growth in various areas of the North Sea were conducted by Mengi (1963), Rae and Devlin (1972), Jones (1974) and Leeuwen and Rijnsdorp (1986). The growth of Mediterranean Sea turbot was studied by Robert and Vianet (1988) and Vianet *et al.* (1989).

Baltic Sea turbot has not been extensively investigated, but the growth of turbot in the Polish EEZ has been addressed in several studies (Cieglewicz *et al.* 1969, Shlakowski 1990, Draganik *et al.* 1996).

There is little knowledge of the biology of turbot from Lithuanian waters. The previously mentioned study by Repechka *et al.* (1998) as well as that by Stankus and Repechka (1998) provided some data on the sex structure and growth of turbot. The influence of commercial pressure on the turbot population in the Lithuanian EEZ was examined by Draganik *et al.* (1996).

The present paper studies the growth and sex structure of turbot inhabiting the Lithuanian EEZ. The commercial significance of turbot and the influence of fishing on its population are also included.

MATERIAL AND METHODS

Turbot samples were taken from catches conducted in the coastal waters extending from Butinge to Juodkrante and in the open sea of the Lithuanian EEZ (Fig. 1).

The research material was collected in 1995 and in the 1998-2000 period from May to August. Nets with a mesh size of 50-125 mm were used for coastal fishing, whereas bottom trawling was used in the open sea. Juvenile fish were caught with a 30 meter-long and 1 m high beach seine equipped with a bag. The total length of all the turbot caught was measured to the nearest mm and their weight to the nearest g.

During the research period 4,125 turbot specimens were measured and sexed. Otoliths were used to determine the age structure of the turbot catches. The otoliths were taken from 720 individuals (259 females and 461 males) and stored in glycerine. The distance between the annual rings was determined using a computerized pictorial analysis technique. Otolith images were transferred to a computer with a YCH 15 video camera.

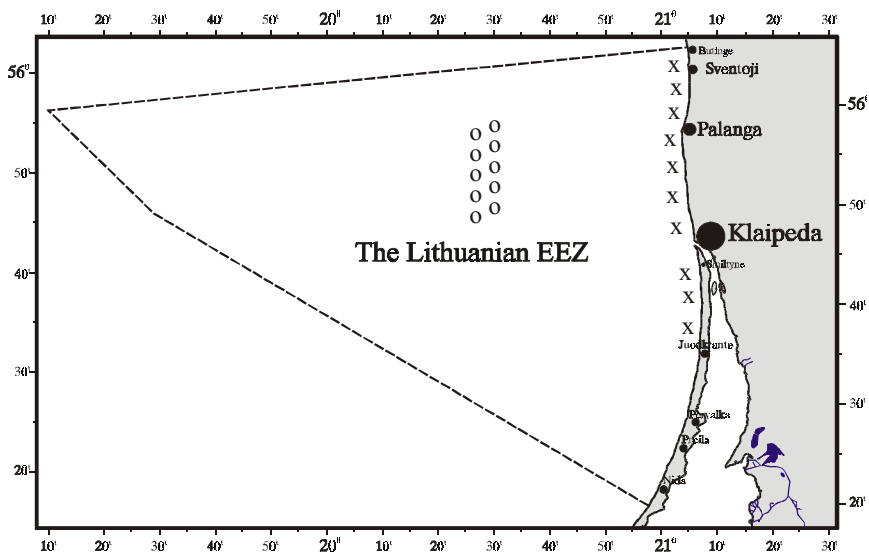


Fig. 1. Sampling areas for turbot in the Lithuanian EEZ (x indicates the coastal zone and o the open sea).

The modified von Bertalanffy equation was used to represent growth rate (Libosvarskij 1981):

$$L_t = L_{\infty} (1 - e^{-k(t-t_0)});$$

where:

L_t – fish length at age t , cm;

L_{∞} – asymptotic fish length, cm;

k – coefficient of growth rate decelerations;

t_0 – theoretical age at which fish length equals zero.

Parameters k and t_0 in the von Bertalanffy equation were obtained from the coordinate system $y = \ln(L_{\infty} - L_t)$ and $x = t$. The L_{∞} parameter was determined with linear regression used within the coordinate system $y = L_{t+1} - L_t$ and $x = L_t$ for points along the line above the inflexion point (Libosvarskij 1981).

The equation $W = aL^n$ was used to analyze the relation between turbot weight and length. Using the L_{∞} value for males and females in these equations, the corresponding W_{∞} values were obtained. The growth performance index $\phi' = 2 \log L_{\infty} + \log K$ was used to compare the growth differences between the sexes (Munro and Pauly 1983). Turbot age and growth rates were analysed for males and females separately.

RESULTS AND DISCUSSION

Growth in length and weight

The growth rate of turbot is the most rapid in the first two years of life. In the first year, females grew to an average length of 7.0 cm and in the second year they reached a length of 14.2 cm. The average length of age group 1 turbot males was 6.8 cm and that in age group 2 was 13.9 cm.

The difference in growth rates between the sexes of the youngest specimens (age groups 1 and 2) is not significant and was only 0.2–0.3 cm on average. A significant difference in total length was detected in age group 3 ($p < 0.01$). This difference becomes even more conspicuous later, and in age group 11 it reached an average of 11.1 cm ($p < 0.0001$).

The annual linear increment is the lowest in females from age groups 9 to 16 and was 1.5–0.9 cm per year. Male growth slows noticeably beginning with age group 6 reaching 1.9–0.9 cm per year. The life cycle of turbot males is shorter than that of females. The oldest males were from age group 11, and in the turbot caught in age groups 12 to 16 there were only females.

The von Bertalanffy equations for turbot in the Lithuanian EEZ are as follows:

for females $L_t = 53.5 (1 - e^{-0.186(t-0.28)})$;

for males $L_t = 35.0 (1 - e^{-0.301(t-0.35)})$.

The rate growth of turbot according to the von Bertalanffy equations is presented in Fig. 2.

Females had a lower growth coefficient (K) and a higher theoretical asymptotic length (L_{∞}) than males, although the growth performance indices were similar (females $\phi' = 2.726$, males $\phi' = 2.632$).

The linear growth of female and male turbot in the Baltic Sea in comparison with those from other range areas, i.e. the Mediterranean Sea (Vianet *et al.* 1989) and the North Sea

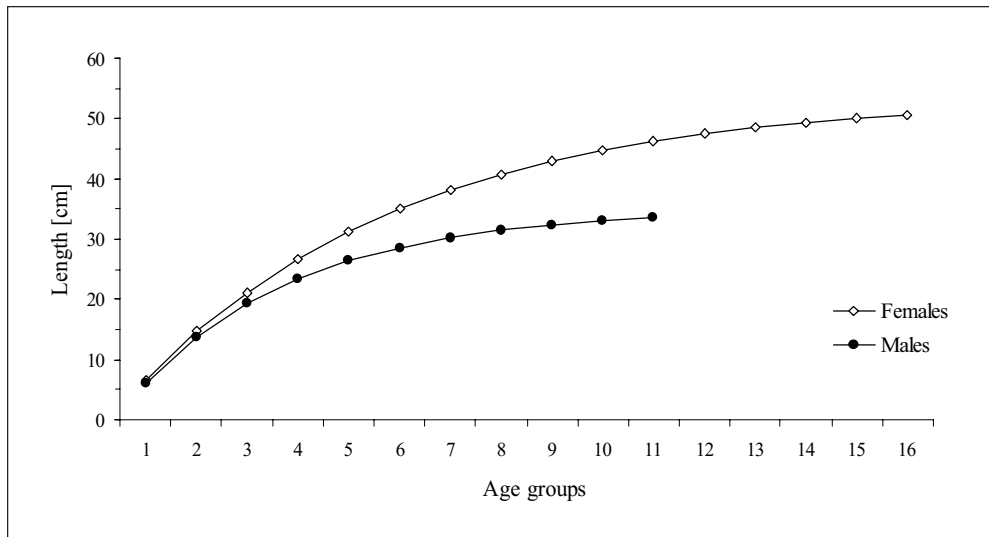


Fig. 2. Length at age growth curves of turbot males and females according to the von Bertalanffy equation.

(Mengi 1963), indicates that the growth rate of turbot in the Baltic Sea is the slowest. The difference in growth rate is already apparent in the first year of life.

These differences can be explained by the influence of environmental factors that affect fish metabolism such as temperature and salinity (Bougis 1976).

However, turbot from different ranges share common features, i.e. the male growth rates are slower and females outnumber males in the older age groups.

Weight growth, unlike length growth, culminates in the later years of life, and it begins increasing rapidly after turbot start to prey. The greatest increase in female weight is observed in age group 8 and in males in age group 4.

To describe weight growth with the modified von Bertalanffy equation, the relationship between total length and weight was estimated:

$$\text{for females } W = 0.00865 \cdot L^{3.2472} \quad (r = 0.981; p < 0.001);$$

$$\text{for males } W = 0.01195 \cdot L^{3.1175} \quad (r = 0.980; p < 0.001).$$

Then, modified von Bertalanffy equations were used to describe the weight growth of turbot in age groups:

$$\text{for females } W_t = 3538.9 (1 - e^{-0.186(t-0.28)})^{3.2472};$$

$$\text{for males } W_t = 777.9 (1 - e^{-0.301(t-0.35)})^{3.1175}.$$

Sex structure

The sex structure of the turbot spawning population depends on the fish age distribution. Males outnumbered females in the younger age groups, whereas females prevailed in the older groups. According to Repechka and others (1998), previously the difference between the maximum total length of males and females was slight. However, males with a total length exceeding 35 cm are currently found quite seldom due to the recent intensification of turbot fishery.

Apparently males are caught before they grow to their maximum total length, whereas in commercial catches females 50 cm or even longer occur quite often.

Turbot spawning time and duration depends on hydrometeorological factors, with water temperature being the most significant ($p < 0.001$). The migration process intensifies as water temperatures reach 9-10°C. At this time, an average of 2.9 turbot individuals are caught with a standard net. At water temperatures of 13.5-14.0°C the CPUE index increases seven-fold (21.3 individuals). The spawning migration towards the coastal sea zone begins in April and reaches its highest intensity at the end of May and in June.

Gonads from 1,169 females and 1,826 males were examined. Of the males, 12% became pubescent in their third year of life when they had reached a length of 18-19 cm. However, most (85%) of their gonads matured when their total length was about 21-24 cm (at the age of 4). Of the females, 7.3% reached sexual maturation by age group 4. In general, female maturation took place in the fifth year of life (92%) when their total length was 25-30 cm. The smallest fish with developed gonads was a 18 cm male and a 24 cm female. All the fish of both sexes ≥ 28 cm total length were mature.

In the 1998 catches in the Lithuanian coastal sea zone age group 5 females prevailed and constituted 40.7% of the number and 27.9% of the weight of all females. The most abundant among turbot males were age groups 5 and 6 which comprised 56.8% of the numbers and 59.4% of the weight of males. Males were dominant in the fraction of immature and younger specimens, while females prevailed in older age groups. The general sex ratio in the numbers of females to males was 1:1.4.

The turbot population structure in 1999 was similar. However, the amount of females caught from older age groups was smaller. The sex ratio in the numbers of females to males was 1:1.7.

In 2000, the fraction of immature females increased to 29.3% of the amount that was observed in the coastal sea zone. The sex ratio in the numbers of females to males was 1:1.9.

In general, the turbot age-frequency distributions were unimodal for both sexes in the 1998-2000 period. The catches were dominated by females from age groups 4 to 7 (67.2%) and males from age groups 3 to 7 (86.2%) (Fig. 3).

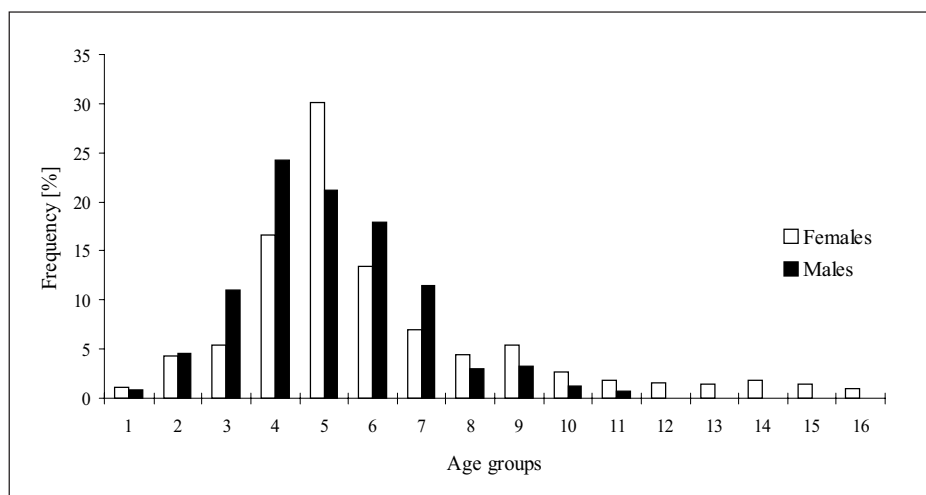


Fig. 3. Age-frequency distribution for females and males in 1998-2000.

Commercial significance of turbot in Lithuanian fishery

Turbot has been recorded as a separate species in Lithuanian fishing statistics since 1993. In that year, private companies fishing in the coastal zone of the Baltic Sea caught 443 kg of turbot. Since then, the amount of turbot catches has been increasing. The annual turbot catches were highest in 1996, afterwards they decreased and fluctuated from 22.1 to 62.0 t. By December 2001, only 14.0 t of turbot had been caught (Table 1).

Recently, the turbot catches in Lithuania have resembled those in Russia and Latvia despite the fact that they are less significant than in other countries.

Due to its low abundance in comparison with other species, turbot accounts for only 0.05-0.35% of the total annual catch by weight of Lithuanian fishermen in the Lithuanian EEZ.

During the monitored period turbot catches in the Lithuanian coastal zone significantly increased in April – May when the turbot migrate to the shore zone to feed before spawning. Although turbot catches in March were only several hundred kilos, in April they increased from 300 kg (in 1997) to 25 t (in 1996). In May of 1996 to 1999, turbot catches were the most considerable and fluctuated from 23 to 47 t. Turbot moves back to the open sea in August at the end of the spawning season. Consequently, turbot catches decrease to several hundred kilos. In autumn and winter, turbot is rarely caught in the coastal zone. After spawning concludes, in September - December the number of catches in the open sea increased. However, in comparison to the turbot catches in the coastal zone during the 1996-1999 period, they were not that significant and were from 2 to 10 times lower than those in the coastal zone.

As the intensity of turbot fishery increased, a decrease was observed in the length of the turbot caught. The amount of older fish caught, females in particular, also diminished. They are

Table 1. Annual commercial catches of turbot in the Lithuanian EEZ and CPUE indices near Palanga in May

Year	Catch [t]	CPUE index	
		[kg]	individuals
1993	0.4		
1994	5.0		
1995	15.0	20.3	24.6
1996	71.5	19.8	25.4
1997	59.3	15.4	20.3
1998	62.1	8.9	15.5
1999	57.6	5.1	11.2
2000	22.1	3.2	8.1
2001	14.0	2.1	5.4

Table 2. The length of turbot caught with nets of different mesh size in 1995 and 2000

Mesh size [mm]	Mean length [cm] and standard error		<i>t</i>	<i>p</i>	Number of fish	
	1995	2000			1995	2000
50	22.1 ± 0.56	21.7 ± 0.56	1.04	0.298	414	398
95	33.7 ± 0.92	29.0 ± 0.34	3.32	0.009	359	231
110	38.8 ± 0.72	34.3 ± 1.44	3.39	0.001	199	69
125	43.1 ± 0.49	37.9 ± 1.60	4.74	0.001	158	46

first caught during the spawning migration towards the coastal sea zone. In 1995, just after the commencement of specialized trout fishery, larger fish were found in commercial catches than in the hauls of the following years. The average length of the turbot caught in 1995 with different mesh size nets was 0.4-5.2 cm longer than the fish caught in 2000.

A close relation was noted between the net mesh size and the length of the turbot caught ($r = 0.94$; $p < 0.001$). The comparison of the average length of the turbot caught in 1995 and in 2000 with nets of different mesh size demonstrated that there is a significant difference in the length of the fish caught with 95, 110 and 125 mm mesh size nets. However, the difference in the length of turbot caught with 50 mm mesh size nets did not prove to be significant as nets of this type are used in fishing juveniles and immature fish of non-commercial size (Table 2).

The fishing effort (kg of fish per day with a 75 m long net) near Palanga also decreased. In May 1995, the CPUE index was 20.3 kg per net. In May 1998, the fishing effort fell to 8.9 kg per net. In the next year the CPUE index dropped to 5.1 kg per net and in May 2001 to 2.1 kg per net (Table 1).

Intensive turbot fishery in the coastal zone has affected the abundance of juvenile fish in age groups 1 and 2. In an area measuring 1,000 m² in 1998 and 1999, 1.8 and 1.4 turbot juveniles were fished, correspondingly. In 2000, a considerable increase in the amount of juvenile fish was noted. The total amount of juvenile fish caught in an area of 1,000 m² was three individuals. On the basis of this sharp rise in the amount of juvenile turbot in the coastal zone of Lithuania in 2000, it can be assumed that the turbot stock will increase in four to five years.

At present, Lithuanian turbot fishery regulations stipulate the temporary closure of fishing during the spawning period (1 June – 31 July) and a minimum landing size (30 cm).

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Food of common bream (*Abramis brama* L.) in the Szczecin Lagoon (Great Lagoon)

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Abstract. The diet of the smallest bream specimens (up to 9 cm *l.t.*) was dominated by zooplankton (about 70 % of food mass) and Ostracoda. Medium-sized specimens (10-19 cm *l.t.*) consumed zooplankton, Ostracoda, but also *Chironomus* larvae. The main diet component of fish longer than 19 cm *l.t.* was *Chironomus plumosus* larvae. On average, *Chironomus* larvae constituted 96% of the food mass consumed by bream from the commercially exploited stock (over 35 cm *l.t.*). The magnitude of the *Chironomus* larvae consumption index depended on their biomass in the benthos. The benthos of the coastal area played an accessory role in the diet of large common bream. The consumption index was, on average, two-fold higher during the vegetation season than outside of this period.

Key words: Baltic estuary, feeding conditions, food of bream.

INTRODUCTION

The Szczecin Lagoon is a key part of the Odra estuary, and despite its significant pollution and polytropy, it is a highly productive basin. The average salinity in the 1982-1998 vegetation seasons was 1.1‰. The shallowness of the lagoon (average depth – 3.8 m, maximum depth – 8 m) and its highly dynamic water masses promote good oxygenation of the entire water column extending even to the bottom (Wolnomiejski 1994, Poleszczuk *et al.* 1995).

The study was conducted in the Polish part of the lagoon known as the Great Lagoon, which has an area of 410 km² (excluding bays and straits). Over 55% of the Great Lagoon's bottom area (225 km²) is covered by muddy sediments that extend from the central part to the 3.5 m isobath near the coast. The macrobenthos of the muddy sediments is usually abundant. In 1982-1998, the average biomass of the total macrofauna was close to 60 g/m², of which *Chironomus f. l. plumosus* constituted 42 g, i. e. 70%. With its rich benthos and the good oxygenation of near-bottom water layers, the Great Lagoon offers good feeding conditions for large benthivorous bream. Common bream are a very important component of the ichthyofauna of both the Szczecin Lagoon and the entire Oder estuary. Bream from the commercially exploited stock makes the third largest contribution to the total mass of local Polish catches. The average annual catch of common bream in the 1982-1998 period was 10.5 kg per ha. The

statistical data regarding commercial catches of common bream in the Szczecin Lagoon do not fully reflect their actual, high number since these fish are of limited demand, or are simply unwanted.

The main aim of this paper, which was based on material collected over many years, was to determine the diet composition of bream of various length classes in relation to the area of occurrence, the abundance of the main dietary component of large bream, i.e. *Chironomus* larvae within or outside of the vegetation period. Particular attention was paid to how benthic organisms, especially pelophilous ones, were utilized.

MATERIALS AND METHODS

The fish used in this study were caught with bottom trawls. The coastal hauls were carried out diagonally towards the coastline from depths of 2-2.5 m to 4 m, i.e. through the shoal slope to the muddy bottom zone. It was presumed that fish caught in this area were free to choose their feeding area – either mud or the cohesive sand bottom of the lower littoral. Hauls in the central part of the lagoon were conducted on the muddy bottom at depths of 5-6 m and at a distance of not less than 1.5 km from the littoral limits. It was presumed that the spatial isolation from the coastal area significantly influenced the common bream dietary composition.

The fish used for analyses, or their digestive tracts alone, were preserved in 4% formalin. After being dried on blotting paper, the contents of the first section of the digestive tract were weighed to the nearest mg. This procedure facilitated calculating the contribution of particular dietary components. The food mass was determined from the consumption index, i.e. it was reconstructed using biomass standards, including the sizes of food organisms. The authors' own materials regarding fauna, which were collected in the Szczecin Lagoon, were used.

The vegetation season was considered to be from April to the end of October and the period from November to February was outside of the vegetation season. No catches were made in March. The majority of the material presented in this work was collected during vegetation seasons.

The results were derived from the analyses of fish caught in 65 hauls from 1982-1992 (excluding 1986) and 1998. About 30% of the fish used in the analyses had empty digestive tracts. Only 307 fish which had at least trace amounts of food in the first section of the digestive tract were used in the investigations. The methodological assumption that only feeding fish should be considered in the calculations was made because:

- almost all the common bream in poor condition (very thin) had empty digestive tracts and intense tapeworm infestations;
- all the common bream caught after storms, when the water salinity was relatively high and there were highly dynamic drift currents, had empty digestive tracts.

The total length (*l.t.*) of the studied common bream ranged from 5.7 to 60.5 cm and they weighed from 1.5 g to 3.12 kg. Four length classes were established - up to 9 cm, 10-19 cm, 20-35 cm, and over 35 cm. The length of 36 cm *l.t.* designated in this work as the lower limit for the largest length class was taken from the common bream legal limit of the 1980s (35 cm *l.t.*). Currently, the legal limit is 40 cm.

RESULTS

The majority of the food analyses were conducted on common bream which were caught in vegetation seasons (239 fish – almost 80% of the fish studied). The food spectrum and the structure of dietary components (percentage of food mass) of common bream from vegetation seasons are presented in Table 1. The consumption index did not vary significantly among common bream of different lengths and it was on average 116‰.

Zooplankton (mesoplankton) and, to a much lesser extent, Ostracoda, were the main food sources for the smallest common bream up to 9 cm *l.t.* These two components together com-

Table 1. Food spectrum and the structure of common bream dietary components (percentage of food mass) in the Great Lagoon during vegetation seasons

Diet components	Fish length classes (<i>l.t.</i>) in cm			
	up to 9	10–19	20–35	> 35
Fish	–	+	+	–
Phytoplankton	–	0.1	+	+
Zooplankton (mesoplankton)	69.7	38.6	2.5	0.9
<i>Neomysis vulgaris</i>	–	–	–	+
Pupae of <i>Chironomus</i>	–	0.4	4.5	0.4
Pupae of other Chironomidae	+	+	0.1	+
<i>Chironomus sp. (semireductus)</i>	–	–	1.0	+
<i>Glyptotendipes e.g. gripekoveni</i>	–	0.1	0.6	0.4
<i>Cladotanytarsus sp</i>	+	0.1	+	+
<i>Dicrotendipes gr. nervosus</i>	–	+	+	–
Other littoral Chironomidae	–	0.1	+	+
Polychaeta	–	–	0.5	–
Hirudinea	–	0.2	+	+
Gastropoda	–	–	0.1	+
Sphaeriidae	–	6.4	0.8	+
<i>Dreissena polymorpha</i>	–	–	2.5	+
Mollusca n.d.	–	–	0.1	–
Benthic Crustacea (<i>Gammarus, Corophium, Asellus</i>)	–	0.1	+	–
Other littoral forms	–	+	–	–
<i>Chironomus f.l. plumosus</i>	–	19.9	80.0	95.7
Oligochaeta (Tubificidae)	–	+	0.8	+
<i>Procladius spp.</i>	1.5	1.6	1.1	0.2
Other pelophilous Chironomidae	–	+	+	+
Ostracoda	28.8	29.5	4.2	0.3
Mud	–	+	0.6	1.7
Chironomidae n.d.	+	0.4	–	–
Other benthic forms	–	+	+	0.2
Thallophytic algae and macrophytes	–	–	0.1	+
Fish spawn	–	0.1	–	–
Land invertebrates	–	–	–	+
Undetermined remains	–	2.2	0.2	0.1
Number of fish analyzed	42	84	62	51
Average fish length (<i>l.t.</i>) [cm]	8.0	14.5	28	43.5
Average fish mass [g]	5.4	33	316	1191
Food mass per fish [mg]	66	354	3964	13156
Consumption index [‰]	122	107	125	110

+ less than 0.1%

prised 98.5% of the digestive tract contents. Only five of 30 identified components in the diet patterns were confirmed for this length class of common bream.

For bream in the 10-19 cm *l.t.* class, in addition to the basic diet components of zooplankton and Ostracoda, *Chironomus plumosus* larvae were the third most common component and constituted almost 20% of the mass of the digestive tract contents. Together these three components constituted almost 90% of the food mass. The dietary spectrum was much wider with 22 components found of the 30 identified in the pattern.

Chironomus plumosus larvae were the main diet component of common bream measuring 20-35 cm *l.t.* and constituted 80% of the food mass (they were supplemented by chironomid pupae at 4.5%). The other components can be classified as accessory and sporadic diet components. Common bream in this length class had the largest dietary spectrum with 25 components found of the 30 identified in the pattern.

The largest common bream (over 35 cm *l.t.*) were characterized by the domination of one principle component – *Chironomus plumosus* larvae (almost 96%). The other components were very insignificant, and the dietary spectrum included 22 components.

Over 90% of the food mass was comprised of two components for specimens up to 9 cm *l.t.*, four components for specimens 10-19 cm and 20-35 cm *l.t.* and one component for specimens over 35 *l.t.*

Considering the ecological aspects of the research, it should be underlined that common bream food composition and origin was found to be related to fish size (Table 1). As fish size increases, the contribution of planktonic forms (mainly mesoplankton) decreases, and the contribution of pelophilous *Chironomus plumosus* larvae increases. The accessory role of littoral benthos is also shown.

During periods outside of the vegetation season, only 68 bream individuals were caught. The consumption index value (57‰, on average) was two-fold lower than that in the vegetation season. In general, the structure of the diet diversity was very similar in both of these periods.

Insignificant differences in the food composition of specimens caught near the coast and in the central areas were only noted in common bream from the smallest length class. In both cases, zooplankton dominated the digestive tract contents. The differences were clear in common bream from the medium length class, 10-35 cm *l.t.* (Table 2). In coastal areas, littoral benthos (especially *Mollusca*) was an important food component of the common bream from this class. The contribution of littoral forms to the digestive tract contents was the same as that of *Chironomus plumosus* larvae. Of the *Mollusca* found, the most important were small *Sphaeriidae* and *Dreissena polymorpha*. In the central areas of the lagoon, *Chironomus plumosus* was the main diet component of medium-sized common bream. The consumption index of the fish from the central areas was 1.5 times higher, which is significant. Practically no differences in dietary composition were observed for the longest common bream, as *Chironomus plumosus* was basically the only component found in fish from both the coastal and central areas. However, the consumption index was higher in the central areas than in the coastal areas. The analysis of all the results, including spatial and temporal diversity, indicates that the contribution of *Chironomus plumosus* larvae to the food mass of common bream from the commercial stock (i.e. fish longer than 35 cm *l.t.*), was 94%, on average.

In years when the biomass of *Chironomus* larvae in the benthos differed, significant variations were observed in the degree of their consumption. This did not effect the smallest fish class, as they do not feed on these chironomids. This is illustrated in Figure 1. The higher

Table 2. Dietary structure of common bream (percentage of food mass) in coastal and central areas of the Great Lagoon

Dietary components	Common bream 10–35 cm <i>L.t.</i>		Common bream over 35 cm <i>L.t.</i>	
	coastal	central	coastal	central
Fish	–	+	–	–
Phytoplankton	+	0.1	–	–
Zooplankton (mesoplankton)	14.2	21.5	0.3	1.0
Neomysis	–	–	–	+
Pupae of <i>Chironomus</i>	2.7	2.5	0.9	0.2
Pupae of other Chironomidae	0.3	–	+	–
Total plankton organisms	17.2	24.1	1.2	1.2
Littoral Chironomidae	7.2	–	1.8	–
Mollusca	24.3	2.0	0.1	–
Other littoral forms	3.1	–	–	–
Total littoral benthos	34.5	2.0	1.9	–
<i>Chironomus plumosus</i>	32.5	52.6	94.7	96.0
Oligochaeta	+	0.5	+	+
Ostracoda	9.2	18.0	0.6	0.3
Other pelophilous forms	4.3	0.9	0.5	0.1
Mud	–	0.4	0.9	2.0
Total pelophilous benthos	46.0	72.4	96.7	98.4
Other benthic forms	1.7	–	+	+
Thallophytic algae and macrophytes	+	–	+	0.2
Other components and undetermined remains	0.5	1.4	0.1	0.2
Number of fish analyzed	30	116	15	36
Consumption index [‰]	79	125	86	119

+ less than 0.1%

abundance of larvae was especially apparent in the increase in the preying effectivity of medium-sized common bream. When *Chironomus* larvae were the least abundant in the benthos, the large common bream were relatively the most efficient in consuming them.

DISCUSSION

It is shown in this paper that small common bream are planktivorous and large bream are benthivorous. Such a hypothesis has already been presented by many researchers both in the field (Michelsen *et al.* 1994, Chłopnikow 1992) and in the laboratory (Winfield and Townsend 1988). The benthivory of large common bream has often been reported (Kozłowa and Panasienko 1977, Lammens and Hoogenboezem 1991), as well as their special predisposition to graze on Chironomidae larvae (Wielgosz 1989), mainly of the genus *Chironomus* (Taran 1964, Lammens and Hoogenboezem 1991). Thus, the results of this research mostly comply with those published

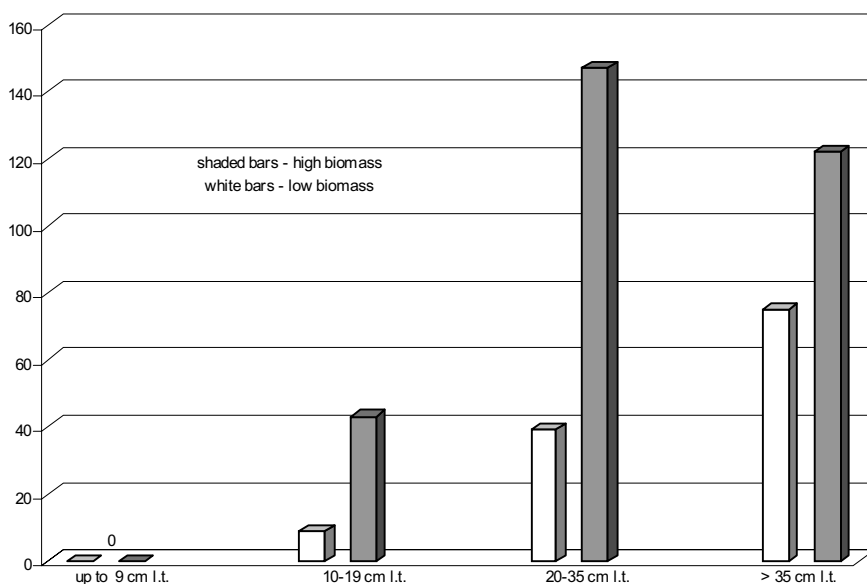


Fig. 1. Common bream consumption index of *Chironomus* larvae (o/ooo) in years when the larvae biomass in the benthos was low (17 gm/m² average) and high (60 g/m² average).

by other researchers. The greatest food selectivity was observed in small common bream towards zooplankton and large common bream towards *Chironomus plumosus* larvae. Medium-sized specimens had the widest diet spectrum. The similarity of diet composition of common bream of various sizes from the Szczecin Lagoon with those from the other two lagoons of the southern Baltic Sea, i.e. the Vistula Lagoon (Chłopnikow 1992) and the Curonian Lagoon (Kozłowa and Panasienko 1977) appears to be very important.

The issue of the role of benthic Oligochaeta in the common bream diet remains controversial. These invertebrates are abundant in the benthic habitats of the Szczecin Lagoon (Masłowski 1992, Wolnomiejski 1994). Despite their abundance, they were practically absent from the common bream diet. Chłopnikow (1992), Wielgosz and Tadjewska (1988) and Brabrand (1984) also noted the insignificant role of Oligochaeta in common bream feeding. However, Pliszka (1956) and Poddubny and Bakanow (1980) state that the role of Oligochaeta in the diet of fish is highly underestimated because they are digested rapidly. In the current study only small amounts of indigestible chaetes of Oligochaeta in the chyme were detected, even under high magnification. Thus, it seems to be reasonable to conclude that these organisms were not consumed on a large scale.

The significant role of Ostracoda in the diet of smaller common bream was confirmed in the Szczecin Lagoon. Szamardina (1967) and Brabrand (1984) also confirmed the significant, though smaller, contribution of Ostracoda in the diet of common bream.

The common bream's preference to feed in muddy bottom areas, and especially to consume relatively large and highly caloric *Chironomus* larvae, was also observed in specimens caught near the shore. According to Lammens (1984), this is connected with the specifics and functioning of the large common bream mouthpart, especially the branchial sieve, which is adapted to sieving larger benthic organisms from fine-grained muddy sediments. The coarse

grains found in coastal area bottoms makes this process difficult; this was confirmed by the aquarium experiments conducted by Lammens and Hoogenboezem (1991). Additionally, based on the analysis of specimens from coastal catches, the low dietary preference of common bream for Mollusca was confirmed. Similar conclusions were drawn for specimens from the Vistula Lagoon (Chłopnikow 1992) and the Włocławek Dam Reservoir (Kakareko in press). Nagelkerke and Sibbing (1996) theorize that the construction and functioning of the common bream feeding structures (size of pharyngeal jaws, masticatory force) explains the low dietary predisposition of this species for *Dreissena polymorpha* and other larger Mollusca. When there are usually high numbers of *Chironomus* larvae in vast areas of the lagoon's muddy bottom, even close to the shore, common bream only feed on the cohesive sediments of the lower littoral to a small extent, despite the fact that this zone is rich in food (Mollusca, Crustacea, Hirudinea, insects larvae, etc.). This data, in combination with data that indicates the insignificance of Oligochaeta in the common bream diet despite the large numbers of these invertebrates in the benthos, confirms that food selectivity cannot be attributed to either the abundance or availability of certain organisms, but also results from behavioral and anatomical fish adaptations.

The common bream from the Szczecin Lagoon exhibit a relatively high consumption of food outside of the vegetation season. Common bream feeding in the winter, albeit on a smaller scale, has also been observed by Chłopnikow (1992) in the Vistula Lagoon.

Ichthyofauna feeding is, however, not only a means of utilizing the basin's productive abilities, but it is also a process that influences other components of the biocenosis and the entire environment. A significantly higher *Chironomus plumosus* larvae consumption index was observed in years when their abundance was high as opposed to years when it was low (benthos abundance according to Wolnomiejski 1994 and to the authors' own unpublished data), which corresponds to data obtained by Lammens and Hoogenboezem (1991). When the primary diet component was more widely available, common bream appease their hunger faster. According to Wolnomiejski (1991), in years when *Chironomus* larvae were abundant in the benthos, the intensity of common bream feeding migrations decreased. This resulted in decreases in commercial catches carried out with set gear. Large common bream, which are highly specialized benthivorous fish, unlike small specimens, fed more effectively on *Chironomus* larvae when their biomass in the benthos was low.

Despite the fact that the Szczecin Lagoon is characterized by a significant abundance of benthos, especially in the vast areas covered by muddy sediments, food competition between benthivorous fish may occur. Since *Chironomus* larvae constituted almost the entire dietary mass of large common bream, these organisms are the best measure of benthos food resources, as is the degree to which they are used in the fish diet. Previous calculations (Wolnomiejski 1994) based on the annual food rations of common bream according to Kozłowa and Panasienko (1977), indicate that the common bream commercial stock in the Great Lagoon consumed an average of 6% of the net annual production of *Chironomus plumosus* larvae (i.e. biomass of 5,700 tons). This indicates that, on the scale of the entire basin, the energy exchange processes of ichthyofauna feeding are intense. However, negative results of food competition among facultative and obligatory benthivorous fish in the Szczecin Lagoon for which larvae of *Chironomus* are the basic or additional diet component are not a real threat (Wolnomiejski and Grygiel 1998). Food shortages may occur sporadically, i.e. in years when the average biomass of *Chironomus* larvae drops below 10 g/m². This has been observed by the authors as well as reported by other researchers (Wolnomiejski 1994). According to the authors' own unpublished data, since 1975 such a low biomass of *Chironomus* in the entire Great Lagoon was observed only once in 1987.

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INSTRUCTIONS FOR AUTHORS

GENERAL INFORMATION

The Bulletin of the Sea Fisheries Institute is a scientific journal which accepts papers from all over the world. Foreign authors are requested to submit their papers in English, the research staff of the SFI in Polish and authors not associated with the SFI in Polish and English.

Papers submitted to the *Bulletin* are classified according to the following three categories: 1) scientific papers, 2) short communications, 3) varia.

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Papers should be submitted in two copies of single-sided, double-spaced typescript on A4 paper and a diskette containing all the material in the article must be included. Words to be set in italic type, i.e. Latin names of species and genera, as well as symbols for the values of variables, should be underlined with a wavy line (~~~~~). No other underlining should be used.

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1. **Title:** brief (up to 100 characters).
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4. **Key words:** a few terms which enable a given paper to be found among computer files.
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6. **Acknowledgments** should be limited to the necessary minimum (the initials and the last name of the person they are addressed to, without listing scientific titles or names of institutions).
7. **References** should be put in alphabetical order, with the year of publication directly after the author's name and should list solely the papers referred to in the text. (e.g. Smith 1990). Titles of journals – in full form. Titles of papers – in the original language. The exception is titles in Russian which are in a non-Latin alphabet, such as Cyrillic, which should be translated into either English or Polish.

8. **Footnotes** should be marked with Arabic numerals in superscript (...¹), and numbered in succession throughout the text, except for tables; footnote content should be on separate sheets of paper.

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