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Fish biology

FEEDING OF HERRING AND SPRAT IN THE SOUTHERN BALTIC OVER 1971–1989

**ODŻYWIANIE SIĘ ŚLEDZIA I SZPROTA W POŁUDNIOWYM BAŁTYKU
W LATACH 1971–1989**

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The paper presents the results of studies on qualitative and quantitative characteristic of herring and sprat feeding in the Southern Baltic. Food amount and composition were established for the two species in relation to the season, fish size, and depth of fishing. The differences noted in particular stages of the study period (1971–1989) were also presented. Daily and annual food rations were determined, as well as stability and differentiation of herring and sprat food.

INTRODUCTION

Long-term studies on herring and sprat feeding were aimed at possibly precise estimation of the trophic status of the two species and of the degree into which they utilized the existing food resources. It was assumed that the results, as well as the data on growth, reproduction and migrations, would constitute the elements of a biological characteristic of the two species, the latter being necessary for establishing the appropriate level of their exploitation. In view of rapidly progressing pollution of the Baltic Sea, the studies could also show whether this phenomenon resulted in some noticeable changes in the quality and quantity of food consumed by herring and sprat.

Synthesis of the results of over 20-year studies has an additional advantage: in such a long period it is much easier to establish trends and tendencies of the relationships than in the case of the results obtained in one or even a few years. It is also possible to eliminate accidental results, untypical, which occur due to low or insufficient representativeness of the data obtained in shorter periods.

MATERIAL AND METHODS

The results were based on the analyses of the content of 22400 fish food tracts (14599 herrings and 7801 sprats). The fish were caught in the Southern Baltic in 1971–1989. Studies were carried out in four stages: 1971–1974, 1977–1979, 1980–1984 and 1986–1989. In the first stage majority of the fish were caught by research ships of the Sea Fisheries Institute in Gdynia. In the next stages more and more fish originated from commercial catches, this having a negative effect on representativeness of the data (especially as regards quantitative estimates). Detailed data on the numbers of fish caught in particular stages of the study are presented in Table 1.

Table 1

Materials collected

Stages	Species	Herring	Sprat
	1971–1974	3569	1033
	1977–1979	4124	2145
	1980–1984	4421	3134
	1986–1989	2485	1489
	Total	14599	7801

Amount and composition of the food consumed was determined estimating weight of particular components consumed daily by the fish in a given sample, and then calculating the so-called daily coefficient (ratio between weight of food consumed daily and fish weight). The results were listed according to the stage of the studies, season, fish size, and depth at which the fish were caught. Differentiation and stability of the food composition were also determined. Detailed description of the methods used has been given in the papers by Szypuła (1971, 1982, 1988) and Szypuła and Załachowski (1984). Standard weights of food components of herring and sprat were taken from Cislénko (1968), Chojnacki and Hussein (1983) and own measurements (unpubl. data).

Contrarily to previous papers on particular stages of the studies (Szypuła 1982, 1986, in print, Załachowski et al. 1976), in this paper orders were treated as separate components (although species dominating in the orders were also determined). This method of analysing the food composition allowed for synthetic determination of long-term tendencies and relations.

RESULTS

a) Herring

Two groups of components were distinguished in herring food: mesoplankton (*Copepoda*, *Cladocera*) and macroplankton with benthos (*Polychaeta*, *Mysidacea*, *Amphipoda*, *Decapoda*, *Cumacea*, *Chaetognatha*, *Pisces*). List of species belonging to these food components in herring is presented below.

1. <i>Copepoda</i> :	5. <i>Amphipoda</i> :
<i>Pseudocalanus elongatus</i>	<i>Pontoporeia femorata</i>
<i>Temora longicornis</i>	<i>Pontoporeia affinis</i>
<i>Acartia</i> sp.	<i>Hyperia galba</i>
<i>Oithona similis</i>	<i>Corophium</i> sp.
<i>Calanoida indeterminata</i>	<i>Gammarus</i> sp.
copepodit	
2. <i>Cladocera</i> :	6. <i>Decapoda</i> :
<i>Bosmina coregoni maritima</i>	<i>Crangon crangon</i>
<i>Podon</i> sp.	7. <i>Cumacea</i> .
<i>Evadne</i> sp.	<i>Diastylis rathkei</i>
3. <i>Polychaeta</i> :	8. <i>Chaetognatha</i> .
<i>Antinoella sarsi</i>	<i>Sagitta</i> sp.
4. <i>Mysidacea</i> :	9. <i>Pisces</i> :
<i>Mysis mixta</i>	<i>Gobiidae</i>
<i>Neomysis vulgaris</i>	<i>Ammodytidae</i>

Table 2 presents composition of herring food in particular stages of the studies. As regards general characteristic of food composition, attention should be paid to noticeably changing relations between the mesoplankton percentage and the percentage of macroplankton and benthos. In 1971–1974 the latter two groups were present at a more or less the same percentage (at unchanged percentage of the mesoplankton), while in the next two stages (especially in 1977–1979) mesoplankton dominated considerably. On the other hand, in the last stage of the studies (1986–1989) macroplankton and benthos dominated in herring food (over 60% of all the food consumed). However, data related to the whole period of the studies (1971–1989) showed that mesoplankton dominated in herring food (63.2%).

More detailed analysis of herring food showed that two components determined food of this fish: *Copepoda* (in which over 90% were represented by *Pseudocalanus elongatus* and *Temora longicornis*) and *Mysidacea* (with the domination of *Mysis mixta*; only in 1977–1979 one third of *Mysidacea* was represented by *Neomysis vulgaris*). The other food components played a marginal role; their highest percentage reached only 3.5% in herring food (*Polychaeta* in 1977–1979).

Table 2

The changes of herring food composition in particular stages

Stages Food components	1971—1974		1977—1979		1980—1984		1986—1989		Mean (1971—1989)	
	‰	%	‰	%	‰	%	‰	%	‰	%
<i>Copepoda</i>	78.68	52.9	59.59	91.8	35.06	76.9	18.49	40.1	47.95	62.8
<i>Cladocera</i>	0.82	0.6	0.12	0.2	0.35	0.8	0.05	0.1	0.33	0.4
Total mesozooplankton	79.50	53.5	59.71	92.0	35.41	77.7	18.54	40.2	48.28	63.2
<i>Polychaeta</i>	5.29	3.5	1.43	2.2	0.93	2.0	0.11	0.2	1.94	2.6
<i>Mysidacea</i>	60.97	41.0	3.39	5.2	7.71	16.9	25.43	55.1	24.37	31.9
<i>Amphipoda</i>	0.87	0.6	0.04	0.1	0.47	1.0	1.14	2.5	0.63	0.8
<i>Decapoda</i>	0.51	0.3	0.01	0.0	0.03	0.1	0.09	0.2	0.16	0.2
<i>Cumaca</i>	0.26	0.2	—	—	0.52	1.1	—	—	0.19	0.3
<i>Chaetognatha</i>	0.40	0.3	—	—	—	—	—	—	0.10	0.1
<i>Pisces</i>	0.89	0.6	0.32	0.5	0.54	1.2	0.83	1.8	0.65	0.9
Total macroplankton and benthos	69.19	46.5	5.19	8.0	10.20	22.3	27.60	59.8	28.04	36.8
Grand total	148.69	100.0	64.90	100.0	45.61	100.0	46.14	100.0	76.32	100.0
Relative annual ratio (in % of fish weight)	542.7		236.8		166.5		168.3		278.6	

Figure 1 presents the dependence of herring food on the season (A), herring size (B) and depth of catches (C), with attention given only to these food components which exceeded 5% in the given sample.

Fig. 1. The changes of herring food composition in relation to: season (A), body length (B) and depth capture (C); (1 - *Copepoda*, 2 - *Mysidacea*, 3 - *Polychaeta*, 4 - *Pisces*, 5 - others)

Seasonal variations of herring food were as follows: macroplankton dominated in winter together with benthos (almost 74%), in spring almost 95% were represented by mesoplankton (*Copepoda* almost exclusively) and this food component dominated also in summer (almost 87%), while macroplankton and benthos dominated in autumn (over 55%). Also in autumn *Polychaeta* were more frequent in the food (almost 6%). As regards the mesoplanktonic component, *Cladocera* were present almost exclusively in summer (in very small amounts). *Temora* dominated in this food component in summer and autumn, and *Pseudocalanus* in winter and spring.

Changes of food composition were followed in herring of different sizes. As a rule, percentage of macroplankton and benthos increased with the fish size, from almost 15% in the smallest fish (10.5–15.0 cm) to over 51% in the biggest ones (20.5–25.0 cm). Only two components were important for this relationship: *Copepoda* and *Mysidacea*. Share of other components did not exceed 5% and they were not included in Fig. 1B.

In general, variations of herring food with depth (Fig. 1C) consisted of increasing role of macroplankton and benthos with the depth. Food of herring caught in the shallowest waters (10–20 m) contained less than 25% of macroplankton and benthos, where over 14% were represented by *Mysidacea* and 10% by *Pisces*. As regards two other depths (30–40 and 50–60 m) percentages of macroplankton and benthos were higher (over and 39% respectively) and these were represented almost exclusively by *Mysidacea*. At the depth of 70–80 m percentages of macroplankton and benthos were slightly higher than at 50–60 m, but along with *Mysidacea* (over 30%) *Polychaeta* were also present (almost 8%). Finally, food of herring caught at the depth of 90–100 m contained considerably higher fraction of macroplankton and benthos (almost 88%), and *Pisces* appeared (over 5%) along with *Mysidacea* (over 79%).

Table 3 presents differentiation of herring food determined using the variation coefficient (Szypuła 1971). Herring food was most differentiated in 1971–1974 and 1986–1989, when the two basic food components (*Copepoda* and *Mysidacea*) played the same role. In other stages of the studies *Copepoda* dominated, and variation coefficient was noticeably lower (especially in 1977–1979).

Similar relations can be noticed with respect to season, fish size, and depth of catches. As regards the seasonal cycle, herring food was most differentiated in autumn, when *Copepoda* and *Mysidacea* played an almost identical role in the food composition. In spring, when *Copepoda* dominated noticeably (i.e. when the food was not much differentiated), value of the variation coefficient approached unity.

Food of bigger fish was more differentiated than of small fish, this being again caused by increased role of *Mysidacea*. Food of the smallest herring was predominated by *Copepoda*, and it was the least differentiated. As the fish grew, *Copepoda* and *Mysidacea* began to play similar roles in the food composition, and food was more differentiated (higher values of the coefficient).

Table 3

Food differentiation of herring expressed by the differentiation coefficient values

Stages	1971–1974	2.23
	1977–1979	1.18
	1980–1984	1.61
	1986–1989	2.15
Seasons	Winter	1.83
	Spring	1.10
	Summer	1.33
	Autumn	2.44
Length class (cm)	10.5–15.0	1.36
	15.5–20.0	1.66
	20.5–25.0	2.34
Depth (m)	10–20	1.68
	30–40	1.99
	50–60	2.06
	70–80	2.16
	90–100	1.55

Table 4

Stability of herring food composition (WS, RWS) in relation to: stage (A), season (B), body length (C) and depth of capture (D); n – number of examined samples

	n	WS	RWS (%)
A	4	3.467	82.2
B	4	3.070	69.0
C	3	2.800	90.0
D	5	4.103	77.6

It is interesting to follow changes in the food composition of herring caught at different depths. Food differentiation in the fish caught at 30–40, 50–60 and 70–80 m was very similar due to almost identical relations between *Copepoda* and *Mysidacea*. In the shallowest and the deepest waters, food was less differentiated due to considerable domination of *Copepoda* at 10–20 m, and even more pronounced domination of *Mysidacea* in the food of herring caught at 90–100 m.

Data related to stability of herring food are presented using the stability index (WS) and the relative stability index (RWS). They are given in Table 4. These indices were

Fig. 2. The changes of herring feeding intensity in relation to: season (A), body length (B) and depth of capture (C)

supposed to show which of the factors under study had the strongest effect on herring food. As results from Table 4, composition of herring food dependend most significantly on the season (the lowest RWS value), while fish size was the least important.

Another important problem with respect to herring feeding was the intensity of food uptake. An attempt was made to determine the relation between the intensity of food consumption and the season, the fish size, and the depth of fishing. In the latter case, intensity of feeding was determined using the index of consumption (ratio between food weight and fish weight), while in the case of the first two relations, daily coefficients were used. This was due to the fact that it was not possible to determine precisely water temperatures at the given depths, and these to a large extent affect values of daily coefficients. In addition to this, intensity of feeding in 1971–1974 was not determined due to the fact that the method of estimating food evacuation time (necessary to calculate daily coefficients) had not been worked out yet (Szypuła, Załachowski 1984), while calculations related to daily and annual food consumption in this period had been made only in a general aspect (Załachowski et al. 1976), with no attention paid to the effect of the mentioned factors.

Seasonal variations in the intensity of herring feeding in particular stages of the studies, and their average level in 1977–1989, are presented in Fig. 2A. In the first two stages (1977–1979 and 1980–1984) variations in the feeding intensity were very similar: the lowest values were noted in winter, then feeding intensity increased in spring and summer (peak of feeding intensity in summer), and in autumn the daily coefficients decreased to the level similar to or slightly lower than in spring, but higher than in winter. This trend was confirmed by the average results for the whole period of the studies. However, in the last stage of the studies (1985–1989), this relation was different: minimal values of the daily coefficient were noted in spring, maximal in autumn. Taking into account seasonal variations of the daily coefficients for the whole period of the studies, it can be stated that the maximal (summer) values were 4 times higher than the minimal (winter) ones.

Dependence between feeding intensity and herring size (Fig. 2B) can be summarized by stating that feeding intensity increased slightly with the fish size. Only in 1980–1984 average-sized herring (15.5–20.0 cm) fed most intensively, while the biggest fish (20.5–25.0 cm) the least. Differences in feeding intensity were much lower between fish of different sizes than between the seasons.

Finally, differences in feeding intensity of herring at different depths were also small (Fig. 2C). Average results revealed small variations of the consumption index (higher values at the depths 10–20, 50–60, and 90–100 m, lower at 30–40 and 70–80 m). Slightly more pronounced variations were noted in the case of the values calculated for particular stages at the depths of 70–80 and 90–100 m (noticeable decrease in 1980–1984, and considerable increase in 1986–1989). Generally, variations in the feeding intensity at particular depths were only slightly greater than the differences related to fish size.

Table 5

The changes of sprat food composition in particular stages

Stages Food components	1971–1974		1977–1979		1980–1984		1986–1989		Mean (1971–1989)	
	‰	%	‰	%	‰	%	‰	%	‰	%
<i>Copepoda</i>	105.30	97.1	135.52	98.9	119.63	96.9	112.21	98.6	118.16	97.9
<i>Cladocera</i>	3.13	2.9	1.48	1.1	3.79	3.1	1.64	1.4	2.51	2.1
Total	108.43	100.0	137.00	100.0	123.42	100.0	113.85	100.0	120.67	100.0
Relative annual ratio (in % of fish weight)	395.8		500.0		450.5		415.5		440.5	

Summing up the results on the intensity of food consumption by herring, it may be stated that the effect of the factors under study was similar as in the case of food composition. Feeding intensity was most strongly related to the season, and the least related to the fish size.

b) Sprat

Practically all zooplanktonic organisms (*Copepoda*, *Cladocera*) constituted the components of sprat food. The same species represented these components as those found in the mesoplanktonic fraction of herring food. Only in the first two stages of the studies, minimal amounts (below 0.05%) of small *Mysis mixta* were found in sprat food. Differences in sprat food compared with the mesoplanktonic fraction of herring food consisted of higher percentage of *Acartia* (over 5%) and *Cladocera* (over 2%). Percentage of these species in herring food did not exceed a fraction of one per cent. Nevertheless, main items of sprat food were represented by the same two species as in the mesoplanktonic fraction of herring food, although *Temora longicornis* was slightly more important.

Quantity and composition of sprat food in particular stages and in the whole period of the studies are presented in Table 5. As can be seen, food of sprat was composed of *Copepoda* exclusively, and the results characterizing particular stages were almost identical.

No effect was noted of the season, the fish size, nor the depth of catches. Seasonal variations of *Cladocera* occurrence and variable relations between the share of *Pseudocalanus elongatus* and *Temora longicornis* (similarly as in the case of herring) were the only regularities noted. Due to this, the variation coefficient did not change much (in the samples caught in different seasons, in the fish of different size and originating from different depth this coefficient slightly exceeded 1, but was always below 1.1). In the same way, food stability was almost always 100% RWS, irrespective of the aspect considered.

On the other hand, seasonal variations of the feeding intensity were much more pronounced than in the case of herring (Fig. 3A). These changes were of a very similar character in all stages of the studies. The lowest values of daily coefficient were noted in winter, slightly higher in spring, very high in summer (over 5 times higher than in herring if average data for the whole period of the studies are taken into account), and low again in autumn (although higher than in spring). When maximal and minimal seasonal values of the daily coefficient are compared it is seen that the latter are almost 70 times higher (in herring only about 4 times).

Usually, feeding intensity of sprat decreased with increasing fish size (Fig. 3B). Only in 1980–1984 an opposite relation was noted. The differences between minimal and maximal values of the daily coefficient (average values for the whole period of the studies) were, however, rather small, similarly as in the case of herring. It should be

Fig. 3. The changes of sprat feeding intensity in relation to: season (A), body length (B) and depth of capture (C); the explanations on the fig. 2

underlined that the discussed relationship was presented basing on the results obtained only in winter, spring and autumn, because in the summer materials small sprats (5.5–10.0 cm) were found only in 1977–1979. Inclusion of these data into the general picture might have distorted the results for all three stages of the studies due to very high intensity of feeding in summer.

Increasing depth inhibited the intensity of sprat feeding (Fig. 3C). In this case, however, the differences between the minimal and the maximal values of the consumption index were more pronounced than in herring. Concluding, it may be stated that – similarly as in the case of herring – season affected the intensity of sprat feeding most significantly, while fish size was the least important.

DISCUSSION

The above results call for some comments, especially with respect to the relation between food consumption and feeding intensity on the one hand, and quantitative and qualitative composition of the food resources for herring and sprat on the other hand. Although the data on these are poor and far from being precise, they do allow for making some comparisons and determining some relationships, at least in a general way.

The first problem consists of significant changes in herring food in consecutive stages of the studies. Unfortunately, in the available literature there were only a few data on increasing biomass of the zooplankton in part of the study period (70-ies) (Chojnacki 1984). The author related this phenomenon to progressing eutrophication of Baltic waters, caused by increasing discharge of pollutants. There are no data on long-term changes in *Mysidacea* resources. Role of these organisms in herring food was very important in the first and the last stage of the studies, and much less so in the other stages (in 1977–1979 they were of marginal importance). On the other hand, seasonal variations in the food resources were quite well reflected in the seasonal variations of the food composition of herring, especially as regards the species constituting basic food components. As results from the studies by Chojnacki et al. (1974) and Chojnacki (1984), *Pseudocalanus elongatus*, *Temora longicornis* and *Acartia* sp. were the most important species in the mesoplankton of South Baltic (from among *Copepoda*), and in summer – also a cladoceran *Bosmina coregonus maritima*. The first two species dominated noticeably in the mesoplanktonic fraction of herring food, and seasonal variations in their abundance corresponded to seasonal changes in the food composition. On the other hand, mass appearance of *Bosmina* in summer zooplankton was not reflected in the composition of herring food. It is possible that *Bosmina* gathered mostly in surface warm water layers, so that it could have hardly been consumed by cold-water herring. Also seasonal relations between *Copepoda* and *Mysidacea* in herring food corresponded to variations of their biomass. Chojnacki stated that the zooplankton

biomass decreased noticeably in winter, but Szwecowa (1986), and Szwecowa and Szewcowa (1990) noted considerable increase of *Mysis mixta* biomass in autumn and winter.

Decreasing intensity of herring feeding in consecutive stages of the studies should also be explained. Average daily coefficient decreased from almost 150‰ in 1971–1974 to slightly over 45‰ in 1980–1984 and 1986–1989. Relative annual food ration decreased in the same way from over 540% to over 160% respectively. It may be assumed that the values calculated for 1971–1974 were closer to the real situation. Since 1977 most materials originated from commercial catches, and in the last stage all of them were obtained from these catches. Preservation of the fish caught was retarded and this might have resulted in an underestimation of the amount of food consumed by the fish.

Atypical seasonal variations of the intensity of herring feeding in 1986–1989 (minimum in spring, maximum in autumn) were caused by improper dates of spring and summer sampling. Spring materials in this period of the studies originated mostly from the peak of herring spawning season (gonads in stages VI and VII according to Maier's scale), whereas summer samples were collected at the end of September, after the peak of feeding intensity, the latter being usually observed at the turn of July and August.

Lack of noticeable effect of the season, fish size, and depth upon the composition of sprat food might have been caused by the fact that sprat food was more uniform than herring food. This is confirmed by the values of the variation coefficient calculated for average food composition (for the whole period) of the two species (herring: 2.01, sprat: 1.04). Notwithstanding considerable differences in the food composition of the two species, food convergence was relatively high and amounted to 63.2%. In a way, this also points to dominating role of the mesoplankton in herring food (sprat food consisted only of the mesoplankton).

Very pronounced summer peak of sprat feeding intensity might have been caused by higher tolerance of this fish to higher temperatures. The observed seasonal variations in the feeding intensity of the two fish species determined also domination of one of the two basic mesoplanktonic species in the fish food. In the case of herring, to which seasonal variations of the feeding intensity were less pronounced, *Pseudocalanus elongatus* usually dominated in the food composition throughout the year. Sprat consumed in summer 60% of the annual food ration (herring only about 38%), and its food was predominated by *Temora*, which dominated in this period among the mesoplanktonic *Copepoda*.

Concluding, it may be stated that the amount and composition of food of the two fish species was largely determined by the abundance of the food resources (and their possible changes). Although biology of the two species is very similar, and food convergence was relatively high, their feeding behaviour seemed to differ considerably. Most of all mention should be made of considerable differences with respect to seasonal variations of the feeding intensity. Also food composition was different, even in the case of fish of the same size. 10.5–15.0 cm sprat fed on mesoplankton only, while

herring of the same length consumed also several per cents of macroplankton and benthos (mostly *Mysis mixta*).

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ODŻYWIANIE SIĘ ŚLEDZIA I SZPROTA W POŁUDNIOWYM BAŁTYKU W LATACH 1971–1989

STRESZCZENIE

Badaniami objęto 22400 ryb (14599 łedzi i 7801 szprotów) złowionych w południowym Bałtyku. Wyróżniono 4 etapy badań: 1971–1974, 1977–1979, 1980–1984 i 1986–1989. Prowadzone analizy dotyczyły składu pokarmu i intensywności żerowania; zmiany składu pokarmu dodatkowo charakteryzowano przy pomocy jego zróżnicowania i stabilności.

U obydwu badanych gatunków określano zależności odżywiania się od etapu badań, rozmiarów ryb oraz głębokości ich poławu. Wyniki dotyczące odżywiania się śledzia wskazują na podstawową rolę dwóch składników: *Copepoda* i *Mysidacea*, podczas gdy pokarm szprota składa się niemal wyłącznie z *Copepoda*. U śledzia zarówno skład pokarmu jak i intensywność żerowania były najsilniej uzależnione od sezonu, najsłabiej natomiast — od rozmiarów badanych ryb. Skład pokarmu szprota praktycznie nie był uzależniony od wymienionych powyżej czynników, natomiast zmienność intensywności żerowania kształtowała się podobnie jak u śledzia z tym, że różnice sezonowe były znacznie wyraźniejsze (wartości maksymalne — letnie — były prawie 70 razy wyższe od minimalnych — zimowych, podczas gdy u śledzia — tylko 4 razy). Pomimo istotnych różnic można zaobserwować stosunkowo duże podobieństwo składu pokarmu obydwu badanych gatunków (63,2% zbieżności pokarmowej).

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