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On the factors determining the abundance of recruitment in the spring spawning herring of the eastern Baltic

by

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Summary

Rich herring year classes often develop simultaneously throughout the whole Baltic (in 1948, 1949, 1952, 1953, 1959, 1961, 1964).

A co-variance exists between the strong influences of North Sea water and the formation of abundant year classes of herring.

In the southeastern Baltic (the Gulf of Gdańsk, the Vistula Bay) rich spring herring recruitment develop shortly after larger inflows of oceanic waters from the North Sea. In the northeastern Baltic abundant year classes can also develop a year later (in 1948 and 1949; in 1952 and 1953).

In the period of weak inflow of North Sea water (1952-1960) the level of recruitment to the Gdańsk-Vistula herring stock was very low. But in the northeastern Baltic, rich year classes formed also in this period (in 1957; in the Gulf of Finland and in the northern part of the Baltic proper also in 1954 and 1955).

The amplitude of fluctuations in recruitment of the Gdańsk-Vistula spring herring is very large and in this respect this stock is similar to the Rügen herring. In these areas the success of recruitment is determined by upmixing of extra phosphates originating from the Bornholm and Gdańsk Deeps, into a layer of photosynthesis. This process is hindered by a strong halocline and favoured by intensive inflows of North Sea water,

In the northeastern Baltic the spring herring recruitment is rather stable. This is similar to the stocks of the northern Baltic proper and of the coast of Sweden. The magnitude of recruitment depends on upmixing of extra phosphates from the central and northern part of the Gotland Deep. Because the halocline is weaker in this area and since there is a steady northeastern motion of water masses, phosphates ascend into the surface layers in the intense mixing zones (on slopes of the deeps, above shoals and reefs) leading in this area to formation of rich year classes also in stagnation periods.

Introduction

In numerous works by Kryshanovsky, Lisivneko, Ojaveer, Rannak, Seletskaya, Toom, Shapiro and others on embryonal, larval and postlarval development of the Baltic herring, several regularities governing the development has been found and the existence of critical periods stated. In spite of this and of the investigations carried out on the reproduction of the herring, it is at present not possible to compose a satisfactory model of the recruitment of herring. Until now, the information on some important links from primary production up to the adult fish is insufficient.

The abundant Baltic herring year classes develop simultaneously over a large area throughout the whole Baltic. This can be explained by a periodicity in changes of the environmental conditions, the most important of which are the changes in the thermal regime (direct and indirect influence) and in the concentration of nutrient salts in the surface layers (direct influence on the abundance of food organisms) (Rannak, 1970). The dependence of the herring recruitment on these factors is relatively complicated because of the large number of other biotic and abiotic factors involved. In the present report changes in the recruitment of the spring herring as depending on the changes in environmental conditions are analysed.

Enrichment of the layer of photosynthesis of the Baltic Sea with nutrient salts and changes in herring recruitment

In an earlier work (Ojaveer & Rannak, 1967) we showed that in the Gulf of Riga a positive correlation exists between the surface water temperature in early spring and the abundance of the spring herring year classes. Similar observations have been made by other authors. In the southern Baltic, where the herring spawns early in spring (III-V) formation of abundant year classes is favoured by mild winters (Jensen, 1966, Popiel, 1958, Elwertowski & Popiel, 1961). In the northern Baltic, where the herring spawning occurs later (V-VII) warm summers are favourable (Sjöblom, 1963).

According to observations by a number of workers the abundant herring year classes develop in the years when the condition of adult herring is good (Popiel, 1958) and its fat content high (Sjöblom). In the years of good growth in length and weight of the herring, the summer is warm and sunny (Dementjeva, 1957, 1963; Jensen, Popiel, Sjöblom). In these years a higher salinity is also observed. According to Popiel, if the salinity is high, the herring growth rate can be on a high level, even in summers following severe winters.

The rise in salinity is accompanied by an increase in concentration of nutrient salts in the layer of photosynthesis, leading to an increase in abundance of food organisms. An increase in the salinity of the surface layers brings about a higher primary production (Segerstråle, 1965). The influence of temperature can be directly favouring digestion , or indirectly favouring development of the food organisms.

The biological productivity of the Baltic is limited by phosphorus. The PO_4 of the productive layer of this sea originates principally from the deep water layers which accumulate this salt in the process of sedimentation and mineralisation of the organic matter as well as by solution of apatites of the sea ground (Aleksandrovskaya, 1966, 1970,: Fedosov and Zaitsev, 1960; Fonselius, 1967, 1969). The vertical stratification of the water layers of different density characteristic for the Baltic Sea which is most clearly expressed above the deeps, hinders the enrichment of the productive layer with mineral phosphorus. The phosphates originating from the deep layers come through the barriers of halocline and thermocline into the layer of photosynthesis mainly in the period of homothermis or by motion of large deep water masses. The latter is caused by episodic strong inflows of saline water from the North Sea.

There is a connection between the strong influxes of the North Sea water and the abundant herring year classes also in the eastern Baltic (Rannak, 1970). The presence of this dependence in the western and southern parts of the sea has been stated earlier (Elwertowski and Popiel, 1961, Roehlin, 1967.).

There are different views regarding the question of the origin of the nutrient salts of the productive layer of the northern Baltic proper. The biological production of this area was thought to be directly dependent upon the quantity of water carried into the sea by the flood of rivers in spring (Dementjeva, 1963, Nikolayev, 1957, etc.). In the gulfs the biological productivity is undoubtedly influenced by the amount of such nutrients, but this has no direct influence on the Gulf of Finland as a whole, or on the abundance of the herring stocks of the Gulf of Riga. For instance, there is no correlation between the discharge of the Daugava in the first half of the year and the abundance of the herring year class developed in the same year ($r = 0.126$, Rannak, 1970).

The later more detailed investigations of the hydrography and hydrochemistry of the Baltic (Aleksandrovskaja, 1970;:Fonselius, 1969; Glowinska, 1960; Hela, 1965; Kalcis, 1970 and others) allow us to look onto the regularities governing the biological productivity in the eastern and northeastern Baltic from a new point of view.

In the period 1946 to 1970 in the northeastern Baltic some very abundant spring herring year classes developed in 1949, 1961 and 1964 and abundant year classes in 1946, 1948, 1953, 1957, 1959 and 1967. A very weak year class was hatched in 1956 and weak ones in 1952, 1960 and 1969 (Table 1, Figure 1).

In the southeastern and southern part of the sea very abundant spring herring year classes were formed in 1948 and 1952, whereas in 1949 and 1950 as well as in 1951 rich year classes developed. After the very rich 1952 year class the abundance of the spring herring declined rapidly in this area. In 1956 a very poor year class developed. In this stock the abundance of all year classes was very low until 1959 when a slight rise was observed. The year class hatched in 1961 was somewhat stronger and in 1964 a rich one appeared.

In the northeastern Baltic fluctuations in the abundance of the spring herring year classes are not great. The ratio between the catches obtained from the richest and the poorest year class is 6.8:1. But the amplitude of fluctuations of abundance of year classes of the spring herring spawning in the Gulf of Gdańsk and the Vistula Bay is great, the corresponding ratio is 70:1 (Rannak, 1970; 1971 - Figure 24). In spite of differences in the amplitude of fluctuations in abundance of the spring herring of the northeastern parts and southeastern parts of the Baltic it is possible to point out "bursts" of formation of abundant year classes. The first of these was in 1948 and 1949, the second in 1952 and 1953, the third in 1959, the fourth in 1961 and the fifth in 1964. Also the increase in abundance of the autumn herring year classes in 1954, 1959, 1960, 1961 and the very rich 1964 year class are connected with these periods. This holds good, especially for the autumn herring of the southern Baltic (the Bornholm and Gdańsk stocks) where the limiting influence of the winter temperature is less pronounced as compared to the northeastern and northern parts of the sea.

According to Rechlin, the 1964 year class was one of the most numerous ones of the autumn race in this century, like the 1937 and 1922 year classes. One year before the formation of these very strong year classes there were heavy inflows of North Sea water (Rechlin, 1967).

Similarly, before the "bursts" of abundant year classes, strong inflows of North Sea water occurred(Figure 1). The strong 1946/1947 inflow was followed by an increase in salinity of Baltic waters (Soskin, 1963). In 1948 a rich autumn herring year class was formed in the Southern Baltic and in 1948 and 1949 rich spring herring year classes were hatched throughout the whole sea, the 1948 year class was especially rich in the Vistula Bay and in the Gulf of Gdańsk, and the 1949 year class in the northeastern Baltic.

The next nighty inflow of North Sea water occurred in November - December 1951. In January of the following year the saline water arrived into the Bornholm Deep, in April into the Gdańsk Deep, in June it reached the northern slopes of the Gotland Deep and only in the spring of 1953 did it occur in the shallows of the Gulf of Finland (Segerstråle, 1965). In 1951 and 1952 good autumn herring year classes were formed in the southern Baltic and in 1952 a strong spring herring year class developed in the Gulf of Gdańsk and in the Vistula Bay. In the Gulf of Riga this spring herring year class was poor and in the eastern part of the Baltic proper, it was moderate. In 1953 a strong year class was formed in the northeastern Baltic.

The second half of the fifties is characterised by a limited exchange of water through the Danish Sounds. In the central and northern Baltic - the Gotland Deep - a deep stagnation took place with accumulation of phosphates. At the end of 1959 the concentration of phosphates increased ten times there (400 mg/m^3 , Aleksandrovkaja, 1970; Fonselius, 1967). The strong inflow of North Sea water in 1958 was followed by a rise in biological productivity of the Baltic in 1959. A rich spring herring year class was formed throughout the whole of the Baltic. This year ended the depression of the spring herring of the Vistula Bay.

The strong inflows at the end of 1960 and 1963 were followed by inflows of saline water in the winters 1961 and 1964 (Kalcis,1970). Due to these two inflows, a considerable part of the phosphates accumulated in the deeps were thrown into the biological production. This resulted in the formation of strong spring herring year classes throughout the Baltic in 1961 and 1964 with especially rich year classes in the Gulf of Finland, in the Rügen and the Gulf of Riga stocks. In 1960 and 1961 and also 1964 very rich autumn herring year classes developed in the Bornholm Basin (Rechlin, 1967); the 1964 year class of the autumn race was also abundant in the Gulf of Riga (Ojaveer, 1970).

The next rich spring herring year class was hatched in 1967 in the whole Baltic and according to preliminary data in 1970 in the northeastern part of the sea. Kaleis points out that a moderate inflow occurred in September 1966 and a strong one in the winter of 1969.

Fonselius (1967) stated that in the winters of 1962 and 1966 the surface layers of the Baltic were rich in phosphorus which caused an increase in the plankton production and in the fatness of the herring in 1962. Nevertheless the 1962 spring herring year class was rich only in the Rügen and in the Gulf of Riga stocks. In 1966 a strong herring year class hatched in the Gulf of Finland; in the Baltic proper, this year class was moderate and in the Gulf of Riga poor.

Macro-regions of the Baltic and fluctuations in recruitment of herring

The peculiar bottom relief of the Baltic Sea (partition of the deep areas into several large areas by thresholds) as well as the stratification and the dynamics of the water masses result in an uneven distribution of phosphates in this sea (Kaleis, 1970).

Based upon the fluctuations in abundance of spring herring year classes it is possible to discern two large regions where the reproduction of herring stocks run differently : 1) the southern and southeastern parts populated mainly by Rügen and the Vistula-Gdańsk herring stocks, 2) the central and northern part of the Baltic proper populated with the herring stocks of the east coast of Sweden, of the northeastern Baltic, of the Gulf of Finland and the Gulf of Riga.

The fluctuations in abundance of the southern and southeastern stocks of the spring herring depend on the supply of phosphates in the Bornholm and Gdańsk Deeps and on the location of these areas relatively near to the Danish Sounds. There, the mobilisation of extra phosphates into the biological circulation may be directly influenced by strong inflows of North Sea water, for in this area abundant herring year classes are hatched immediately after the inflow. In the period of decreased water exchange in 1952-1961 the spring herring stock remained on a minimum level there, The recovery in the abundance of the spring herring of this area began with the appearance of the very rich 1961 year class (in the Rügen stock it was the most abundant one during a period of 13 years, Rechlin, 1967) after a strong inflow in 1960. This also explains the great fluctuations in the spring herring stock of the Vistula Bay (ten times more than in the northeastern Baltic).

The dynamics of the herring stocks of the Central and Northern Baltic depend on the regime of phosphates in the Gotland Deep area and in the gulfs connected with it. This region is characterised by 1) stability in recruitment of the spring herring and 2) formation of abundant year classes also during the long stagnation periods. The rich year classes do not always develop at the same time in all parts of the region. For instance, in 1954 and 1955 in the northeastern Baltic moderate year classes were formed, whereas the very strong 1955 year class of spring herring was hatched in the eastern part of the Gulf of Finland (Moroshova, 1967). In the northern part of the Baltic proper and in the Gulf of Finland strong spring herring year classes developed in 1954 and 1955 (Sjöblom, 1963). In the herring stocks of the east coast of Sweden feeding in the Bornholm Basin and the Gulf of Gdańsk, a rich year class was hatched in 1955. A very poor year class was formed in the stock of the east coast of Sweden in 1963 (Popiel and Strzyzewska, 1968).

In the period of stagnation rich spring herring year classes developed simultaneously throughout this region in 1957 and 1959. Judging from the dynamics of spring herring recruitment the middle and northern parts of the Baltic should be supplied with phosphates also in periods of small influx of North Sea water.

Detailed investigations by Ojaveer and Kaleis (in press) showed that in the areas off the middle and northern slope of the Gotland Deep a steady fertilisation by phosphates of the layer of the photosynthesis exists. Mixing of the deep water, rich in phosphates, with the surface layers takes place upon the shoals and on the coastal slope where the thermocline and halocline reach the bottom. They refer to this area as the zone of intense mixing and show that a higher production of plankton and large concentrations of plankton feeding fish (herring and sprat) occur there.

As the central and northern part of the Gotland Deep is the largest "storehouse" of the phosphates in the Baltic (Aleksandrovskaya, 1970), the upwelling of phosphates in the zone of intense mixing accounts for the development of rich spring herring year classes also in the stagnation periods. In the Bornholm Basin and the Gulf of Gdańsk a corresponding process is obviously hindered by a very strong halocline.

The dependence of the dynamics of the recruitment of the Gulf of Riga spring herring on strong inflows of North Sea water can be explained as follows : The phosphates released by deep water in the zone of intense mixing are carried into the Gulf of Riga where they cause a rise in biological productivity.

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TABLE 1. Abundance dynamics of the spring herring stocks (‡ very rich, + rich, 0 moderate, - poor, = very poor year class, ⊕ good condition, fatness, ⊖ small increment, low fatness.

Year class	off Saaremaa	Gulf of Riga	Gulf of Finland S	Gulf of Finland E	Gulf of Finland N	Summer/autumn Bornholm	Summer/autumn Gdańsk	Gulf of Gdańsk	Vistula Bay	Rügen
1948	+	⊕ +	0					⊕ ++	++	
1949	++	⊕ ++	+	+		+	+	⊕ +	+	
1950	>0	0	0	0		0	0	>0	+	
1951	+	>0	++	+		0	0	⊖ 0	+	
1952	>0	-	0	0	+	+	0	⊕ ++	++	++
1953	+	+	+	0	-	+	+	< 0	< 0	0
1954	0	< 0	+	⊖	+	0	>0	< 0	< 0	0
1955	0	< 0		++	+	+	+ +	< 0	> 0	0
1956	=	=	=	=	⊖=	=	=	⊖=	=	0
1957	++	⊕ +	>0	+	⊕+	+	+	⊕=	=	0
1958	-	< 0	<0	0	⊖-	-	-	=	=	0
1959	+	+	+	+	⊕++	++	++	-	-	0
1960	=	⊖ -	=	-	⊕-	-	-	-	-	> 0
1961	+	⊕ ++	++		⊕+	0	0	-	-	++
1962	0	+	0		⊕-	⊕0	⊕ -	-	-	+
1963	< 0	> 0	0		⊕>0	⊖-	⊖ =	=	-	0
1964	+	+	+		++		+	++	< 0	0
1965	0	0	0	0	-		0	<+	< 0	<+
1966	0	⊖ -	+	0	-		0	+	0	+
1967	+	⊕ +	+	+	⊕+		+ +	+	> 0	+
1968	< 0	⊖<0	-		⊖			+		+
1969	-	⊖ -	-					0		0
1970	+	+	+							
	Rannak		Morozova, Smirnov	Sjöblom		Elvertowski, Popiel Strzyzewska			Birjukov Seletskaya, Shapiro	Rechlin

Figure 1. Absolute dynamics of different spring herring stocks of the the eastern Baltic. On the ordinate the percentage deviations of year class abundances from the long term average.

1 - strong inflow of North Sea water

2 - larger inflow of North Sea water.