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GUIDE FOR THE USE OF BALTIC SPRAT AND HERRING OTOLITHS IN FISHERIES STUDIES

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PART I

GUIDE FOR THE USE OF BALTIC SPRAT OTOLITHES IN FISHERIES STUDIES

APS, R., Tallinn Department of the Baltic Fisheries Research Institute, Tallinn

USTINOVA, L., Baltic Fisheries Research Institute, Riga

GENTZEN, B., Institute of Sea Fisheries and Fish Processing, Rostock

GRYGIEL, V., Institute of Sea Fisheries, Gdynia

PAAT, A.; UDER, Y.-O., Tallinn Technical University, Tallinn

Contents

Introduction

For a long time fish otoliths have attracted the attention of scientists. As a rule the external morpohology and some internal structural elements of otoliths are species-specific. This accounts for the interest directed towards the otoliths by systematists and paleontologists. The primary interest of ichthyologists and ecologists concerns the inner structure of otoliths where the main events of the fish life are recorded. Interpretation of these "records" is a complicate but interesting work providing valuable material for both fisheries science and practice.
The present Guide for the use of Baltic sprat otoliths in fishery studies is the result of international cooperation of specialists from several Baltic countries. The work is aimed at generalizing the results of long-term studies on Baltic sprat otoliths, showing their significance and potentials of use in fishery and ecological studies. The results obtained by analysing the structure of Baltic sprat otoliths are highly important in stock assessment and protection of this valuable commercial fish, as well as for monitoring the condition of pelagic layer in the Baltic Sea.
The possibilities of usage of otoliths, including those of Baltic sprat, in fishery and ecological investigations are far from being exhausted. Contemporary light and electron microscopes combined with problem-oriented systems for image automatic analysis will enable in the near future to widen the possibilities of the otoliths structure analysis as a method contributing to the knowledge of the ecology of fish. Considering that mentioned above the present Guide should be regarded as a summary of preliminary results in this dynamically developing field of research.
The authors are greatly indebted to their colleagues from the Baltic Fisheries Research Institute (Riga) and its Tallinn Department (Tallinn). Thanks are also due to colleagues from the Tallinn Technical University (Tallinn), the Institute of Sea Fisheries (Gdynia), the Institute of Sea Fisheries and Fish Processing (Rostock) for valuable discussions on the problems related with the study of Baltic sprat otoliths, but also for useful critical remarks during the preparation of the manuscript.

1. Systematic pertinence and population structure of Baltic sprat

Baltic sprat Sprattus sprattus balticus (G. Schneider, 1904) is the Baltic subspecies of European sprat Sprattus sprattus L. (genus Sprattus, family Clupeidae) which inhabits the West- and South-European seas from Gibraltar to the Lofoten Island, the Baltic Sea, northern Mediterranean and the Black Sea /39/.
Within its area, European sprat is classified into several populations. Baltic subspecies serves as one of those populations, which has adapted to live in the brackish Baltic Sea /27/.
The high gradient of physiochemical characteristics of the sea in the area of the Belts, prevents the mixing of Baltic and North Sea sprat populations.
The unity and integrity of sprat populations, as well as its subdivision into intrapopulational units – subpopulations – is determined by the reproduction pecularities. Intrapopulational subdivision is based on remarkable and permanent attachment of the main sprat concentrations to more productive Baltic Sea areas /37, 39/, determined by the sea floor relief and system of surface currents /23, 38/. In productive areas better feeding conditions promote the survival of larvae and young fish and result in the appearence and maintenance of spatial heterogenity of the sprat population.
International Council for the Exploration of the Sea (ICES) has differentiated three Baltic sprat assessment units: ICES subdivisions 22, 24–25, 26–28 and 27, 29–32. In view of oceanological and biological data available, these stock assessment units can be regarded as the Baltic sprat subpopulations /3/.
It has been established that in the 1980s, the variability of sprat growth parameters by sea areas was too small to provide the basis for reliable distingiushing of subpopulations /3/.
The results of morphometric analysis and growth allometry studies cannot serve for characterization of sprat intrapopulational subdivisions either /4/. The use of "natural tags" observable in the structure of otolith enabled to establish the attachment of sprat to its main distribution areas and showed that this fish does not perform extensive migrations /33/.
The greatest differences between Baltic sprat subpopulations are expressed in the year-class strength, and as a result in age composition. The structure of Baltic sprat population, as a whole, depends on the abundance dynamics of its subpopulations – their areas in dependence of the abundance may considerable change and the boundaries between them are quite conventional.

2. Collection and storage of sprat otoliths

General problems, related with the collection and storage of fish otoliths have been discussed in literature /12, 25, 26/. Less material has appeared on collection and storage of Baltic sprat otoliths /28/.
For age, microstructure and shape studies otoliths are taken from fresh or fixed in ethanol fish. Sprat otoliths, fixed in formaldehyde are unsuitable for further treatment. As a rule, prepared otoliths, two from each fish, are placed into dry storage or on object glasses. In the latter case, the pairs of otoliths may be arranged in rows – 25–50 pairs of otoliths on each glass and poured over with the Canadian balsam. The preparation needn't be covered with glass. The preparations obtained, are convenient to handle, the losses of otoliths in ageing are excluded.
Sprat otoliths can also be stored on special transparent (sometimes on opaque)plastic plates with numbered cavities. The pairs of otoliths are placed into cavities, and in case of ageing, poured over with the Canadian balsam or with some transparent plastics. 100 pairs of otoliths are usually placed on one plate.
If the samples are prepared for studying under light or electron microscope, otoliths are kept in dry storage, on plates with numbered cavities, or in small glass tubes in 75% ethanol.

3. Morphology of sprat otoliths

3.1. External morphology

The external morphology of Baltic sprat otoliths has been described on the basis of images, attained by means of scanning electron microscope (SEM) /28, 31/.
The following parts are distinguished on Baltic sprat otoliths: rostrum, postrostrum, anterostrum and pararostrum (Fig. 1). The dorsal edge of the otolith, between anterostrum and pararostrum is usually smooth, sometimes sligthly carved. The ventral edge between rostrum and postrostrum is usually notched. A big excisura major is between rostrum and anterostrum, and a small exicura minor between postrostrum and pararostrum.
The outer side of the otolith, which is turned off the brain of fish, has a relatively smooth surface, where sometimes the central area and grooves can be seen. The internal side of the otolith, which is turned towards the brain of fish, has a strongly pronounced relief (Fig. 2). Sulcus acusticus divides the inner side of the otolith into dorsal and ventral parts.

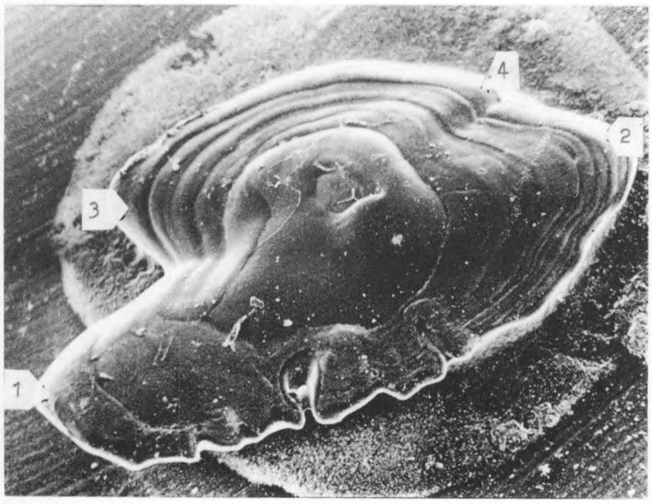


Fig. 1
The outer side of the Baltic sprat otolith:
1 – rostrum, 2 – postrostrum, 3 – anterostrum,
4 – pararostrum /31/

Fig. 2
The internal side of the Baltic sprat otolith:
1 – excisura major, 2 – excisura minor, 3 – fossa /31/

The external structure of Baltic sprat otoliths doesn't show any important differences from the otoliths of the other sprat subspecies /28/. There is a remarkable similarity in the structure of the otoliths of Baltic sprat and Atlantic herring Clupea harengus harengus L. /18, 19/.

3.2. Inner structure

While speaking about the inner structure of Baltic sprat otoliths, attention should be paid to their seasonal zones and daily increments.

Seasonal zones of Baltic sprat otoliths appear as a result of seasonal growth of the fish /28/. In spring, in the period before spawning, a relatively narrow winter growth check zone is formed on the otoliths. At the end of spring, sprat intensive feeding period begins and on its otoliths a relatively wide summer growth zone starts to form. In case of one-year old sprat the most intensive growth of otoliths is observed from June till September, inclusive. In connection with spawning in older year-classes the period of more intensive somatic growth and growth of otoliths may shift towards autumn. By the beginning of the succeeding hydrological winter (the first months of the following year) the formation of summer growth zones is completed.

Summer growth zones and winter discontinuous growth zones have different optical density /28/. In transmitted light to the periods of summer growth of sprat more transparent (hyaline) zones correspond and less transparent (opaque) otolith zones to the periods of winter growth checks (Fig. 3). It has to be mentioned that only on studying very thin microscopic sections, with the zones perpendicular to the section's surface, we can speak about relative transparency of the zones, in a more strict sense of the word. Studying light penetration through the whole otolith or its parts having complicated structure one can only judge in general lines, about the relative transparency of single layers.

Besides, according to M. MINA /20/, visual qualitative evaluation of optical density of otolith zones is relative – neighbouring zones on otoliths can be visually differentiated only in case if the gradient of optical density on the boundary of these zones is high enough.

Differences in optical density of otoliths growth zones are connected with different ratio of mineral and organic components /9, 16, 21, 26/. The structure of the Baltic sprat otoliths growth zone was studied by x-ray microanalysis. It has been established, that the winter opaque zones of Baltic sprat otoliths

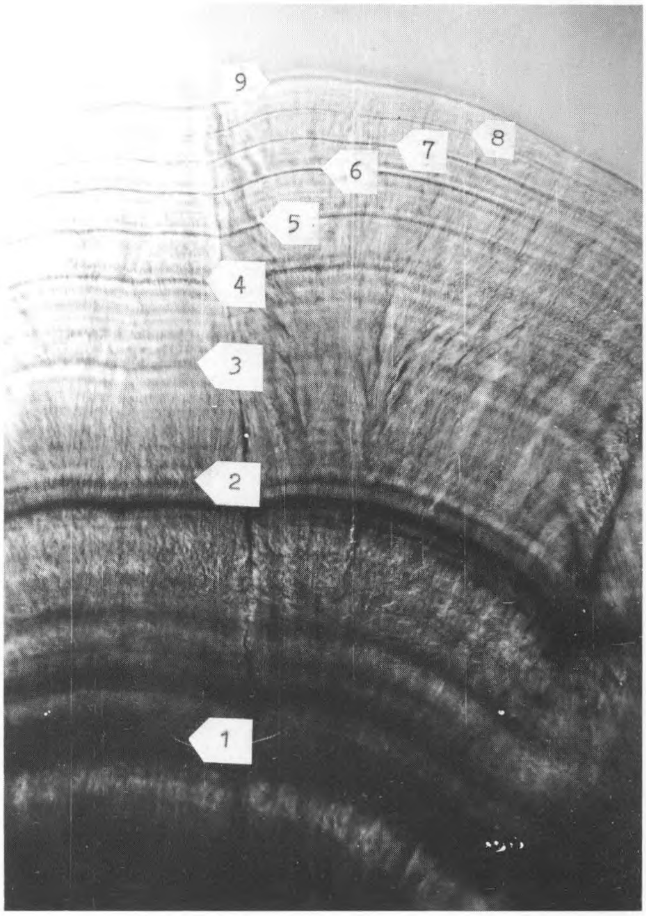


Fig. 3
The dorsal part of the Baltic sprat otolith in transmitted light:
1–8 – winter growth checks, 8 – dorsal edge

comprise relatively more organic matter than summer hyaline zones /30/.

In studying daily growth increments of Baltic sprat otoliths, one has to distinguish some basic morphological elements. For this purpose use has been made of the currently acknowledged terminology /10/:

(1) Primordium – optically relatively thick formation. On the basis of optical characteristics and the results of etching of the surface of sections, it can be concluded that primordiums of fish otoliths, Baltic sprat inclusive, consist mainly of organic matter. Preparing samples for SEM, the area of the primordium of Baltic sprat otoliths is usually etched deeper (Fig. 4).

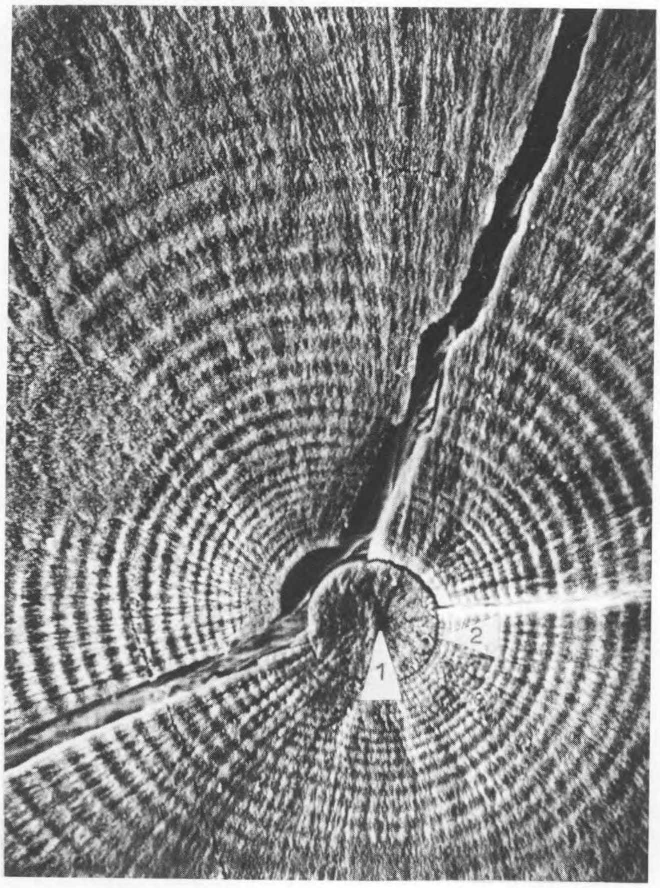


Fig. 4
Etched section of the Baltic sprat otolith, viewed with a SEM: 1 – primordium, 2 – nucleus /32/

(2) Nucleus – relatively homogenous zone of calcified material, surrounding otolith's primordium, it is rather distinctly delimited from the succeeeding region of regular increments (Fig. 4). Sections whose planes pass through otolith primordium, show that the nucleus of Baltic sprat otolith has a form of a sphere, about 20 μm in diameter.

(3) Increment, daily growth increment – a structure, usually being formed during 24 hours and consisting of two parts: incremental zone and discontinous zone. Under light microscope, in transmitted light, daily growth increments look like an adjacent wide hyaline growth zone and narrow opaque discontinuous zone. On the samples, prepared according to standard technique for SEM /15/, daily growth increments resemble a relatively wide lightly etched area (incremental zone) and a narrow and deeply etched area (discontinous zone), as is seen in Fig. 5.

Fig. 5
Incremental growth sequence in a juvenile Baltic sprat otolith, viewed with a SEM /32/

Longitudinal sections give a good idea of the inner structure of otoliths (Fig. 6). The structures, observable on transversal sections of otoliths, have their peculiarities.

First of all, one has to consider the bipartite structure of Baltic sprat otoliths. Structurally, otoliths are rather distinctly divided into external and internal parts (Fig. 7). The more massive, external part of a otolith is characterized by the regularity of its increments. The structure of the internal part, where belongs the area of sulcus acusticus is less regular, increments are compressed and difficult to distinguish.

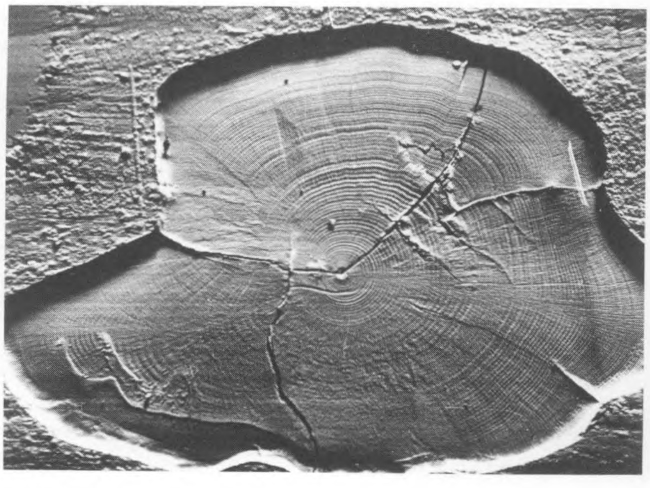


Fig. 6
Etched surface of the longitudinal section of the juvenile Baltic sprat otolith, viewed with a SEM /32/

It is shown /7/ that the described increments on otoliths are really daily increments, and their formation starts on the sixth day after the hatch of larvae at water temperature of 15 °C.

3.3. Allometric growth

Growth of Baltic sprat has been relatively well studied /1, 28, 34/. However, at the same time, only the first steps have been taken studying allometric growth of this fish /4/. Allometric growth of Baltic sprat otoliths has remained practically unstu-

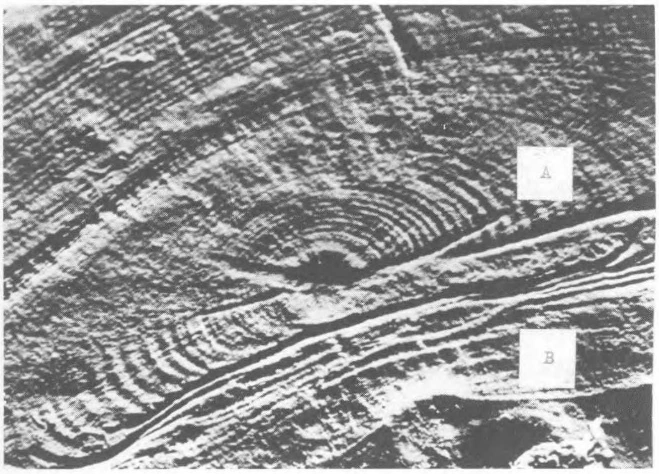


Fig. 7
Etched surface of the transversal section of the central part of juvenile Baltic sprat otolith, viewed with a SEM:
A – external and B – internal parts of otolith /32/

died. It is a pity, because the results of investigations of the allometric growth could remarkably widen the possibilities of classical morphometric analysis in populational studies.
The scheme presented in Fig. 8, can be used for studying of the allometric growth of Baltic sprat otoliths. Allometric growth of Baltic sprat otoliths was studied on the basis of the material collected from ICES subregions 22, 24 and 25 (the South-Western Baltic) in 1982–1988.

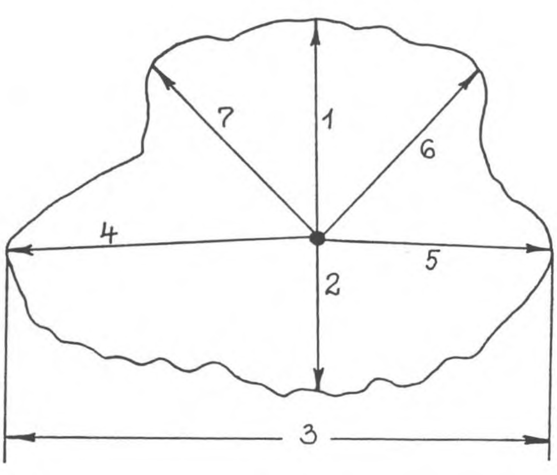


Fig. 8
The contour of the Baltic sprat otolith.
1 – dorsal and 2 – ventral distances, 3 – total length of otolith, 4 – rostral, 5 – postrostral, 6 – pararostral and 7 – anterostral distances

The results obtained by studying allometric growth of the features of otoliths presented in Fig. 8 versus total fish length (L, cm) are given in Table 1. It is worth of mentioning that in the considered interval of total length of sprat, growth of the majority of studied features of otoliths is close to the isometric (the value of coefficient b in simple allometry equation Y = aX^b is close to 1). Here we have a weakly pronounced positive (b > 1) or negative (b < 1) allometric growth. Weakly pronounced positive allometric growth characterizes rostral, postrostral, pararostral distances of sprat otoliths. Dorsal distance and total length of otoliths showed weakly pronounced negative growth allometry. Only the ventral distance revealed more pronounced negative allometric growth i.e. in the studied total length interval of the fish, the ventral part of otolith grew relatively slower than the sprat total length.
Growth of various parts of otolith can be studied versus the growth of one of them.

Table 1

Values of sprat otolith characters (mm) by the intervals of fish total length (L, mm) calculated by simple allometry equation (Y = aX^b) and coefficients a and b of this equation in ICES Subdivisions 22, 24–25 in 1983–1988. 1 – dorsal and 2 – ventral distances, 3 – length of otolith, 4 – rostral, 5 – postrostral, 6 – pararostral and 7 – anterostral distances.

Fish length, L, mm	Otolith character						
	1	2	3	4	5	6	7
75	0.361	0.343	1.08	0.491	0.488	0.437	0.408
80	0.385	0.361	1.15	0.527	0.524	0.467	0.433
85	0.409	0.379	1.22	0.562	0.559	0.498	0.458
90	0.432	0.397	1.288	0.598	0.595	0.529	0.483
95	0.456	0.414	1.35	0.634	0.631	0.56	0.507
100	0.48	0.431	1.42	0.67	0.667	0.591	0.532
105	0.503	0.449	1.48	0.70	0.703	0.622	0.556
110	0.527	0.466	1.55	0.742	0.74	0.653	0.58
115	0.55	0.483	1.61	0.778	0.776	0.684	0.605
120	0.574	0.499	1.68	0.815	0.813	0.715	0.629
125	0.598	0.516	1.74	0.851	0.85	0.746	0.653
130	0.621	0.532	1.80	0.888	0.887	0.778	0.677
135	0.645	0.549	1.87	0.925	0.92	0.809	0.701
140	0.668	0.565	1.93	0.962	0.96	0.841	0.724
145	0.692	0.581	2.00	0.998	0.998	0.872	0.748
150	0.715	0.597	2.06	1.03	1.03	0.903	0.772
155	0.739	0.613	2.12	1.07	1.07	0.935	0.795
Parameters							
a	0.0051	0.0108	0.0199	0.0050	0.0046	0.0047	0.0077
b	0.9857	0.8000	0.9255	1.062	1.081	1.048	0.9192

Table 2 presents the results obtained by studying allometric growth of different parts of Baltic sprat otoliths versus the otolith total length, in the South-Western Baltic.

Table 2

Values of sprat otolith characters (mm) by the intervals of otolith total length (mm) calculated by simple allometry equation (Y = aX^b) and coefficients a and b of this equation in ICES Subdivisions 22, 24–25 in 1983–1988. 1 – dorsal, 2 – ventral, 3 – rostral, 4 – postrostral, 5 – pararostral and 6 – anterostral distances.

Otoliths length, mm	Otolith character					
	1	2	3	4	5	6
1.0	0.3726	0.3381	0.5395	0.4994	0.4218	0.4010
1.1	0.4027	0.3620	0.5874	0.5489	0.4624	0.4349
1.2	0.4324	0.3854	0.6348	0.5984	0.5050	0.4683
1.3	0.4616	0.4082	0.6818	0.6479	0.5466	0.5012
1.4	0.4904	0.4305	0.7284	0.6973	0.5881	0.5338
1.5	0.5188	0.4524	0.7446	0.7467	0.6296	0.5661
1.6	0.5469	0.4738	0.8205	0.7961	0.6701	0.5980
1.7	0.5746	0.4949	0.8661	0.8455	0.7124	0.6297
1.8	0.6021	0.5156	0.9114	0.8948	0.7538	0.6610
1.9	0.6292	0.5361	0.9565	0.9441	0.7952	0.6921
2.0	0.6561	0.5562	1.0012	0.9934	0.8365	0.7230
2.1	0.6828	0.5760	1.0458	1.0427	0.8778	0.7536
2.2	0.7092	0.5956	1.0901	1.0919	0.9191	0.7840
Parameters						
a	0.3726	0.3381	0.5392	0.4994	0.4218	0.4010
b	0.8164	0.7181	0.8921	0.9922	0.9878	0.8504

The above holds entirely true also in the following case: growth of various parts of sprat otoliths versus their length is usually close to isometric. In the present case dorsal and ventral distances of otoliths serve as an exception, since their growth is characterized by more deeply pronounced negative growth allometry. It means that the width of an otolith (the sum of the ventral and dorsal distances) grows relatively slower than their length: with the increase in age the otoliths become more elongated in form. This is revealed in the increase of the otolith length/width ratio increase of otolith length (Fig. 9).

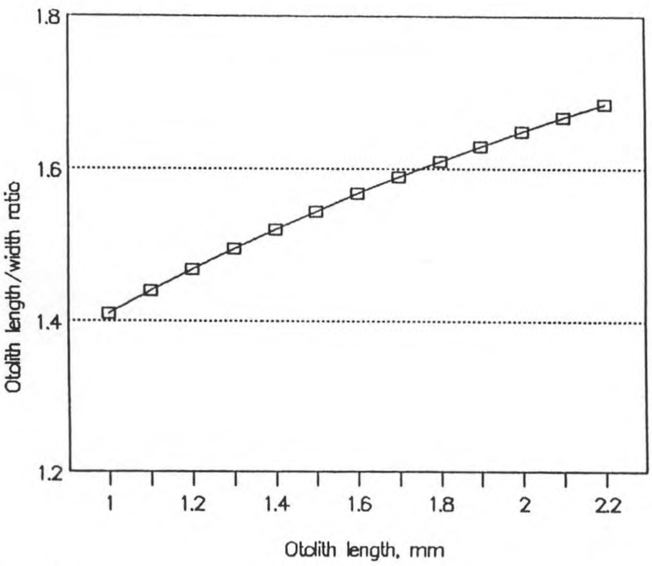


Fig. 9
The Baltic sprat otolith length/width ratio versus otolith length

The variability of the allometric growth in different Baltic Sea areas is also of interest. Table 3 presents the distribution of average lengths of otoliths by the intervals of fish total length and by the ICES subdivision. As is seen, the growth of otolith length is characterized by weakly pronounced negative allometry ($b<1$), the variability of allometric growth by the Baltic Sea regions is insignificant.

Table 3

Length of sprat otoliths (mm) by the intervals of fish total length calculated by simple allometry equation ($Y = aX^b$) and coefficients a and b of this equation by the ICES Subdivision 22, 24–29, 32 in 1986–1988 /34/.

Fish length, L, mm	ICES Subdivisions							
	22	24	25	26	27	28	29	32
110	1.57	1.59	1.60	1.56	1.62	1.59	1.59	1.58
115	1.64	1.65	1.66	1.62	1.67	1.64	1.65	1.64
120	1.70	1.71	1.71	1.69	1.72	1.70	1.71	1.70
125	1.77	1.77	1.77	1.75	1.78	1.76	1.76	1.76
130	1.83	1.83	1.82	1.81	1.83	1.81	1.82	1.82
135	1.89	1.90	1.87	1.87	1.88	1.87	1.87	1.88
140	1.95	1.96	1.93	1.93	1.94	1.93	1.92	1.94
145	2.02	2.02	1.98	1.99	1.99	1.98	1.98	1.99
Parameters								
a	0.02	0.03	0.05	0.02	0.05	0.03	0.04	0.03
b	0.90	0.87	0.76	0.89	0.75	0.80	0.78	0.84

The main difference of the investigations of growth allometry from the traditional morphometric analysis is that compared are not the mean values obtained by measuring single parts of otoliths, but the character of their relative growth. This enables to considerably widen the possibilities of the traditional morphometric analysis. The use of allometric growth curves of single morphometric features, enables one to speak with confidence about the existence of possible differences or about their absence in proportions of otoliths from different Baltic Sea areas.

3.4. *Variability in otolith shape*

Variability in shape of fish otoliths, including those of the Baltic sprat, may be due to both the fish age and sea area. An important indicator of the shape of otoliths is the silhouette.
In Figure 10 is shown the development of the silhouette of Baltic sprat otolith. As is seen in the course of the first four months of life the concentric core develops into a typical silhouette of the Baltic sprat's otolith.

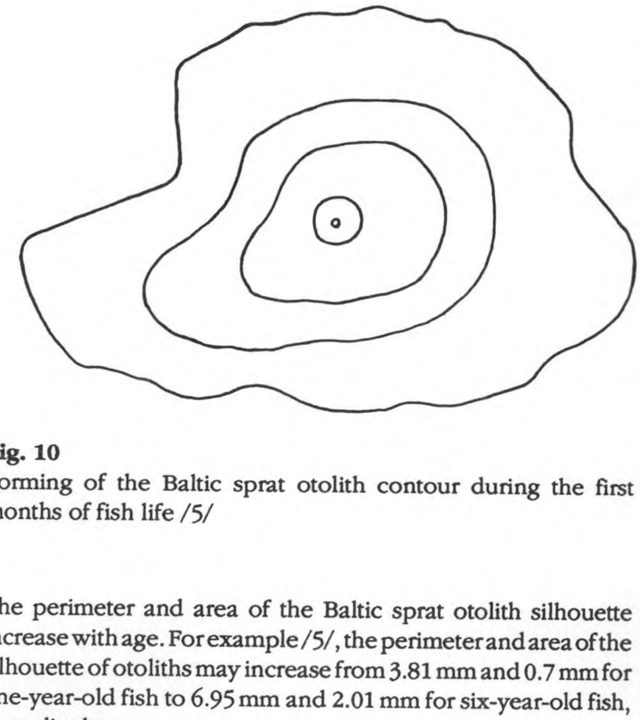


Fig. 10
Forming of the Baltic sprat otolith contour during the first months of fish life /5/

The perimeter and area of the Baltic sprat otolith silhouette increase with age. For example /5/, the perimeter and area of the silhouette of otoliths may increase from 3.81 mm and 0.7 mm for one-year-old fish to 6.95 mm and 2.01 mm for six-year-old fish, accordingly.
In addition to the traditional methods applied for the morphometric analysis of the shape of Baltic sprat otoliths /28, 33/, semiautomatized system for image analysis /5/ was used for describing and comparing of the otoliths.
Baltic sprat otoliths were studied by the SEM, their silhouettes were digitized and recorded in the computer memory. Fourier expansion of radius-vector, drawn from the centroid of a shape as a function of angle about the centroid was obtained /5, 8/. In other words, the silhouettes of sprat otoliths were presented as the Fourier spectra. Figs. 11 and 12 contribute to the understanding of the importance of a single Fourier harmonics in reconstructing of the shape of Baltic sprat otoliths. It is seen that the gross shape of sprat otoliths is determined by the sum of the first 5–6 harmonics. The silhouette of sprat otolith can be recorded quite precisly by the sum of the first twelve Fourier harmonics. The sum of the 0 to 127 harmonics enables to reconstruct the shape of otoliths in detail /5/.

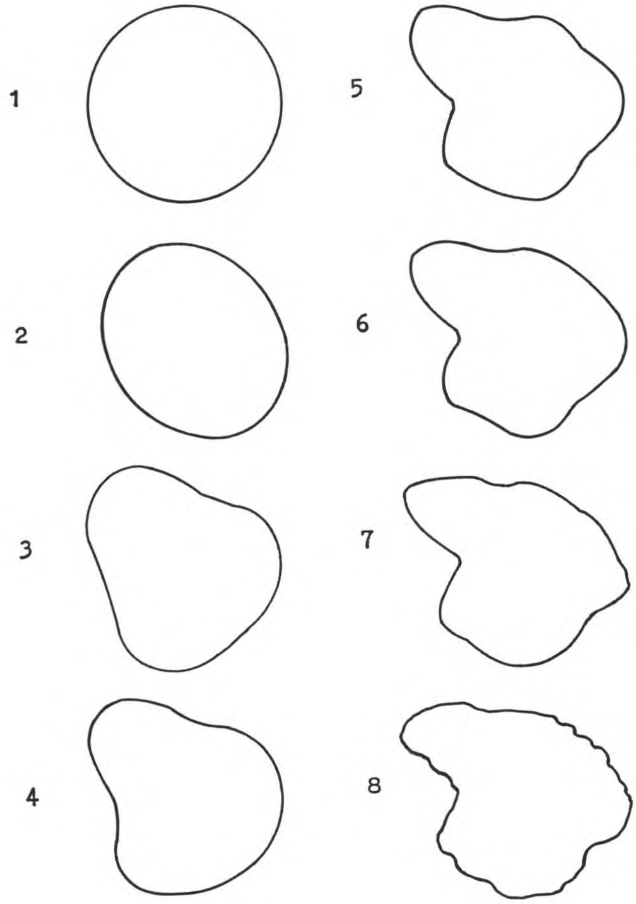


Fig. 11
One-year-old Baltic sprat otolith contour reconstruction by addition of Fourier harmonics:
0 harmonic – 1, sums of harmonics 0–2 –2, 0–3 – 3, 0–4 – 4, 0–5 – 5, 0–6 – 6, 0–11 – 7 and 0–127 – 8 /5/

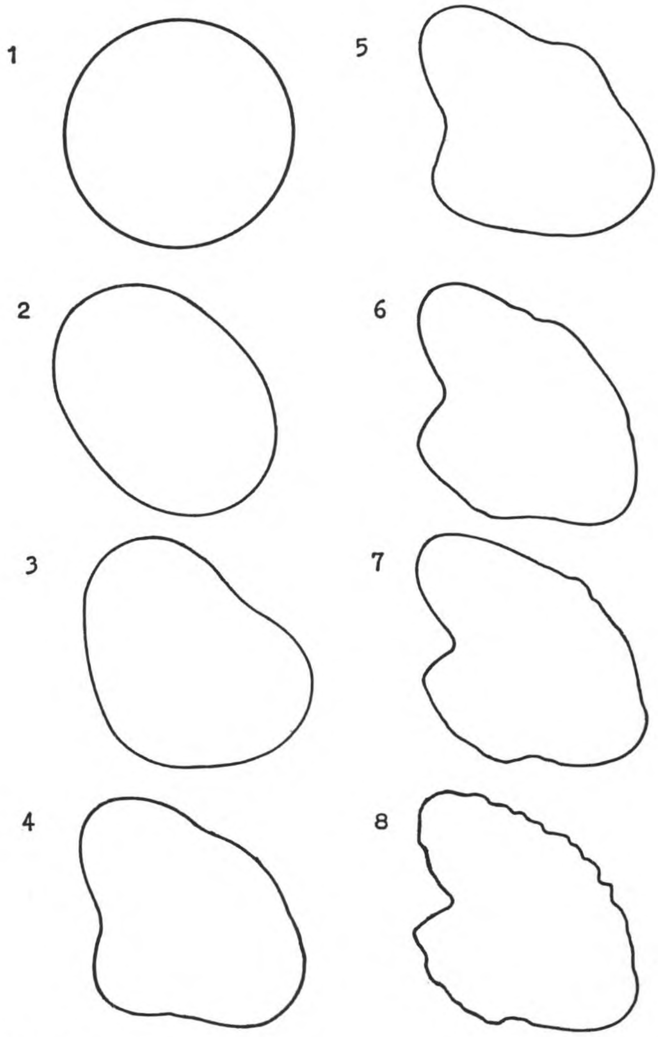


Fig. 12
Six-year-old Baltic sprat otolith contour reconstruction by addition of Fourier
harmonics: 0 harmonic – 1, sums of harmonics 0–2 – 2, 0–3 – 3, 0–4 – 4, 0–5 – 5

It is of interest that while reconstructing otoliths contour starting with low and ending in high order harmonics one has, as if to do with the reoccurence of main stages of the development of sprat otoliths shape in ontogeny. The shape undergoes gradual change from rounded towards more complex silhouette of adult Baltic sprat otoliths.
The preliminary results, obtained in this field, indicate that the silhouette of the otoliths turns more complex and variable with increase in the age of sprat /6/. No systematic differences has been observed in the shape of left and right otoliths of sprat of the same age from different Baltic Sea areas.
It has been established that the pecularities of otolith shape are more prominent in the variability of the phase than in the amplitude of the Fourier series harmonics /6/. Under typization the finding of a typical otolith is meant, in whose shape characteristic features of the type as much as possible would be reflected. For this purpose, it is enough to calculate the correlation matrix of shape of all the studied otoliths. Most typical is the otolith with the form showing the best correlation with that of all remaining ones (e.g. the sum of its correlation coefficients with all the others is the highest).

4. Ageing of Baltic sprat

4.1. Age in years

Methods of Baltic sprat ageing by seasonal layers in its otoliths are described quite completely /28/. For that purpose otoliths kept in envelopes are transferred by means of a scalpel onto an object depression slide and are cleared up by 2–5 drops of 80–90 per cent ethanol. Xylol, toluene, or some other organic liquids are not recommended because of their toxicity. Otoliths put into the Canadian balsam or plastic are examined without any additional preparation.

Cleared up otoliths are examined in transmitted (Fig. 13) or reflected (Fig. 14–15) light by means of a microscope. In most cases 80–100 times magnification will be adequate for ageing. Magnification up to 250 times is necessary only for ageing of some older specimens. Good results are obtained by the usage of transmitted polarized light and of the phase contrast, because then the otolith zonality is seen more clearly and on a dark background human eyes become less tired.

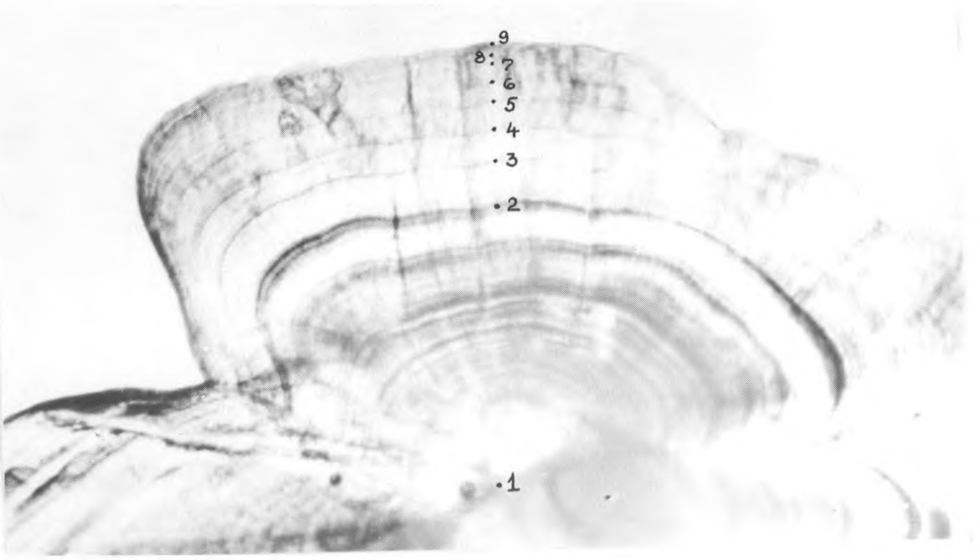


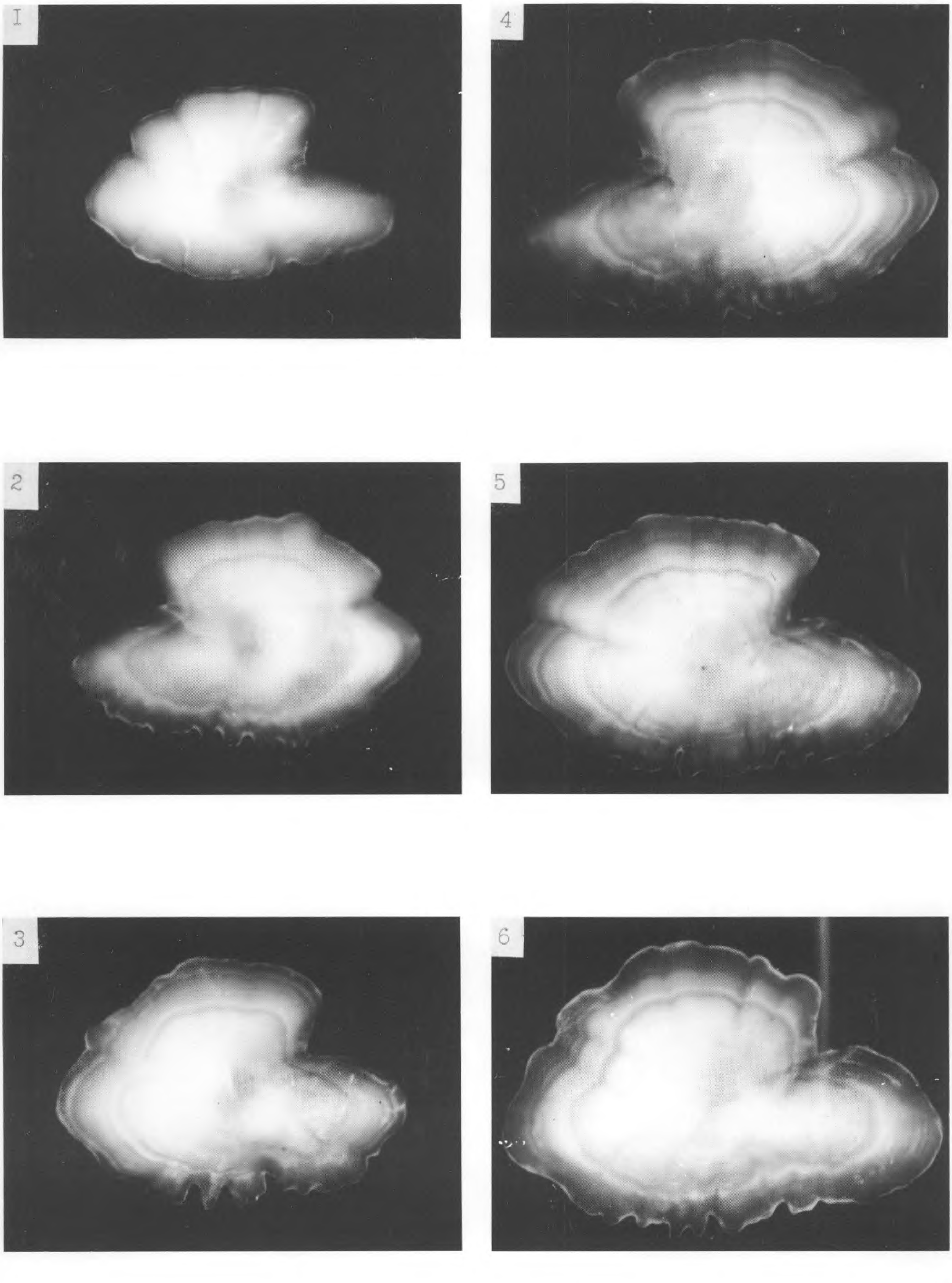
Fig. 13
The Baltic sprat otolith in transmitted light:
1 – nucleus, 2–8 – winter growth checks, 9 – dorsal edge of otolith

Ageing of Baltic sprat consists of recognition and counting of annual increments in otoliths, i.e. of the zones which are formed during a full year. Annual increments in Baltic sprat otoliths include two neighbouring zones: a wider summer hyaline zone and a narrower winter opaque one (Fig. 16). Summer hyaline zones may include one or several narrow opaque zones of intraseasonal growth checks which are not regarded in the case of ageing.
In the Baltic sprat otolith the distance from the otolith center to the first opaque winter zone in the dorsal direction is nearly 0.4 mm. The first opaque zone is followed by the second comparatively wide hyaline zone and the second narrow opaque zone. The distance from the first opaque winter zone to the second one is about 0.1 mm, but it is 0.06 mm from the second zone to the third one. Age of sprat is usually determined on the dorsal edge of the otolith where the growth seasonality can be seen the most clearly.
During microscopal examination of whole sprat otoliths in transmitted light additional light effects often arise due to inner heterogeneity of otoliths. These effects can be modified by wide possibilities of light adjustment. The opaque center of an otolith and the first opaque winter zone look, as a rule, darker than the adjacent hyaline zones in transmitted conventional light at magnifications up to 200 times. The second and the following narrow opaque winter zones may look more dark or light than the adjacent hyaline zones depending on light, adjustment and orientation of otoliths on the stage. Smooth changes of otolith orientations on the microscope stage allow to observe all possible transitions in relative optical density of neighbouring growth zones.
Application of polarized light in sprat otolith studies raises considerably the contrast of image, but it als may cause some additional light effects. It is to be stressed, that under microscope both in transmitted conventional or polarized light clear differences in optical densities of otolith growth zones are preserved in any case, irrespective of light adjustment and otolith orientation on the stage. Therefore, only relative differences in optical densities of the zones and peculiarities of their morphology are to be taken into account in ageing of Baltic sprat.

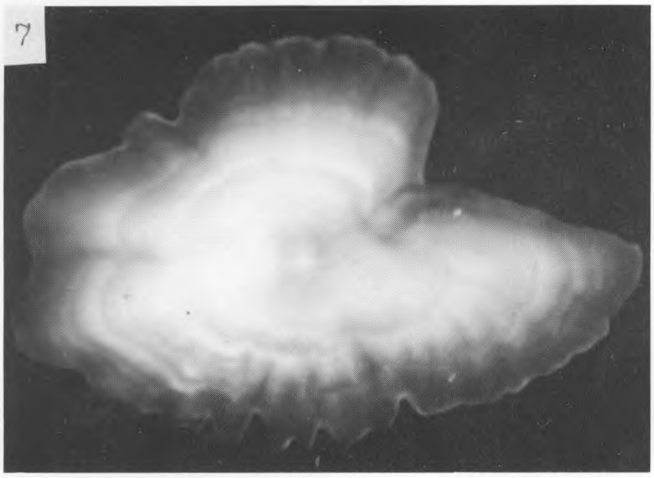
4.2. Daily growth increments

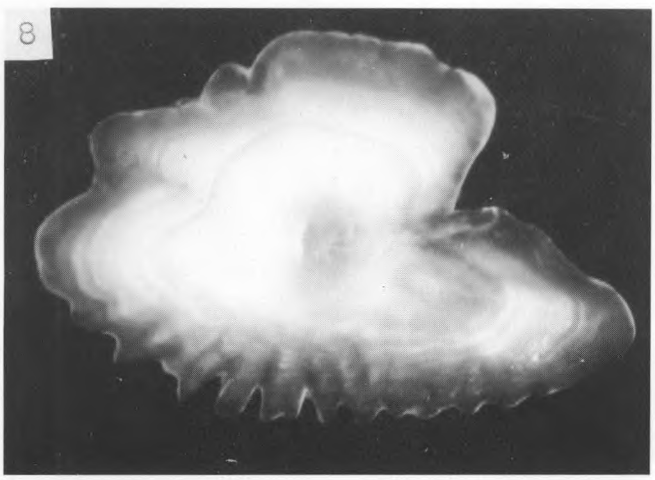
Studies of daily growth increments in fish otoliths can provide a lot of valuable information /10/. The determination of ages in days for fish larvae and juveniles turns to be the most effective. Counting of daily growth increments in otoliths permits to find birth dates of fishes, as well as to investigate the factors influencing upon their growth and mortality.
Both light and electron microscopy methods /5, 7/ can be used for studies of daily growth increments in otoliths of Baltic sprat larvae and juveniles.
In the case of application of the scanning electron microscope (SEM) separate parts of otoliths are to be grinded to receive longitudinal or transversal sections. In order to obtain a longitudinal section in the frontal plane an otolith is glued to a metallic pedestal. Clean surface of a pedestal is varnished and then it is dried. The otolith is pressed into the nearby dry varnish, its outer side being turned upwards. The appropriate position of the otolith is controlled with a stereoscopic microscope. The whole preparation is then varnished, and after its drying up, the otolith is grinded with abrasive to the level of its core. During the grinding the surface is periodically controlled by means of a microscope. Grinding is stopped when the otolith core is going to be seen directly under the surface. The surface obtained is etched by 1 per cent hydrochloric acid, then it is washed and dried up.
To gain transversal sections of otoliths they are put into the epoxy resin, e.g., and further preparation is made by the above described method.
Prepared surfaces of samples are vacuum-coated with a thin layer of gold. Exploration of the samples via SEM is usually carried out with the acceleration voltage of 5–15 kV. The samples are examined using the secondary or backscattered electrons at magnifications from 60 to 15,000 times (general view, chosen fragment, detail). An object is inclined at an angle of about 20 degrees for better exposition of its relief.
For the case of Baltic sprat the most regular zonality is observed in the dorsal part of the otoliths. Therefore it is advisable to begin counting of the daily growth increments from the core in the direction to the otolith dorsal edge. However, the general pattern of zonality differs noticeably depending on the object being examined: either the longitudinal surface or the transversal section.
Longitudinal sections provide adequate information on the inner structure of otoliths. It is not very difficult to make longitudinal sections, they have a drawback. Due to a concave form of otoliths it is impossible, as a rule, to get sections which would expose the daily growth increments across their whole extension from the core to the edge. If the study is aimed at counting and measurement of width of the daily growth increment, then

Fig. 14
The Baltic sprat otoliths in reflected light
(ICES Subdivision 25): 1–9 – age groups 1–9



Continuation **Fig. 14:**





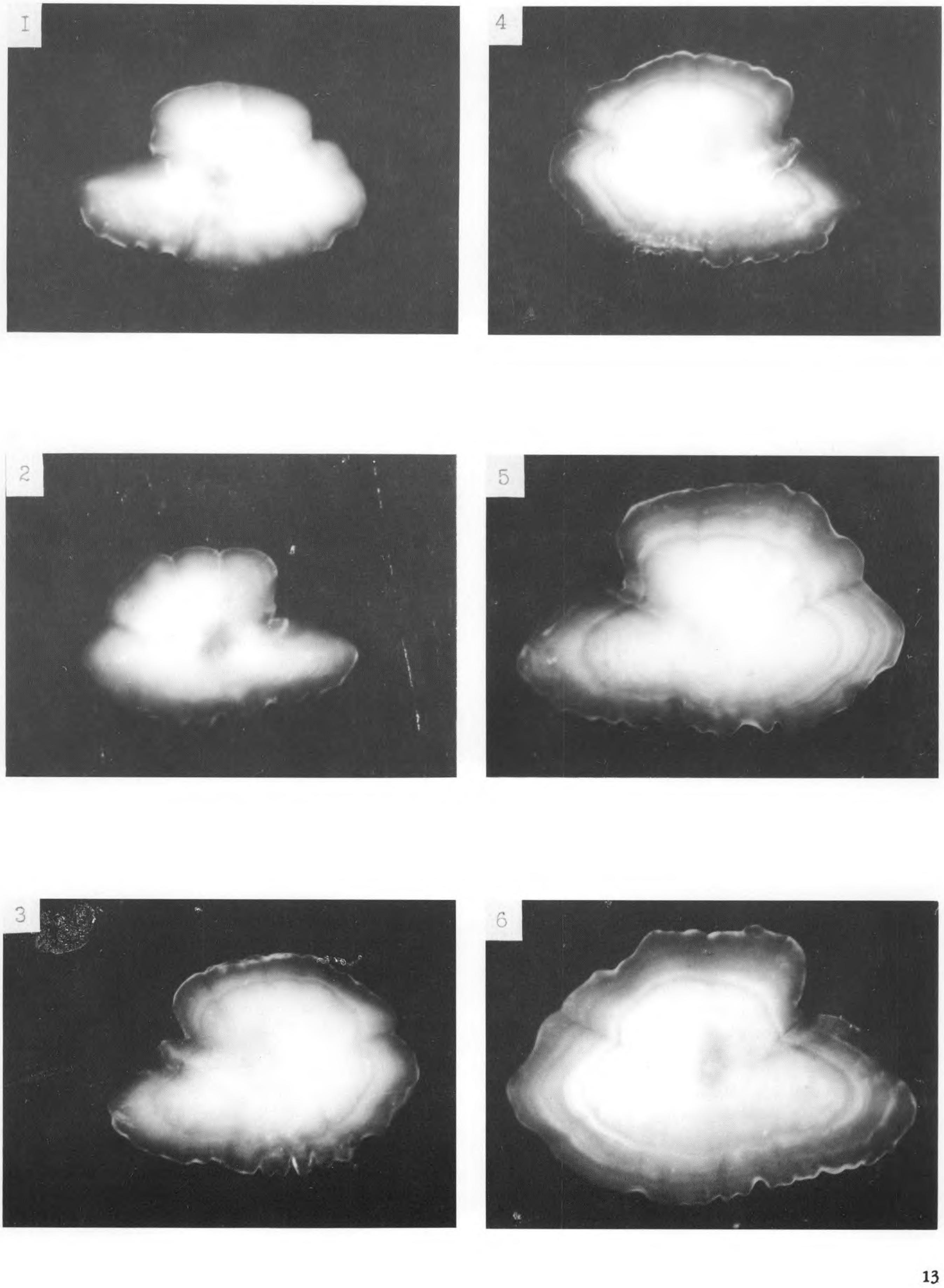
a section has to be made out of the dorsal part of the otolith, the plane of the section being disposed perpendicularly to the daily growth increments. But even in this case a part of daily growth increments can remain out of the section plane. Another drawback is that very thin edges of sections are sometimes etched, and some growth increments at the edges are, therefore, absent.

Transversal sections passing through the otolith core cross all daily growth increments from the core, to the edge of the otolith. When studying the transversal otolith sections two possible directions of counting of daily growth increments are to be considered, i.e., from the core to the outer edge, or from the core to the dorsal edge. Certain difficulties appear in the first case connected with counting of daily growth increments, which are becoming exceedingly narrow at the otolith edge. However, in this case daily growth increments can be counted in one direction. In the other case the width of the increments is praktically the same as that in the longitudinal sections, but the direction of counting needs certain changes due to the conçave form of otoliths. It should be emphasized that the directions of counting of daily growth increments may only be recommended. As a rule, the direction of counting does not influence appreciably to the precision of ageing, but it contributes essentially in the back-calculation of growth rate by otolith daily growth increments. To gain comparable results measurements of increments are to be performed always in the same direction. It is quite advisable to measure the width of the daily increments in the direction from the core to the dorsal edge.

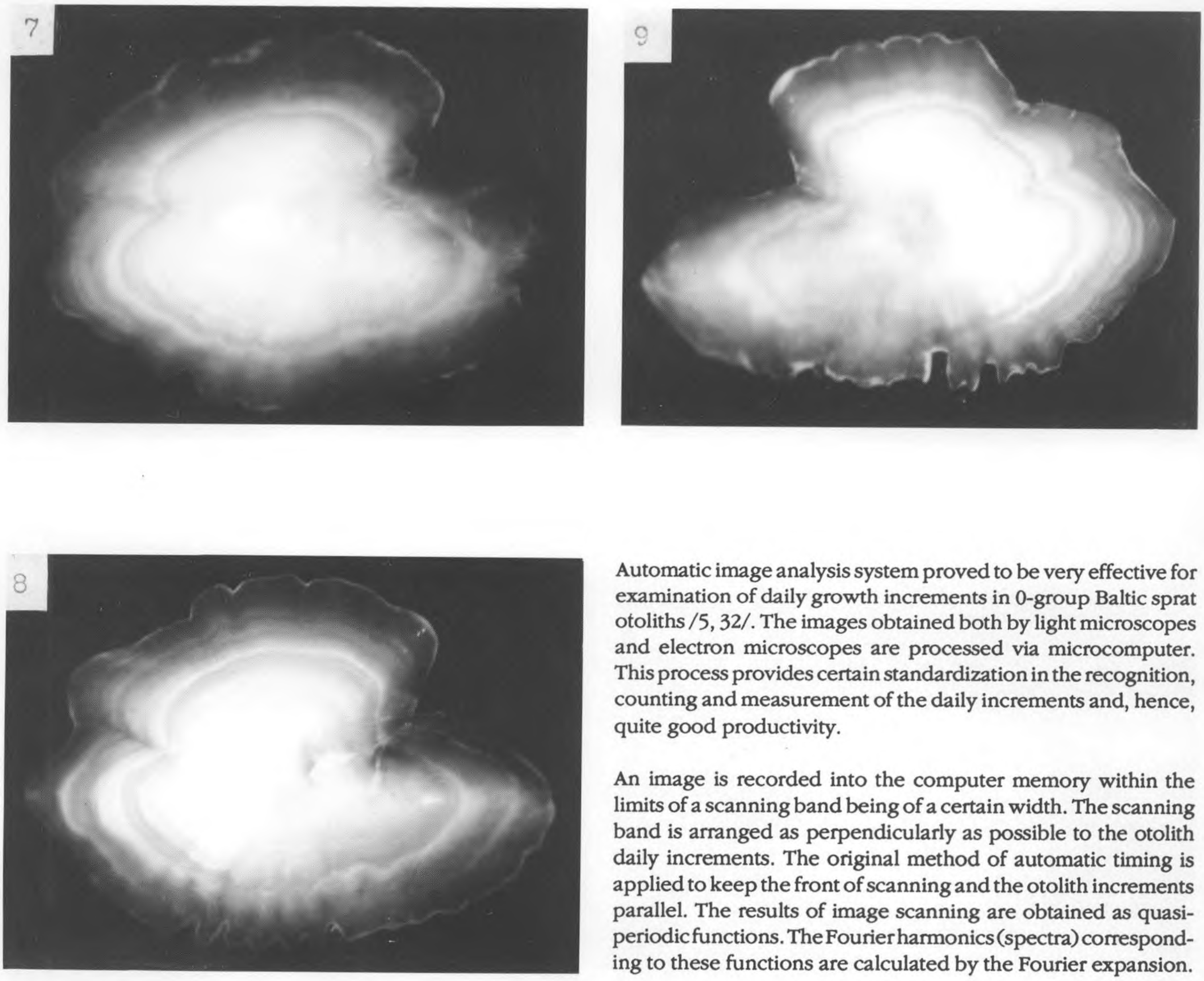
The following method of counting of daily growth increments in sprat otoliths using light microscope were presented by S. ALSHUT /7/. Otoliths are removed from the labyrinth of the inner ear of larvae by means of a thin needle under the microscope at 50 times magnification. Then otoliths are separated from the tissues, washed in a drop of distilled water and 96 per cent ethanol. Otoliths are being dried up in the air during 3 hours, then they are placed on the object slide into a drop of immersion oil and protected by a cover glass. Preparations are examined under the light microscope using phase contrast at magnifications up to 1,000 times.

Certain difficulties emerge in the process of proper focus adjustment of a microscope to real series of increments, when counting daily growth increments in otoliths of sprat juveniles (0-group). The results of the counting can be improved, if the longitudinal sections of otoliths are used, instead of the whole otoliths. For this purpose the otolith is put on the object slide into the Canadian balsam, its outer side being turned upwards. Subsequently it is grinded approximately to the level of the core by a fine abrasive. The longitudinal otolith sections put into the transparent resin can also be used, though it will complicate the studies to a certain extent.

Fig. 15
The Baltic sprat otoliths in reflected light
(ICES Subdivision 26): 1–9 – age groups 0–8



Continuation **Fig. 15:**



Automatic image analysis system proved to be very effective for examination of daily growth increments in 0-group Baltic sprat otoliths /5, 32/. The images obtained both by light microscopes and electron microscopes are processed via microcomputer. This process provides certain standardization in the recognition, counting and measurement of the daily increments and, hence, quite good productivity.

An image is recorded into the computer memory within the limits of a scanning band being of a certain width. The scanning band is arranged as perpendicularly as possible to the otolith daily increments. The original method of automatic timing is applied to keep the front of scanning and the otolith increments parallel. The results of image scanning are obtained as quasi-periodic functions. The Fourier harmonics (spectra) corresponding to these functions are calculated by the Fourier expansion.

Filtration of the high order spectra obtained can be carried out to smooth down and reduce the effect of noises.
The smoothed quasi-periodic functions are backcalculated by means, of the inverse Fourier expansion. Then the extrema are found and distances between the minima of the quasi-periodic curve (in µm) are calculated corresponding to the width of concrete daily increments in the otoliths. The low order harmonics of the Fourier spectrum give the main contribution to the formation of quasi-periodic functions describing the periodicity of otolith growth. High order harmonics are determined to a great extent, by noises.
Quite a serious problem is the recognition of subdaily increments in fish otoliths, including Baltic sprat otoliths. The area of probable exhibition of subdaily increments in Baltic sprat otoliths are the first 30–40 increments. Usually they are not numerous – only few subdaily increments. Grooves of subdaily increments in sprat otoliths are characterized by noticeably smaller depth and cannot be duly recognized.

5. "Natural tags"

5.1. Seasonal increments

Studies of variability of the mean width of growth zones in Baltic sprat otoliths have begun not long ago: in early 70s by A. LINDQUIST /17/. The mean width of the first summer growth zone in sprat otoliths from the Northern Baltic was shown to be less than in the otoliths from the Southern Baltic.
In the middle of the 70s the otolith measurements were used for back calculations of sprat length, the specimens were taken from the Bornholm and Gdansk regions of the Baltic Sea /14/. Differences in radii dimensions of sprat otoliths from those regions were also shown in the paper.
Later it was supposed that the mean values of the first and second growth zones and their statistical parameters could be used as "natural tags" in population studies /28, 33/. It was established that the mean width of the first summer growth zone in Baltic

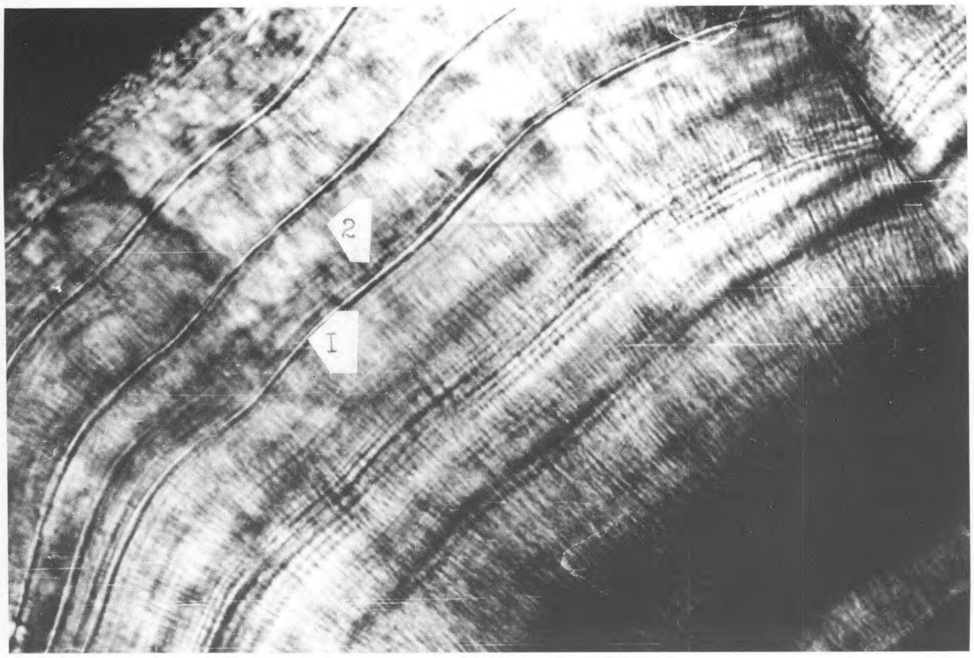


Fig. 16
Dorsal part of the Baltic sprat otolith:
1 – winter growth check,
2 – summer growth zone

sprat otoliths tended to decrease rather smoothly in the direction from the Southern Baltic regions to the Northern ones. The mean width of the first growth zone in the otoliths of 1972, 1975, 1982 and 1983 sprat year classes was shown to be characterized for the ICES subdivisions by the following values: 0.43–0.45 mm for subdivisions 25; 0.41–0.44 mm for subdivision 26; 0.40–0.43 mm for subdivisions 27 and 28; 0.40–0.41 mm for subdivision 29; 0.38–0.40 mm for subdivision 32 /33/. The mean width of the second growth zone in the otoliths of the same year classes was within the limits of 0.09–0.16 mm.

The mean width of the first growth zone in sprat otoliths depends most probably on the time of spawning season and growth conditions during the first year of life. The existing differences in those characteristics are apparently caused by later spawning of sprat in the Northern regions of the Baltic Sea.

The mean width of the second growth zone depends on the feeding conditions and growth of sprat during its second year of life and on its length reached during the first year. The otolith "natural tags", i.e. the mean widths of the first and the second growth zones are shown /33/ in many cases to be applicable for differentiation, e.g., sprat of the Gulf of Finland from sprat of the Baltic proper. Also separate sprat year classes from the Gulf of Finland can be usually differentiated by these characteristics.

The relative temporal stability in the values of examined otolith characteristics for separate year classes and sea regions gives evidence to a definite attachment of sprat to concrete large regions of the Baltic Sea and to the fact that sprat does not undertake extent migrations.

5.2. Microstructure

Microstructure of Baltic sprat otoliths, as shown above may be revealed by the methods of light and electron microscopy. Some peculiarities in otolith microstructure of sprat juveniles can be used as "natural tags" /29/:

1. the number of daily growth increments which corresponds to the age in days with a certain correction;
2. mean width of the daily growth increments and the character of its variability depending on age of fishes;
3. the pattern of growth regular periodicity, the period fluctuating from 3 days to 3 weeks;
4. the characteristic checks of single irregular growth discontinuities caused by sharp influence of environmental factors, e.g., low temperature.

Distinctions in otolith microstructure are due to differences in the complexity of environmental conditions in various parts of sprat habitat.

6. Prospects of usage of fish otoliths in the studies on fisheries and ecology

By M. V. MINA and G. A. KLEVEZAL /35/ the recording structures of plant and animal organisms "... are characterized by the fact that parts of a structure emerging at different times have different morphological parameters, and once appeared, the structural pecularities of newly formed parts are preserved then for a long time". The properties of fish otoliths as recording structures, i.e. their lamellarity, morphological heterogenity of their parts being formed at different times and correspondence of one or another structural element to definite events in fish life were used in ichthyological (ecological) studies long ago. The analysis of otoliths, of these truly unique formations, can be considered as a method in studies on fish ecology.

Most often otoliths are used for ageing of fishes. The age of many fishes in the temperate zone can be determined by the regularly forming otolith yearly layers. For ageing of tropical fishes the otolith daily growth increments are used at least in the first years of their lives /10/. Nevertheless relatively few examples of fish ageing methods can be found which are scientifically valid. Elaboration of such methods can become a perspective trend of studies. Correct ageing determines the quality of all recomendations concerning rational use and protection of exploited fish stocks.

Studies in fish growth are closely connected with their ageing. Examination of otolith daily increments opens new prospects for these studies /10/. The main problem is wether the width of the otolith increment reflects the actual growth of fishes by days. When the problem is solved, a unique possibility appears for detailed studies on the influence of ecological factors upon the growth rate of fishes. The difficulties arising in precise measurements of increments having widths of some micrometers only, can be surmounted using problem-oriented image analysis systems.

There also exists an attractive opportunity to use otoliths in systematics and population studies. As a rule, the external morphology and some elements of inner structure, including otolith microstructure, are species-specific. The possibility to study variability of otolith silhouettes for herring /8, 13/, as well as for sprat /5, 6/ was demonstrated using image analysis systems.

A lot of pecularities in the otolith lamellar structure that depend on fish ecology are successfully used as natural (ecological) tags in population studies and in the research on fish distribution and migrations. The ratio of the stable oxygen and carbon isotopes in otolith substances allows to measure the water temperature in the inhabit places of the fish and in some cases to reveal its migration tendencies /11, 22/. The stable nitrogen isotope ratio allows to draw conclusions on the character of fish trophic level /24/.

Studies on otolith elemental composition are of great interest /10/. Series of daily increments are being examined by means of SEM and microanalyser. That contributes to better understanding of the structure of increments /30/. Moreover, possibilities of detecting of certain specific elements (pollutants) in otolith substance and of the time when those have affected fishes, will be available.

Conclusions

1. Use of Baltic sprat otoliths in fisheries studies allows to solve a number of problems related with distinguishing of stock units, stock assessment and management, as well as with revealing of stock recruitment regularities.
2. Seasonal zones and microstructure of Baltic sprat otoliths are a kind of integral indicator of many changes in the Baltic Sea pelagial.
3. Application of new approaches, e.g. isotope and elemental analysis, considerably increases the importance of the analysis of Baltic sprat otoliths in fisheries and ecological studies.

References

1. APS, R.: Age and growth of sprat in the Gulf of Finland. Finnish Fisheries Research, 6 (1985), p. 134–140.
2. APS, R.: Sprat stock dynamics in the Northern Baltic in 1950–1987. Rapp. P.-v. Reun. Counc. int. Explor. Mer, 190 (1989), p. 210–222.
3. APS, R.; BENENSON, I.; KALEIS, M.; KORYTIN, N.; KRYAZHIMSKI, F.: Spatial model of the Baltic sprat population dynamics. ICES, Baltic Fish Committee, C.M. 1987/J: 16, 16p.
4. APS, R.; GENTZEN, B.; SHIROKOV, S.; USTINOVA, L.: Allometric growth of the Baltic sprat. ICES, Baltic Fish Committee, C.M. 1989/J.: 6, Ref. D, 16p.
5. APS, R.; PAAT, A.; UDER, Y.-O.: Growth and shape of Baltic sprat otoliths. ICES, Baltic Fish Comittee, C.M. 1988/I: 14, 20p.
6. APS, R.; PAAT, A.; UDER, Y.-O.; USTINOVA, L.: Variability of shape of the Baltic sprat otoliths. ICES, Baltic Fish Committee, C.M. 1989/J: 5, Ref. D, 9p.
7. ALSHUTH, S.: Daily growth increments on otoliths of laboratory-reared sprat, Sprattus sprattus L., larvae. Meeresforschung, 32 (1988), p. 23–29.
8. BIRD, I. L.; EPPLOR, D. T.; CHECKLEY, D. M.: Comparisons of herring otoliths using Fourier series shape analysis. Can. J. Fish. Aquat. Sci., 43 (1986), p. 1228–1234.
9. BLACKER, R. W.: Recent advances in otolith study. In: Sea Fisheries Research, F. R. Harden Jones (Ed.), London (1974), p. 67–90.
10. CAMPANA, S. E.; NEILSON, I.: Microstructure of fish otoliths. Can. J. Fish. Aquatic Sciences, 42 (1985), p. 1014–1032.
11. DEVEREUX, I.: Temperature measurements from oxygen isotope ratios of fish otoliths. Science (Wash., DC) 155 (1967), p. 1684–1685.
12. FAO: Fisheries Circular No. 736 (1981). – 100p.
13. GROTH, B.; APS, R.; PAAT, A.; UDER, Y.-O.: The shape of adult herring otoliths in the Western Baltic. ICES, B. F. C. C.M. 1988/I: 25, 12p.
14. GRYGIEL W. I.: Growth pattern of the sprat caught in the southern Baltic in 1974–1977. ICES, C.M. 1978/I: 12.
15. HAAKE, P. W.; WILSON, C. A.; DEAN, I. M.: A technique for the examination of otoliths by SEM with application to larval fishes. In: Proc. of the 5th Ann. Larval Fish Conf. Bryan, C. F.; Conner, I. V.; Truesdala, F. M. (Eds.). LSU Press, Balton Rouge, Luisiana (1982), p. 12–15.
16. IRIE, T.: On the forming season of annual rings (opaque and translucent zones) in the otoliths of several marine teleosts. F. Fac. Fish. Anim. Husb. Hiroshima Univ., 1 (1957), p. 311–318.
17. LINDQUIST, A.: Contribution to the knowledge of Baltic sprat (Sprattus sprattus). ICES, C.M. 1971/H. 19.
18. MESSIEH, S. N.: Use of otoliths in identifying herring stocks in the Southern Gulf of St. Lawrence and adjacent waters. J. Fish. Res. Board Canada, 29 (1972), p. 1113–1118.
19. MESSIEH, S. N.: Growth of the otoliths of young herring in the Bay of Fundy. Trans. Am. Fish. Soc., 4 (1975), p. 770–772.
20. MINA, M. V.: A note on a problem in the visual qualitative evaluation otolith zones. J. Cons. Int. Explor. Mer., 32 (1968), p. 93–97.
21. MUGIYA, Y.: Calcification in fish and shellfish. IV. The differences in nitrogen content between the translucent and opaque zones of otolith in some fish. Bull. Jap. Soc. Sci. Fish., 31 (1965), p. 896–901.
22. MULCAHY, S. A.; KILLINGLEY, J. S.; PHLEGER, C. F.; BERGER, W. H.: Isotopic composition on otoliths from a benthopelagic fish, Coryphaenoides acrolepis, Macrouridae: Gadiformes. Oceanol. Acta, 2 (1979), p. 423–427.
23. OJAVEER, E.: Marine pelagic fishes. In: The Baltic Sea . A. Voipio (Ed.). Elsevier Oceanography Series, 30 (1981), p. 276–292.
24. SCHOENIGER, M. J.; DENIRO, M. J.: Nitrogen and carbon isotopic composition of bone collagen from marine and terrestial animals. Geochim. Cosmochim. Acta, 48 (1984), p. 625–639.
25. TESCH, F. W.: Age and growth. In: Methods for assessment of fish production on fresh waters. W. E. Ricker (Ed.). Blackwell Scientific Publications, Oxford and Edinburgh, (1968), p. 93–102.
26. WILLIAMS, T., BEDFORD, B. C.: The ose of otoliths for age determination. In: Ageing of fish. Bagenal T. B. (Ed.), Proc. Sympos. Reading (1974), p. 114–123.
27. АПС Р. А.: К вопросу о структуре популяции Балтийского шпрота. В кн.: Проблемы современной экологии. Тарту (1978), с. 105-106.
28. АПС Р. А.: Возраст и рост балтийского шпрота. Рига, Авотс (1986). 56 с.

29. АПС Р.А., МЕЙЛЕР Б.Л., ПААТ А.А.:
Естественные метки в микроструктуре отолитов рыб.
В кн.: Биологические ресурсы водоемов Балтийского моря, Вильнюс (1987), с. 15-16.
30. АПС Р.А., МЕЙЛЕР Б.Л., САММЕЛСЕЛЬГ В.А.:
О строении зон роста отолитов балтийского шпрота Sprattus sprattus balticus (G.Schneider)(Clupeidae).
Вопросы ихтиологии, 22 (1982), с. 503-507.
31. АПС Р.А., ПААТ Ю.А.:
О морфологии отолитов балтийского шпрота по данным сканирующей электронной микроскопии.
В кн.: Рыбохоз. исслед. в бассейне Балтийского моря. вып.14. Рига, Звайгзне (1979), с. 133-139.
32. АПС Р.А., ПААТ А.А., УДЕР Ю.-О.Ф.:
Проблемы определения возраста сеголетков балтийского шпрота по суточным приростам на отолитах.
Fischerei-Forschung, Rostock, 26 (1988), с. 82-86.
33. АПС Р.А., УСТИНОВА Л.А.:
Об изменчивости зон роста отолитов балтийского шпрота.
Fischerei-Forschung, Rostock, 24 (1986), с. 47-49.
34. АПС Р.А., ШИРОКОВ С.В., УСТИНОВА Л.А.:
Изменчивость роста балтийского шпрота.
Fischerei-Forschung, Rostock, 26 (1988), с. 77-81.
35. МИНА М.В., КЛЕВЕЗАЛЬ Г.А.:
Принципы исследования регистрирующих структур.
Успехи современной биологии, 70 (1970), с. 341-352.
36. НИКОЛАЕВ И.И.:
Влияние планктона на распределение салаки и балтийской кильки.
Труды НИИ рыбного хозяйства СНХ Латвийской ССР, 3 (1961), с. 201-223.
37. ОЯВЕЕР Э.А.:
Об экологических основах дифференциации внутривидовых группировок пелагических рыб Балтийского моря.
В кн.: Проблемы совр. экол. Тарту (1978), с. 104-105.
38. ОЯВЕЕР Э.А., КАЛЕЙС М.В.:
О некоторых океанологических предпосылках, определяющих количество и распределение пелагических рыб в Балтийском море.
Океанология, 14 (1974) с. 544-554.
39. СВЕТОВИДОВ А.Н.:
Фауна СССР. Рыбы.
Москва-Ленинград, Издательство АН СССР,2 (1952),- 331 с.

PART II

GUIDE FOR THE USE OF BALTIC HERRING OTOLITHS IN FISHERIES STUDIES

FETTER, M., Baltic Fisheries Research Institute, Riga

GROTH, B., Institute of Sea Fisheries and Fish Processing, Rostock

KESTNER, D., Institute of Sea Fisheries and Fish Processing, Rostock

WYSHINSKI, M., Institute of Sea Fisheries, Gdynia

Contents

Introduction

Studies of the Baltic herring otoliths are of great importance for the stock assessment and management. By means of the otoliths not only ageing of specimens is carried out but also their belonging to a definite biological group is determined.
Despite the existence of several well elaborated classification systems for the Baltic herring otoliths, their practical application for identification of the stock units often brings disagreements between different workers /36/. The cause lies on the one hand in the complexity of obtaining the objective assessments (the object of studies is rather complex), and on the other hand in an inadequate formalization of the existing systems of the otolith classifications.
The present paper is aimed at the data compilation on studies, usage, and classification of the Baltic herring otholiths. Taking into account the significance of the herring otoliths for the fishery studies, this paper, not claiming on the completeness of exposition, can provide an idea of morphological diversity of the Baltic herring otoliths.
The paper has been prepared according to the joint programme adopted by specialists from Institut für Hochseefischerei und Fischverarbeitung (Rostock), Morski Instytut Rybacki (Gdynia), and Baltic Fisheries Research Institute (Riga).
Tha authors are grateful for valuable help in preparing this paper to the colleagues: V. BELYASHOVA, R. GRZEBIELEC, G. KORNILOV, A. NAGLIS, A. PAAT, T. RAID, B. SHLIMOVICH, N. KRASOWSKAJA.

1. On Baltic Herring

The history of the Baltic herring studies numbers more than two hundred years when C. LINNAEUS /20/ had defined Baltic herring (Clupea harengus varietas membras L.) as a variety of Atlantic herring (Clupea harengus harengus L.). Data on different aspects of herring biology are given in summarizing papers by G. SCHNEIDER /35/, J. LUNDBECK /21/, N. BIRYUKOV /3/, E. OJAVEER /5/, E. BIESTER /11/, G. OTTERLIND /30/.
Spring-and-autumn-spawning herrings inhabiting the Baltic Sea differ by the time of maturation and spawning and adapt to spring and autumn maxima of zooplankton productivity. These two groups of herring have different complexes of morphometric parameters which reflect the differences in the feeding habits, temperature conditions for embryonal and larval development, migration patterns, etc. /1, 2, 6, 10, 12, 17, 26, 33/.
Spring and autumn herrings are relatively well identified by means of the otoliths, the size of the central field and the form of the first growth zone being the main criteria /4/.
In its turn, the population of the spring and auttumn herrings consists of a number of smaller biological groups which need special studies for their taxonomic status identification.
According to E. OJAVEER /5/ these herring groups differing by many biological parameters, e. g. sexual cycle, spawning time and place, conditions of eggs and larval development, etc., are self-reproducing, although not always panmictic and correspond to the local population /5/.
So far as many climate factors undergo clinal changes in the Baltic Sea, morphometric herring parameters have analogous clinal variability too. The herring length and weight are decreasing, the width of the otolith first growth zone is diminishing, the ratios between the otolith length and head length, the otolith length and head height, the head length and body length are increasing with the decrease of salinity and vegetation period reduction from the Western Baltic to the Northern and Eastern Baltic /5/.
Comparative analysis of herring biological groups from different areas of the Baltic Sea was made in many papers /6, 8, 10, 12, 32, 33/.
At present populations of the sea and gulf herrings are distinguished by E. OJAVEER /27/ amongst the spring herring of the Baltic Sea. The gulf herrings can be divided into five populations of different abundance dynamics, morphological features, spawning times, etc. /5, 29/.

These are the following:

- Gulf of Riga herring;
- Gulf of Finland herring;
- Gulf of Bothnia herring;
- Bothnian Sea herring;
- Swedish fjord herring.

Sea herrings can be subdivided into the following populations of different abundance dynamics, growth rate, morphological and other features /5, 11, 29, 31, 33/:

- Swedish east coast herring;
- herring of the Eastern part of the Central and Northern Baltic;
- coastal herring of the Southern Baltic;
- Western Baltic herring (mainly Rügen herring).

Seven populations are distinguished amongst autumn herring /27/. These are:

- Western Baltic herring;
- Southern Baltic herring;
- herring of the Western part of the Central and Northern Baltic;
- herring of the Eastern part of the Central and Northern Baltic;
- Gulf of Riga herring;
- Gulf of Finland herring;
- Gulf of Bothnia herring.

2. Studies of Baltic herring otoliths.

2.1. Methodical aspects.

Baltic herring otoliths are examined under a light microscope in reflected light against a dark background. There are some methods for preparing the otoliths to be examined under the microscope.

1. An otolith is put on a object depression slide, its outer side being turned upwards. To obtain a clear image it is fully submerged in ethanol or xylol. When required, the otolith examined may be turned upside down by means of a scalpel or pincers, or its position may be changed in order to obtain the clearest image of growth zones on a rostrum. This is of great importance for ageing of older specimens.

2. Before examination the otoliths are put on a special black plastic plate with depressions and are covered by Canada balsam or another transparent resin (or plastic). Usually 100 pairs of the otoliths can be placed on one plate. The plates may be made of transparent plastic. In this case the otoliths are examined against a black background.

3. To study the microstructure of herring otoliths, their longitudinal or transversal sections are made in advance using the methods described in Part II of the present paper dealing with the sprat otoliths.

Magnifications of 6x8 or 4x12 are usually adequate for Baltic herring ageing by the otoliths. Photos for the present paper were made using the S_z-T_r model of zoom-stereoscopic microscope OLYMPUS with PM-10 M photographic nozzle. For inner light measurements and determination of the exposure time, an automatic EMM-7 exponometer was used. Photographic material was the 35 mm ORWO film withe the light sensitivity of 15 DN. The otoliths were put in 96 % ethanol and photographed against a black background. Two light sources were used. They were located paralell to the otoliths long axis and directed to an object at an angle of about 60°. Exposure at a proper light intensity was 1 second. The otoliths presented in this paper are given in scale of 21.4 : 1.

For this paper 50 otoliths in every age group were collected from the spawners sampled in the main spawning areas (Fig. 1) during the spawning periods of 1987 and 1988. It should be noted that those years were not typical as regards thermal conditions of the Baltic Sea environment /37/.

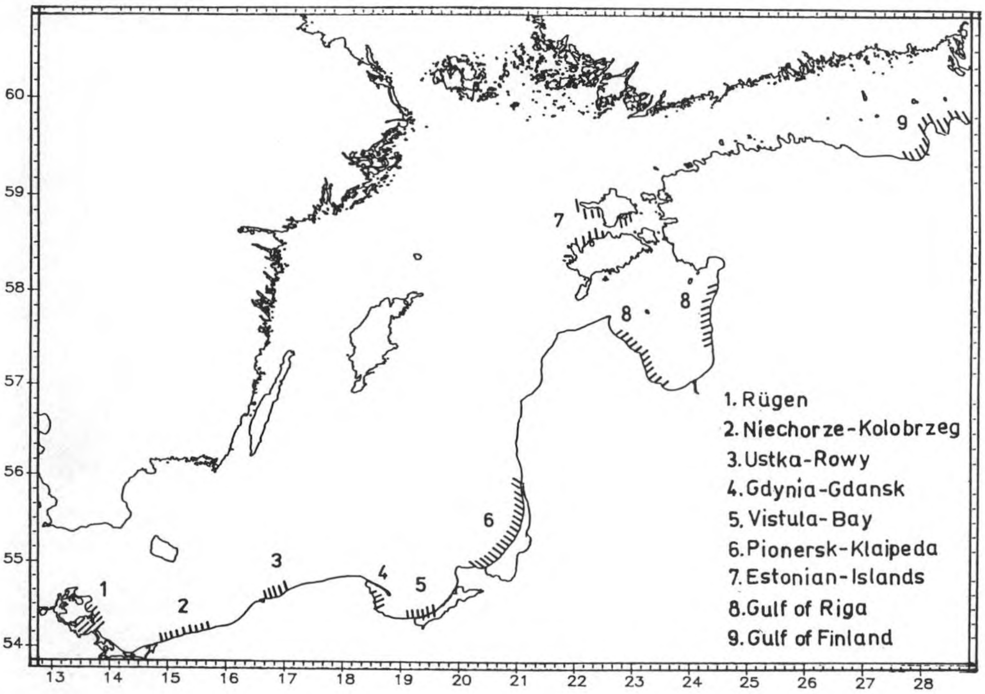


Fig. 1
Herring spawning areas with the places of sampling (1–9)

The long-term cooling begun in 1984, inconsiderably decreased only in 1988. This factor probably violated the spawning migrations of herring at Poland coasts (instability and low density of spawning concentrations, certain displacements of some spawning concentrations among the spawning grounds). The evidence to the phenomena was manifested through the increased number of specimens infected by Anisakis simplex nematode of Gdansk and through a greater number of specimens with a higher growth rate. On the other hand, the occurence of specimens with the otolith characteristic of the gulf herring was noted on the spawning grounds near Klaipeda in 1985–1987 /13/. The situation described was supposed to affect the results of morphometric analysis, smoothing down the differences between separate spawning areas.

Measurements of otoliths from principal spawning areas were carried out by the coordinated scheme (Fig. 2).

Stereoscopic microscope with ocular micrometer was used for measurements. The value of one ocular micrometer point was 0.0462 mm for the otolith samples from the Rügen area, and it was 0.025 mm for all the rest.

The following relative parameters of the otoliths were calculated:

- ratio of the second (third, etc.) growth zone width to the first growth zone width,
  $\frac{R_u - R_{u-1}}{R_1} \cdot 100$ (for all samples);

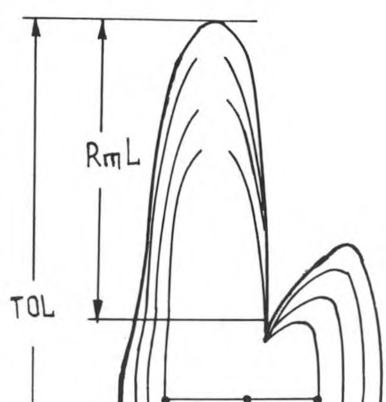


Fig. 2
Scheme of Baltic herring otolith.
TOL – total otolith length;
TOW – total otolith width;
RmL – rostrum length;
OW_1 – the first growth zone width;
$R_1, R_2, \ldots$ – otolith radii.

- ratio of total otolith length (TOL) to the total otolith width (TOW) –
- $\frac{TOL}{TOW}$ (for samples from the Rügen area, the Vistula Bay, the Pionersk-Klaipeda region, eastern part of Subdivision 29, the Gulf of Riga, the Gulf of Finland);
- ratio of the total otolith width (TOW) to the total otolith length (TOL) –
- $\frac{TOW}{TOL} \cdot 100$ (for samples from the Niechorze- Kolobrzeg, Ustka-Rowy, Gdynia-Gdansk regions);
- ratio of rostrum length (RmL) to the total otolith length (TOL) –
- $\frac{RmL}{TOL} \cdot 100$ (for all samples).

2.2. *External morphology*

Baltic herrings have the typical otoliths for herring in general. Principal datails of the herring otolith outer structure are described /22, 23/.
Baltic herring otoliths have the following basic elements of their outer structure: rostrum, anterostrum, postrostrum and pararostrum (Fig. 3). Ventral (between rostrum and postrostrum) and dorsal (between anterostrum and pararostrum) edges of the otolith have rather pronounced dentation. The otolith outer side is relatively smooth. The otolith central field is often protruding as a kind of rising of the outer side, radial grooves are slightly marked. The acoustic groove (sulcus acusticus) dividing the otolith surface into ventral and dorsal parts is seen on the inner side turned to the brain (Fig. 4).
There is a pit (fossa) approximately in the middle part of the acoustic groove which thus is divided into a fore and back parts.

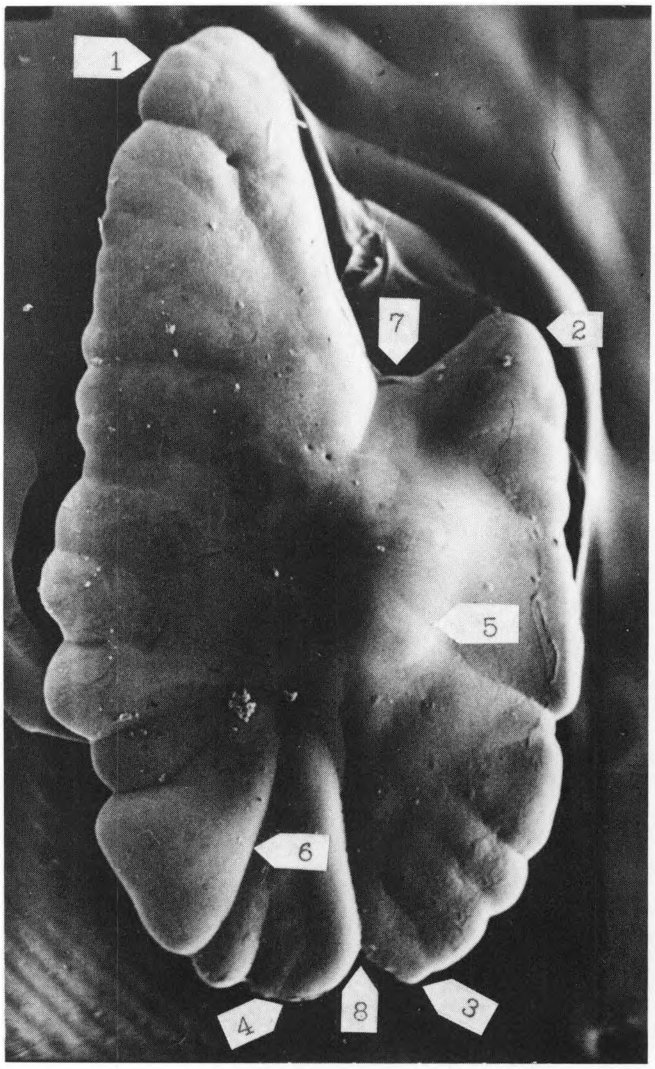


Fig. 3
Outer side of Baltic herring otolith.
1 – rostrum;
2 – anterostrum;
3 – pararostrum;
4 – postrostrum;
5 – central field;
6 – radial groove;
7 – excisura major;
8 – excisura minor.

2.3. *Classification of otoliths*

Since the time when Baltic herring became an object of studies valid criteria for differentation of its biological groups heve been searched for. K. Anwand /9, 10/ studying spring and autumn herring near the Rügen Island found certain differences in their otolith structures. The ratio of the second zone width and the first zone width were 19 % and 23 % for autumn-and spring-spawning herring, respectively.
Imaginary line connecting rostrum into unequal parts in spring herring, and into equal parts in autumn herring. In Rügen autumn herrings, exisura minor was developed more considerable than that in spring ones.
E. OJAVEER /24/ showed the possibility to distinguish the North-Eastern herring seasonal groups by the otoliths. Later these studies were continued: A. KOMPOWSKI /18/ published the classification of Southern Baltic herring otoliths, E. OJAVEER et al. /25/ gave a detailed classification of herring otoliths throughout the Baltic Sea using the methods of multidimensional statistics. Structural differences in the central part of the otoliths of spring and autumn herring juveniles were revealed in relation to their abundance in the Southern Baltic /15/.
Morphological analysis of Baltic herring juveniles (age group 1) showed that the majority of the otolith morphometric parameters are closely related to their length and hence, to the growth of fishes. Five morphometric parameters of the otoliths were revealed which well distinguished spring herring juveniles (age group 1) from the Southern and Northern Baltic /7/.
W. GRYGIEL /16/ exposed morphological differences among the otoliths of spring open sea herring, spring coastal herring and autumn herring /16/. The shapes (silhouettes) of herring otoliths in the Western Baltic were studied using semiautomated image analysis technique /14/.

2.3.1. Classification by G. RAUCK /34/.

An attempt to classify the otoliths of Western Baltic herring was made by G. Rauck /34/, who distinguished three types of the Western Baltic otoliths. Otoliths of Type A had an elongated shape with a small nucleus, a wide first growth zone and a narrow first winter zone. Excisure minor was well developed. Within the first growth zone so-called "metamorphosis ring" with a radius of 0.2–0.65 mm was often observed. The appearance of the ring is most probably connected with the changes of a biotope by 60–70 mm herring juveniles. After reaching this length, herring juveniles pass from the coastal zone to the distant

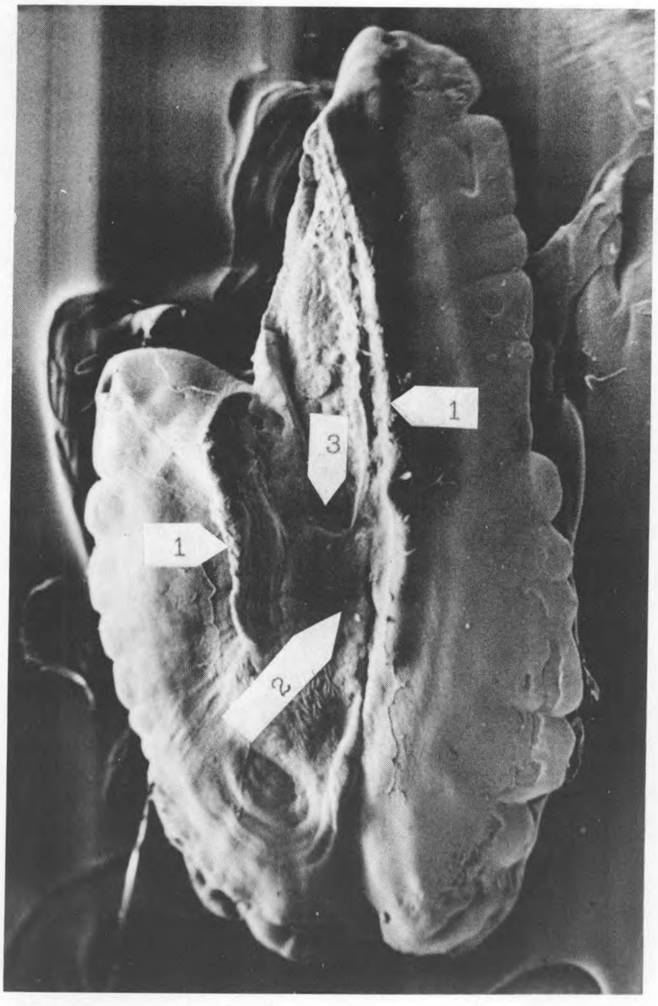


Fig. 4
Inner side of Baltic herring otolith.
1 – crests;
2 – sulcus acusticus;
3 – fossa.

parts of the Western Baltic. Herring of this otolith type are the objects of the fishery in the Bay of Kiel in spring.

Otoliths of Type B had a large first growth zone, a large nucleus, especially in juveniles, and poorly developed excisura minor. Herrings of B type otoliths were sampled in autumn, had gonads of IV-V maturity stages, and were identified as autumn spawning herring.

Otoliths of Type C had numerous growth zones, their widths being smaller than those in A type otoliths. The size and location of excisura minor were analogous to spring herring. G. RAUCK suggested that the herrings with C type otoliths were a mixture of different spawning groups, which might be subsequently divided into other types, e. g. E, D types, etc.

2.3.2. Classification by A. KOMPOWSKI /18/

A most detailed classification of otoliths collected from the Southern Baltic herring was elaborated by A. KOMPOWSKI /18,19/ who stated that they showed considerable diversity. In spite of this fact, three definite frequently encountered types of otoliths could be distinguished.

Type I. Otoliths are large and considerably elongated with a long rostrum. Nucleus is usually small. The first growth zone is relatively large. Excisura minor is incised sharply but not deeply. The line led trough excisura minor and the nucleus is paralell to the long axis of the otolith.

Type II. Otoliths are large but not so elongated as in Type I. The first growth zone is relatively narrow. The number of growth zones is generally much greater than in the otoliths of Type I. Other characteristics are similar to those of Type I.

Type II can be subdivided into three subtypes. Subtype IIA. Otoliths are large and have a long rostrum.

The nucleous is small or medium size. The winter zones are broader than in Type I. The first growth zone is small, the following zones are narrow, gradually diminishing.

Subtype II B. Otolith are large, massive, having rough surface and irregular shape. The nucleous is small or medium, but generally hardly visible trough an opaque substance secreted fairly abundantly. The first growth zone is small, the second zone is relatively broad.

Subtype II C. Otoliths are similar to those of Subtype II A, the difference exists in the second and in the third and sometimes in the fourth zone which are is much broader than the following ones.

Type III. Otoliths are smaller than those of the preceding types. In young herring, the nucleous is large and transparent, in older specimens it is very often covered by a secreted opaque substance and seems to be much smaller than it really is; sometimes the nucleous is even completely conealed. The first growth zone is relatively large. Exisura minor is poorly developed, frequently even completely missing. The line led through exisura minor and the nucleous forms an angle with the long axis of the otoliths. The exisura minor is deep and frequently most noticeable in young specimens. The most intensive growth rate is characteristic for Type I otoliths which are dominant amongst spawners of the southern coasts of the Baltic Sea in spring. The lowest growth rate is observed for Type II. Herrings with this type of otoliths prevail in summer-autumn season on feeding grounds of the southern Baltic. The majority of those herrings migrate to these areas from the north, from Swedish coasts.

Otoliths of Type III show a very rapid growth during the first three years of herring life. These otoliths are characteristic of herring spawning in autumn near the southern coast of the Baltic Sea.

The analysis of the data on the occurence of herrings with definite otolith types in various areas of the southern Baltic and in different seasons resulted in the following conclusion (A. KOMPOWSKI /18/). The otoliths of Type I are characteristic of herrings described by J. POPIEL /31, 32, 33/, i. e. coastal spring herrings which inhabit waters of low salinity in the river mouths and estuaries at the southern Baltic coasts. They spawn in the Pomeranian Bay from March till May and in the Bay of Gdansk from April till May. These are herrings with a short life cycle and a high growth rate abruptly inhibited when reaching maturity. The otoliths of Type II are encountered in the sea herrings which according to J. POPIEL /31, 32, 33/ and J. ELWERTOWSKI /12/ have a longer life cycle and a lower growth rate as compared to the coastal herring. For the first time they probably spawn in their third or fourth year. Most of these herrings come to the southern Baltic feeding grounds from the north: from central Baltic and, sometimes, from the Aland Islands. This was proved by G. OTTERLIND who had performed tagging of herrings /28/. However, a small part of these herrings may stay in the southern Baltic in certain years and spawn together with the coastal herring. Sea spring-spawning herrings are a mixture of many populations.

Therefore, structures of their otoliths are quite diverse. Due to this Type II can be divided into three subtypes.

Subtype II A is frequent in the Bornholm area and in the Bay of Gdansk. Subtype II B is less occuring: in the Bay of Gdansk mainly. Subtype II C is rare.

The otoliths of Type III are characteristic of autumn herring encountered throughout the Baltic Sea and especially frequent in its western part. They are spawning from August till November in the coastal zone and probably in the sea banks (the Middle banks, the Slupsk bank). These herrings reach maturity in the second or third year of life.

Classification of the otoliths proposed by A. KOMPOWSKI can be applied in identifying the three main biological herring groups, i. e. autumn, spring sea and spring coastal herrings inhabiting the southern part of the Baltic Sea.

2.3.3. Classification by E. OJAVEER.

A special study concerning the problem of spring and autumn herrings identification using their otoliths was carried out by E. OJAVEER/4, 5, 24, 25/. North-Eastern Baltic herrings could be distinguished nearly always by the central field size and the first growth zone width of their otoliths. The distance from the otolith center to the inner opaque edge of the first summer growth zone is taken for a radius of the otolith central field. The central field is usually distinct especially when placed in xylol for 1–2 minutes.

The central field radius is usually 0.18–0.25 mm for autumn herring otoliths, and up to 0.15 mm for spring herring. The spring herring otoliths have deeper grooves than those of autumn herring, and the angle between the medians of rostrum and anterostrum is greater in the first case. Besides, the first growth zone of the autumn herring otolith is much wider as compared to its subsequent zones than it is in the spring otoliths. Postrostrum and excisura minor are better developed in spring herring otoliths.

The classification of autumn and spring herring otoliths of the North-Eastern Baltic was also alaborated by E. OJAVEER /5/, the following parameters for autumn herring being under examination:

- degree of central field coating by opaque substance;
- otolith general form;
- relative widths of summer growth zones;
- size of an otolith;
- first winter zone width;
- peculiarities of the otolith surface;
- number of additional rings;
- percentage of abnormal, i. e. partially hyalined otoliths.

Autumn herring otoliths.

Autumn herring otoliths were divided into types on the basis of differences in the growth pattern, i. e. relative widths of growth zones. The size of otoliths, peculiarities of their surfaces, the number of additional rings and the percentage of abnormal otoliths were chosen as supplementary characteristics. The following types of otoliths were singled out on the basis of these parameters for the autumn herring of the Gulf of Riga and the adjacent part of the open sea.

Type I. The second and the third growth zones, and, sometimes even the fourth one, are considerably broader as compared to the subsequent zones. Otolith surfaces are even, smooth, additional rings being in small numbers or absent at all. The first winter growth zone is indistinct. Type I is characteristic of autumn herring in the Central and Southern Baltic.

Type II. The second growth zone is significantly broader than the subsequent ones. Otoliths are smaller in size than those of Type I, and their surface is rougher. Additional rings are observed on some otoliths of this type. Type II is characteristic of the Northern Baltic autumn herring.

Type III. Otoliths are small in size having a comparably narrow second growth zone. In juveniles they are corner-like. A lot of grooves (sulci) and additional rings are observed on a rough surface of the otoliths. Partially hyalined otoliths are encountered in this type in considerable numbers. Type III is characteristic of the Gulf autumn herring.

Autumn herrings with the I type otoliths are characteristic of the Baltic proper but they also occur in the Gulf of Riga in rather large amounts during the pre-spawning and spawning seasons, being seldom encountered there in the inter-spawning period. Autumn herrings with the II type otoliths are found chiefly in the Strait of Irben, but they may also occur in the Gulf of Riga and in the Baltic proper. Autumn herring with the III type otoliths is typical for the Gulf of Riga, especially for its eastern and southern parts. In the Gulf of Finland specimens with the III type otoliths dominate amongst autumn herring; herrings of the II type otoliths are numerous too. Herring with the I type otoliths are encountered in the central part of the Gulf of Finland in small numbers.

Spring herring otoliths.

Generalizing study of the Baltic Sea spring herring population composition and the otoliths was carried out by OJAVEER et al. /25/. Quite comprehensive classification of the Baltic spring herring otoliths was prepared basing on morphological peculiarities of their structure. It was stated that the otoliths of the Baltic Sea spring herring could be divided into three main types with respect to the widths of the two or three first growth zones, sizes of otoliths and lengths of rostrums. The first two types were subdivided into subtypes. Consideration of the subtypes is of special interest.

Type I, Suptype I-1. Otoliths are large with a relatively long rostrum and a large first growth zone. The growth zones beginning from the second to the fourth, or even to the sixth zone are broad or every broad. The first winter zone is indistinct. Additional rings are few or absent at all. Subtype I-1 in spawning concentrations is mainly encountered in the Western and Southern Baltic, and less frequently it occurs at the Central Baltic coasts.

Subtype I-2. Otoliths are large with relatively long rostrum. The second and the third growth zones are wide, much broader that the following ones. The first winter zone is mostly indistinct. Additional rings are few or absent at all. The otoliths of this subtype differ from the previous one mainly by a smaller width of the second growth zone. In spring concentrations, Subtype I-2 occurs generally in the Western, Southern, and Central Baltic. This subtype is encountered in smaller numbers as compared to other subtypes.

Suptype I-3. Otoliths are large with relatively long rostrum. The first growth zone is very large. The second, or the second and the third growth zones are very wide, considerably broader than the following ones. Beginning from the third or the fourth zone, their width sharply decreases. The first winter zone is seen distinctly. The central field is relatively small. Subtype I-3 differs from other subtypes principially by a larger first growth zone by a faster decrease in the widths of the subsequent growth zones, by a narrow first winter zone and by a small central field. The otoliths of Subtype I-3 are typical for the coastal herring of the Southern Baltic.

Type II, Subtype II-1. Otoliths are large or of medium size, with a long rostrum. The first growth zone is medium or broad.

Growth zones from the second to the fourth-sixth ones are relatively broad. The first winter growth zone is usually indistinct in samples from the South, and it is clearly seen in those from the North.

Subtype II-1 differs from Subtype I-1 by smaller first and second growth zones; and from Subtype I-2 by a smoother decrease in the widths of the growth zones beginning from the third one; it differs from Subtype I-3 by a smaller first growth zone, a smoother decrease in the growth zone widths and by the indistinct first winter zone. In spawning concentrations, Subtype II-1 is mainly encountered in the Central and Northern Baltic.

Subtype II-2. Otoliths are of medium size and broader than those of the previous subtypes. In most cases, the first growth zone is not large. The second, or the second and the third growth zones are much wider than the following ones. The first winter zone of otoliths from the Southern Baltic is indistinct, but that from the Northern Baltic is well distinctive as a rule. Otoliths of Subtype II-2 have usually additional rings. The otoliths in which opaque substance is completely or partially missing are sometimes encountered. This subtype differes from the I type otoliths by a smaller first growth zone; it differs from Subtypes I-1, I-2 by a conventionally narrow first winter zone; it differs from Subtype II-1 by smaller growth zones beginning from the third, usually narrow, first winter zone and by a larger number of additional rings. The otoliths of Subtype II-2 are typical for herring from the Northern and Central parts of the Baltic proper.

Type III. Otoliths are small and broad with a relatively short rostrum. The first growth zone is usually not large. The second growth zone is generally much broader than the following ones. The first winter zone is indistinct in the otoliths with a very small first growth zone, but it is distinct in the otoliths with a broader first growth zone. The otoliths surface is generally uneven, having many grooves. The otoliths have a lot of additional rings. Sometimes opaque substance is completely or partially missing in the otoliths. This type of otoliths is characteristic of the Gulf herring.

The occurence of herring with different otolith types in the spawning areas within the Baltic proper gives evidence to the fact that otoliths of Type I are typical for the Southern and Western Baltic, and those of Types II, III are typical for the Eastern and Northern Baltic.

2.4. *Problems of Identification.*

Three principal classification systems of Baltic herring otoliths are reduced to Table I basing on the descriptions of otolith structures and on the analysis of occurence of herring with different otolith types which were given in the studies by G. RAUCK, A. KOMPOWSKI, and E. OJAVEER /5, 19, 34/.

At a certain experience it is evidently possible to identify quite surely at least four large groups of herrings from the Baltic proper by outer appearance of otoliths and the length of fishes:

- autumn-spawning herrings in all areas of the Baltic Sea;
- spring coastal herrings of the Southern and Western Baltic;
- spring open sea herrings typical for the Central and Northern Baltic (Some difficulties arise in identifying the feeding period or when they are caught in the Southern Baltic);
- spring gulf herrings from the Gulf of Riga and of Finland.

It can be noted that the principal parameter for identifying the spring herring is the growth rate which is is reflected by absolute and relative values of the otolith growth zones widths and the fish length. So far as the lengths and the growth rates are gradually decreasing from south-west to north-east, morphological peculiarities of the otoliths allow rather roughly to consider Baltic herring either "northern" or "southern" populations. In the open sea herrings (Types C, II-A, B, C; II-1,2) caught during the feeding period in the Southern Baltic the origin-based differentiation between "western" and "eastern" is extremely difficult, although just this kind of identification would be of great importance for herring stock assessments. Besides, a considerable decrease in the growth rate of the Southern Baltic coastal herring is observed in recent years. This effects the structure of otoliths making them resemble the open sea herring otoliths. On the other hand the occurence of migrants from the Northern Baltic on spawning grounds of the Southern Baltic coastal herring also constributes to the difficulties of herring identification with respect to stock units.

Table I
Interrelation of the main classification systems of Baltic herring otoliths (A, B, C; I, II, III are types of otoliths).

<table>
<tr><th rowspan="2">Seasonal groups</th><th rowspan="2">According to</th><th colspan="5">Areas of the Baltic Sea</th></tr>
<tr><th>Western</th><th>Southern</th><th>Central</th><th>Northern (Eastern)</th><th>Gulf of Riga Gulf of Finland</th></tr>
<tr><td rowspan="3">Autumn herring</td><td>Rauck G.</td><td>B</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Kompowski A.</td><td></td><td colspan="2">III</td><td></td><td></td></tr>
<tr><td>Ojaveer E.</td><td></td><td colspan="2">I</td><td>II</td><td>III</td></tr>
<tr><td rowspan="5">Spring herring</td><td>Rauck G.</td><td>A</td><td colspan="2">C</td><td></td><td></td></tr>
<tr><td>Kompowski A.</td><td colspan="2">I coastal herring</td><td colspan="2">IIA, IIB, IIC open sea herring</td><td></td></tr>
<tr><td>Ojaveer E.</td><td colspan="2">I-1 coastal herring</td><td colspan="2">II-1, II-2 open sea herring</td><td>IIIA, IIIB gulf herring</td></tr>
<tr><td></td><td></td><td colspan="2">I-2 coastal herring</td><td></td><td></td></tr>
<tr><td></td><td></td><td>I-3 coastal herring</td><td></td><td></td><td></td></tr>
</table>

It must be stated concerning otoliths from the Western Baltic herring that the studies of numerous otoliths of the Rügen herring and practical attempts of their individual distinction from other populations did not result in a well-definable uniform type of "Rügen herring otolith". The morphological and morphometric characteristics of otoliths are extremely varying in one sample, and even to greater extent they are different when comparing samples taken at different times. This fact cannot surprise under consideration of different herring groups spawning in different places and times in a relatively wide total spawning area and later migrating to wide feeding areas with different environmental and feeding conditions. It can be also assumed that spawners not always use the former spawning places. These facts support the stated high variance of the otoliths characteristics.

Nevertheless, the Rügen herring can be distinguished by means of otoliths from autumn spawners and from herring originating from ICES Subdivisions 26, 27 and from distant northern areas. Nearly impossible is a serious individual distinction of herring originating from the Northern Arkona Basin, the Hanö Bay, and the area around Bornholm.

When studying Southern Baltic coastal herring, certain difficulties also arise from the fact that coastal spring herrings spawning at Poland coasts undertake feeding migrations in the direction of the Southern Baltic open sea or the Danish Straits. This refers to herring from the Pomeranian Bay, from Bornholm Basin and probably from the Bay of Gdansk. The herring feeding in the Danish Straits is infected by nematode of Anisakis genus, thus receiving a "natural tag". Infected specimens are encountered on spawning grounds in the Bay of Gdansk and sporadically in the Vistula Bay being distiguished by a higher growth rate. It can be assumed that infected specimens on these spawning grounds are migrants from the Western Baltic. The increase in number of infected herrings on spawning grounds in the eastern part of the Bornholm Basin coasts (Poland coast) and in the Bay of Gdansk was observed in 1985–1987 when strong cooling of sea water occured. It is supposed that extrem changes in water temperature made spawning herring migrate intensively from the west to the east in search for optimal thermal conditions for reproduction.

Thus spring coastal herrings migrate along the Southern Baltic coast within considerably vast area. However, it is impossible to determine in detail origin of several specimens using only the otolith characteristics. It should be emphasized that for the stock assessment the most essential problem is individual identification of any herring specimen in accordance withe the stock units. The reference of herring otoliths to a definite type is apparently subjective and depends not only on a specialist's experience but on a time and place of sampling. Otoliths of fishes caught in the spawning period on the spawning grounds or near them are more or less easily identified. When identifying herring caught in the feeding period on the feeding grounds difficulties are quite frequent. In this respect it is essentially difficult to analyse samples obtained from the fishery places in the summer period in the Southern Baltic where mixing of fishes having different origin occurs more intensively.

3. Baltic herring otoliths from the main spawning regions.

3.1. Rügen

Statistical parameters of herring otolith morphometric features are given in Table 2, photographs of otoliths are shown in Fig. 5.

Table 2
Statistical parameters of Baltic herring otoliths from the Rügen area (M is average, δ is standard deviation).
Designations are given in 2.1.

Parameters	Age group							
	2		3		4		5	
	M	δ	M	δ	M	δ	M	δ
TOL	3.19	0.19	3.87	0.25	3.98	0.24	4.47	0.16
TOW	1.60	0.08	1.87	0.09	1.92	0.08	2.09	0.09
RmL	1.19	0.11	1.42	0.12	1.47	0.14	1.67	0.13
OW_1	1.18	0.07	1.26	0.09	1.17	0.07	1.21	0.08
R_1	1.00	0.10	1.09	0.11	0.99	0.09	1.04	0.08
R_2	1.37	0.11	1.47	0.12	1.37	0.10	1.45	0.09
R_3	–	–	1.68	0.11	1.57	0.10	1.67	0.09
R_4	–	–	–	–	1.69	0.12	1.82	0.08
R_5	–	–	–	–	–	–	1.91	0.09
$\frac{TOL}{TOW}$	2.0	0.09	2.07	0.11	2.08	0.13	2.14	0.10
$\frac{RmL}{TOL}\cdot 100$	37.1	2.1	36.7	2.1	36.8	2.5	37.2	2.3
$\frac{R_2-R_1}{R_1}\cdot 100$	38.3	10.2	36.5	10.7	40.1	10.5	39.4	7.9
$\frac{R_3-R_2}{R_1}\cdot 100$	–	–	19.2	7.2	20.2	7.3	21.4	6.6
$\frac{R_4-R_3}{R_1}\cdot 100$	–	–	–	–	12.4	4.4	14.3	5.2
$\frac{R_5-R_4}{R_1}\cdot 100$	–	–	–	–	–	–	9.0	3.1

3.2. Niechorze-Kołobrzeg

Statistical parameters of herring otolith morphometric features are given in Table 3, photographs of otoliths are shown in Fig. 6.

Table 3
Statistical parameters of Baltic herring otoliths from the Niechorze-Kołobrzeg region (M is average, δ is standard deviation).
Designations are given in 2.1.

Parameters	Age group									
	1		2		3		4		5	
	M	δ	M	δ	M	δ	M	δ	M	δ
TOL	2.42	0.17	3.19	0.18	3.44	0.17	3.72	0.20	3.91	0.18
TOW	1.27	0.08	1.57	0.08	1.68	0.08	1.80	0.09	1.88	0.08
RmL	0.89	0.10	1.25	0.11	1.34	0.09	1.40	0.11	1.44	1.10
OW_1	1.25	0.08	1.22	0.07	1.09	0.07	1.13	0.07	1.14	0.08
R_1	1.04	0.09	1.03	0.09	0.89	0.08	0.95	0.07	0.95	0.08
R_2	–	–	1.35	0.11	1.28	0.08	1.32	0.08	1.34	0.08
R_3	–	–	–	–	1.45	0.09	1.48	0.09	1.51	0.09
R_4	–	–	–	–	–	–	1.59	0.09	1.61	0.10
R_5	–	–	–	–	–	–	–	–	1.69	0.10
$\frac{TOW}{TOL}\cdot 100$	52.2	2.8	49.2	1.9	48.8	0.27	48.5	1.9	48.3	2.14
$\frac{RmL}{TOL}\cdot 100$	36.6	2.5	39.1	3.0	38.8	2.3	37.8	2.6	36.9	1.8
$\frac{R_2-R_1}{R_1}\cdot 100$	–	–	31.6	9.0	44.6	8.8	39.4	6.8	42.1	8.0
$\frac{R_3-R_2}{R_1}\cdot 100$	–	–	–	–	20.3	6.4	18.0	4.8	18.1	6.4
$\frac{R_4-R_3}{R_1}\cdot 100$	–	–	–	–	–	–	11.4	4.4	10.7	3.7
$\frac{R_5-R_4}{R_1}\cdot 100$	–	–	–	–	–	–	–	–	8.2	2.5

3.3. *Ustka-Rowy*

Statistical parameters of herring otolith morphometric features are given in Table 4, photographs of otoliths are shown in Fig. 7.

Table 4
Statistical parameters of Baltic herring otoliths from the Ustka-Rowy region (M is average, δ is standard deviation). Designations are given in 2.1.

Parameters	Age group									
	1		2		3		4		5	
	M	δ	M	δ	M	δ	M	δ	M	δ
TOL	2.45	0.18	3.17	0.19	3.58	1.19	3.76	0.21	3.80	0.16
TOW	1.28	0.08	1.57	0.07	1.73	0.07	1.81	0.08	1.84	0.07
RmL	0.94	0.11	1.24	0.10	1.37	0.10	1.41	0.13	1.42	0.10
OW_1	1.25	0.09	1.19	0.08	1.18	0.07	1.16	0.08	1.11	0.07
R_1	1.06	0.09	1.00	0.10	0.99	0.08	0.98	0.10	0.94	0.07
R_2	–	–	1.35	0.12	1.37	0.09	1.35	0.09	1.33	0.09
R_3	–	–	–	–	1.55	0.11	1.50	0.09	1.50	0.10
R_4	–	–	–	–	–	–	1.61	0.11	1.58	0.09
R_5	–	–	–	–	–	–	–	–	1.65	0.09
$\frac{TOW}{TOL}\cdot 100$	52.2	2.2	49.6	2.2	48.4	1.9	48.2	2.8	48.5	2.2
$\frac{RmL}{TOL}\cdot 100$	38.2	3.1	39.0	2.5	38.3	2.2	37.5	2.5	37.3	2.4
$\frac{R_2-R_1}{R_1}\cdot 100$	–	–	34.8	7.8	38.5	7.2	38.3	10.2	42.7	8.7
$\frac{R_3-R_2}{R_1}\cdot 100$	–	–	–	–	18.8	4.3	16.4	7.1	18.4	5.4
$\frac{R_4-R_3}{R_1}\cdot 100$	–	–	–	–	–	–	11.5	4.5	9.0	4.6
$\frac{R_5-R_4}{R_1}\cdot 100$	–	–	–	–	–	–	–	–	6.6	2.4

3.4. *Gdynia-Gdansk*

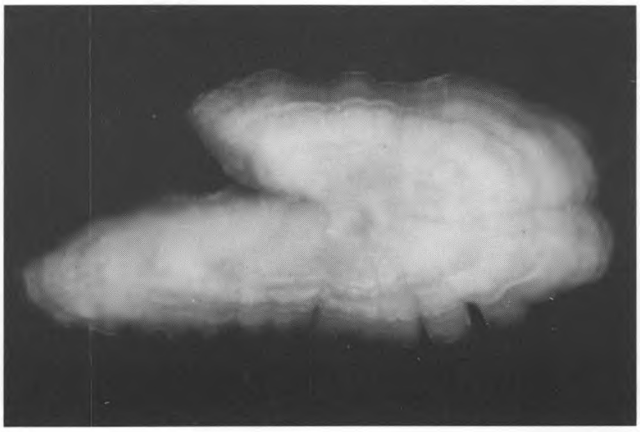
Statistical parameters of herring otolith morphometric features are given in Table 5, photographs of otoliths are shown in Fig. 8.

Table 5
Statistical parameters of Baltic herring otoliths from the Gdynia-Gdansk region (M is average, δ is standard deviation). Designations are given in 2.1.

Parameters	Age group									
	1		2		3		4		5	
	M	δ	M	δ	M	δ	M	δ	M	δ
TOL	2.26	0.20	3.10	0.15	3.55	0.17	3.66	0.14	3.81	0.21
TOW	1.20	0.09	1.56	0.07	1.74	0.09	1.78	0.07	1.85	0.08
RmL	0.84	0.11	1.20	0.11	1.35	0.11	1.35	0.10	1.42	0.12
OW_1	1.15	0.09	1.20	0.09	1.20	0.06	1.14	0.08	1.11	0.08
R_1	0.96	0.10	1.00	0.09	1.02	0.08	0.97	0.09	0.95	0.08
R_2	–	–	1.33	0.09	1.39	0.08	1.35	0.09	1.33	0.09
R_3	–	–	–	–	1.57	0.09	1.51	0.08	1.50	0.10
R_4	–	–	–	–	–	–	1.60	0.09	1.60	0.11
R_5	–	–	–	–	–	–	–	–	1.66	0.12
$\frac{TOW}{TOL}\cdot 100$	53.0	2.6	50.4	2.09	49.1	2.5	48.7	1.8	48.6	2.2
$\frac{RmL}{TOL}\cdot 100$	36.9	2.5	38.6	2.6	37.9	2.6	36.9	2.4	37.3	2.5
$\frac{R_2-R_1}{R_1}\cdot 100$	–	–	33.9	10.3	36.2	6.0	38.5	7.2	41.2	8.7
$\frac{R_3-R_2}{R_1}\cdot 100$	–	–	–	–	17.4	4.2	16.9	5.5	18.0	5.4
$\frac{R_4-R_3}{R_1}\cdot 100$	–	–	–	–	–	–	9.7	3.4	10.3	3.6
$\frac{R_5-R_4}{R_1}\cdot 100$	–	–	–	–	–	–	–	–	7.2	2.5

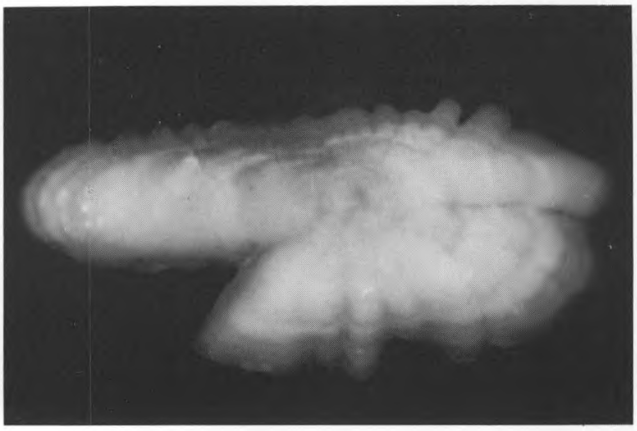
Fig. 5
Herring otoliths from the spawning area near Rügen.

– age group 1, fish length 13.0 cm, 1987 year-class;

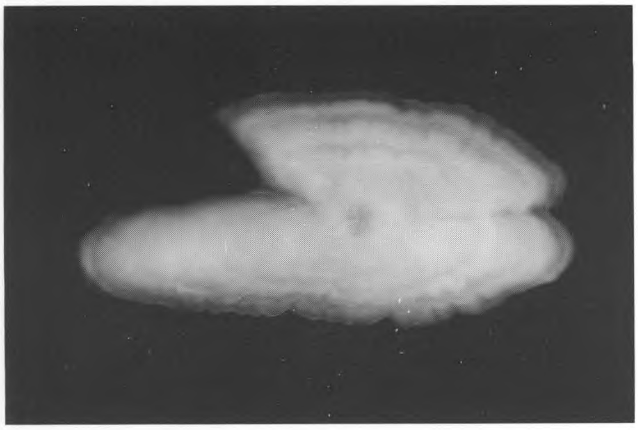


– age group 5, fish length 28.5 cm, 1982 year-class;

– age group 3, fish length 21.5 cm, 1985 year-class;

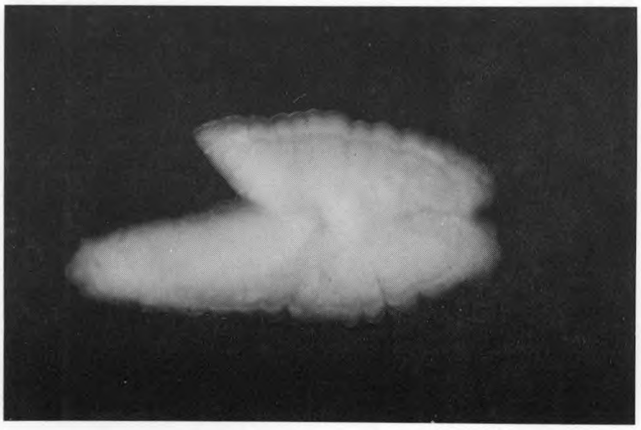


– age group 6, fish length 28.5 cm, 1982 year-class.

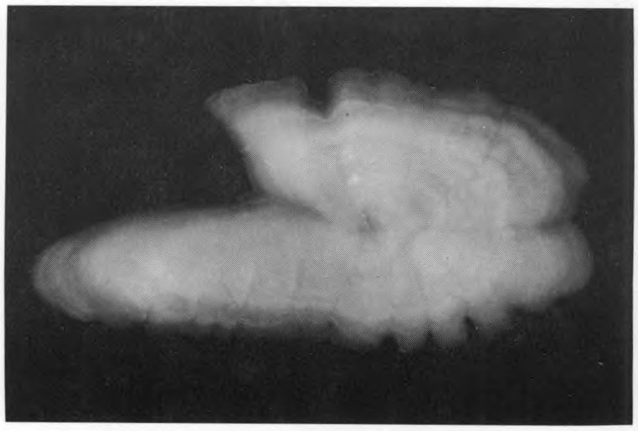


– age group 4, fish length 22.5 cm, 1984 year-class;

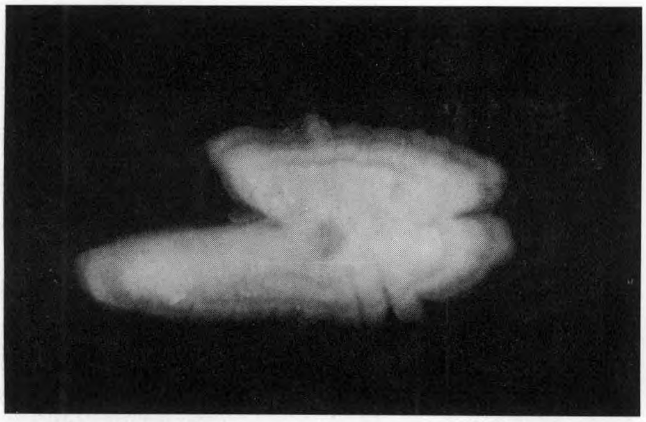
Fig. 6
Herring otoliths from the spawning region Niechorze-Kołobrzeg.



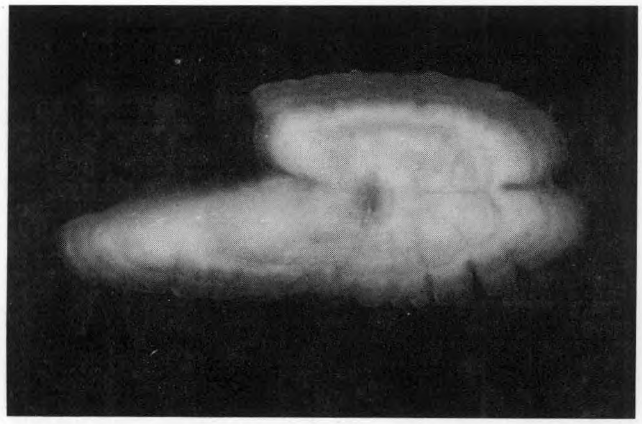
– age group 2, fish length 18.5 cm, 1986 year-class;



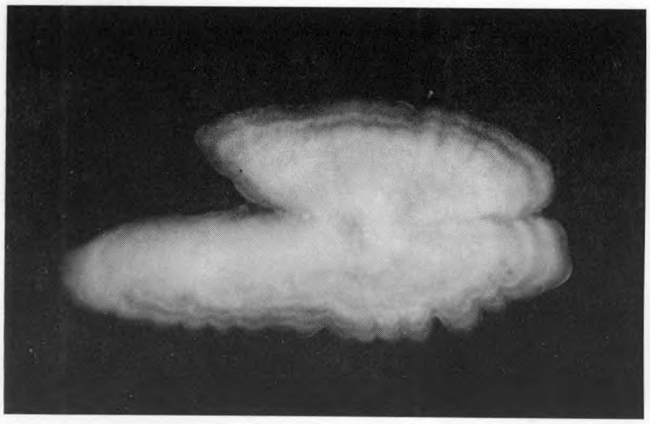
– age group 5, fish length 28.0 cm, 1983 year-class;



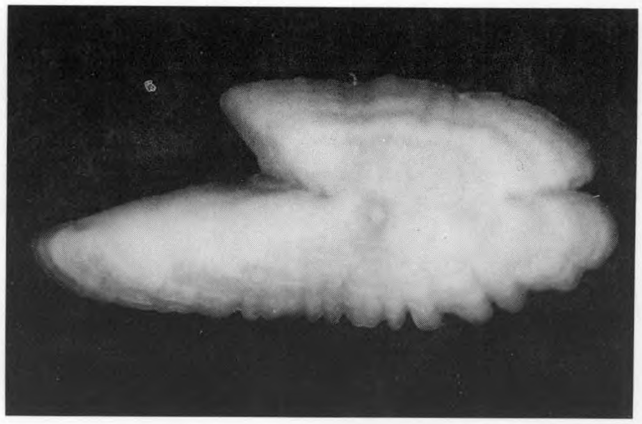
– age group 3, fish length 20.5 cm, 1985 year-class;



– age group 5, fish length 22.5 cm, 1983 year-class; otolith can be referred to open sea herring, probably from eastern Baltic coast;

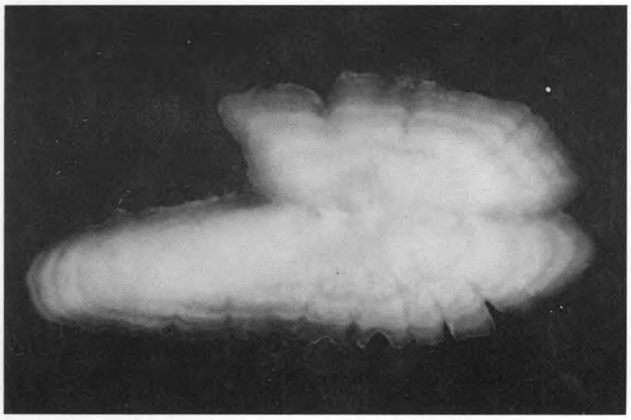


– age group 4, fish length 25.5 cm, 1984 year-class;

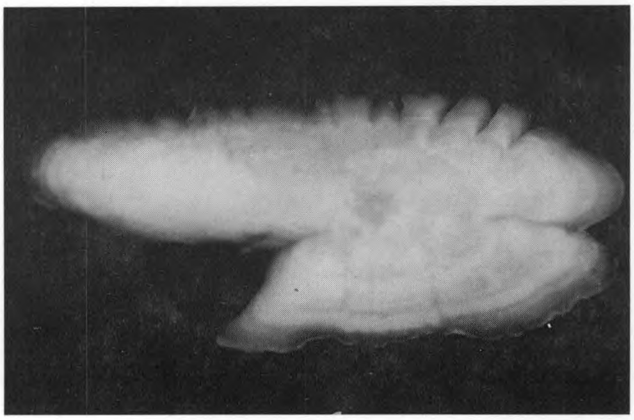


– age group 6, fish length 26.0 cm, 1982 year-class;

Continuation **Fig. 6.**

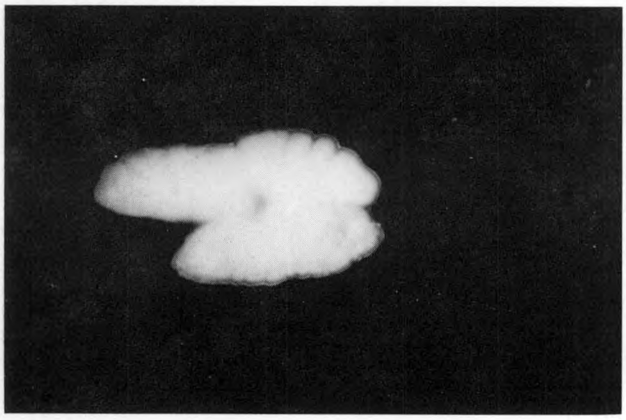


– age group 6, fish length 29.0 cm, 1982 year-class, infected by Anisakis nematode;

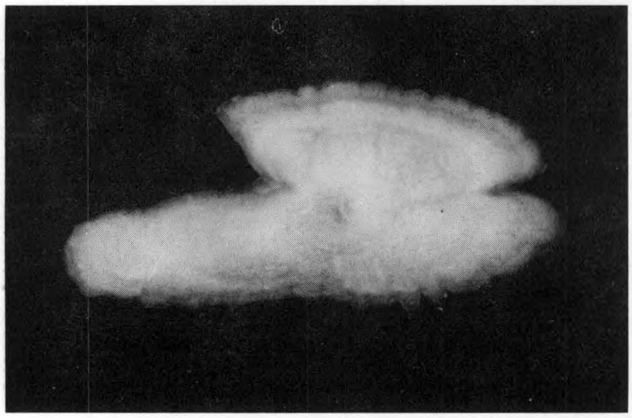


– age group 8, fish length 29.5 cm, 1980 year-class, infected by Anisakis nematode.

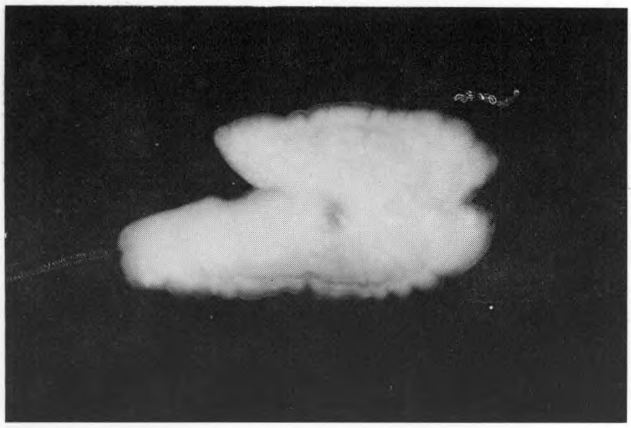
Fig. 7
Herring otoliths from the spawning region of Ustka-Rowy.



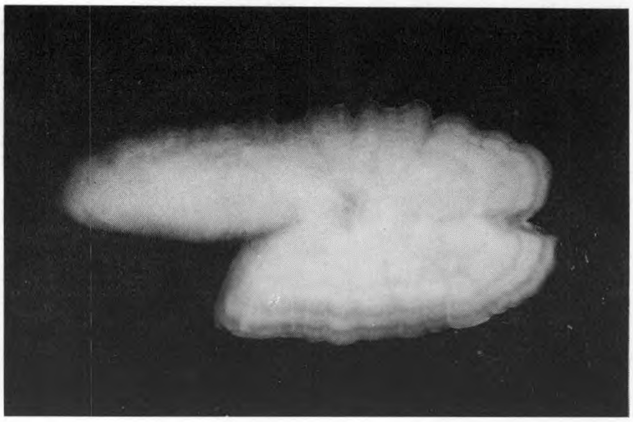
– age group 1, fish length 12.5 cm, 1987 year-class;



– age group 3, fish length 21.5 cm, 1984 year-class;

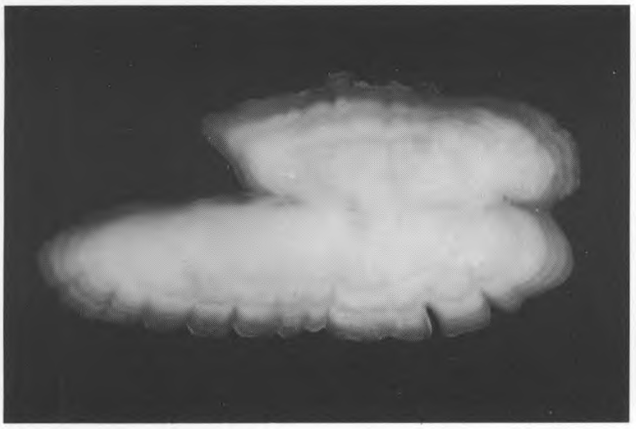


– age group 2, fish length 17.5 cm, 1986 year-class;

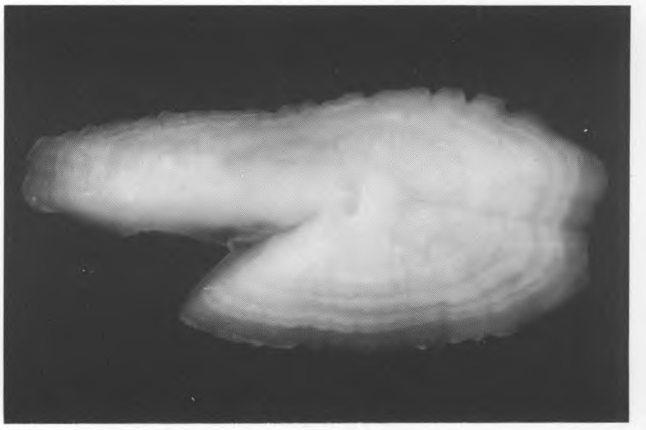


– age group 4, fish length 23.5 cm, 1984 year-class;

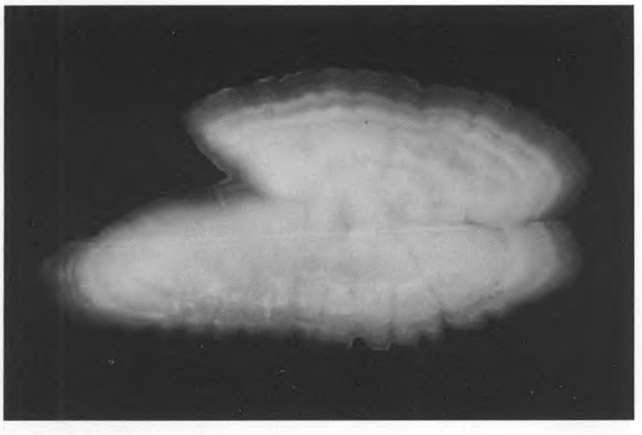
Continuation **Fig. 7**



– age group 6, fish length 24.5 cm, 1982 year-class;

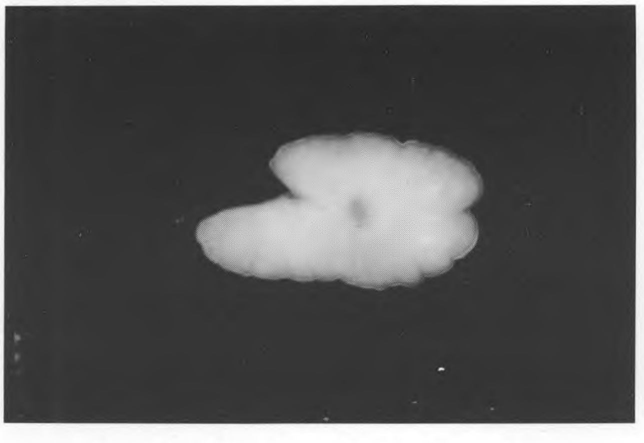


– age group 9, fish length 26.5 cm, 1979 year-class

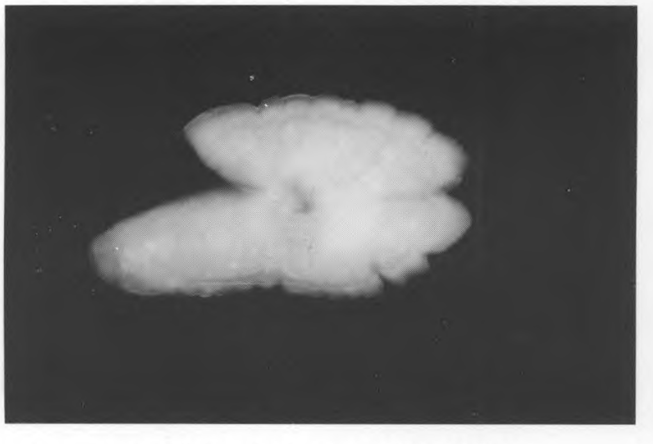


– age group 8, fish length 28.0 cm, 1980 year-class;

Fig. 8
Herring otoliths from the spawning region of Gdynia-Gdansk.

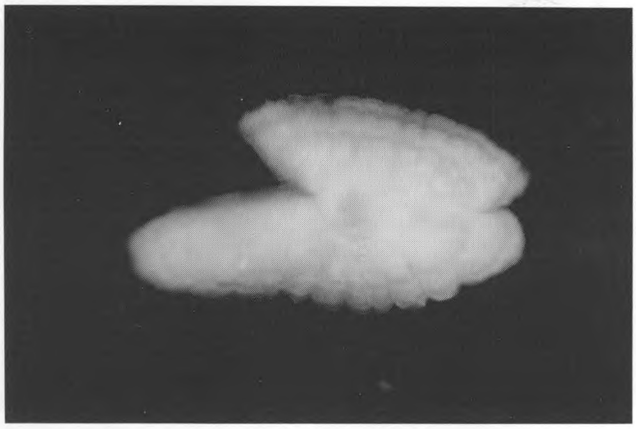


– age group 1, fish length 12.5 cm, 1987 year-class;

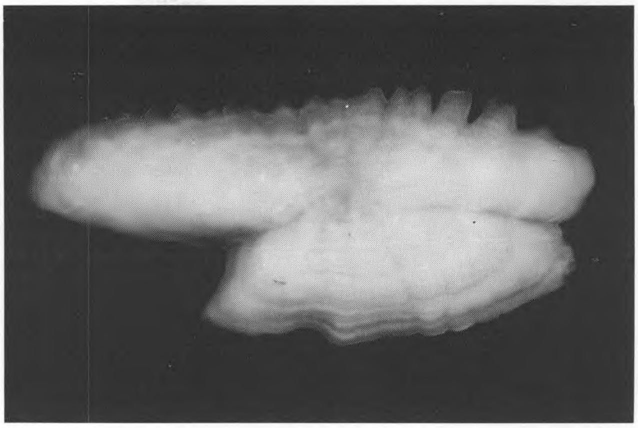


– age group 2, fish length 18.0 cm, 1986 year-class;

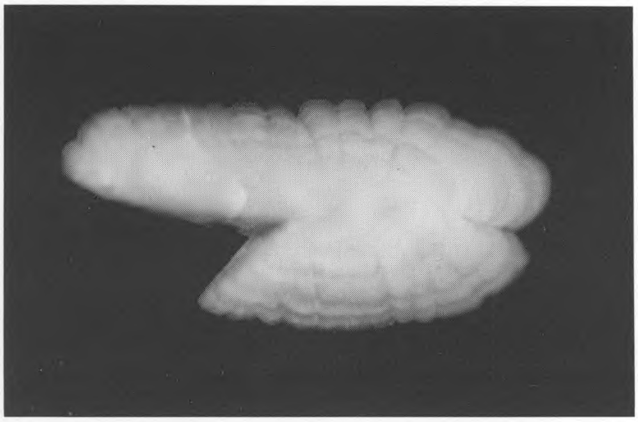
Continuation **Fig. 8**



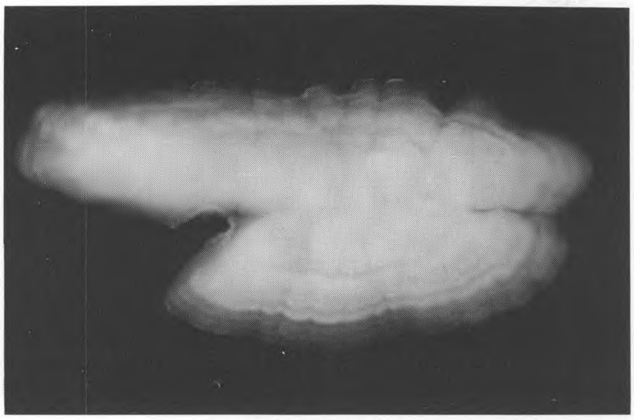
– age group 3, fish length 19.5 cm, 1985 year-class;



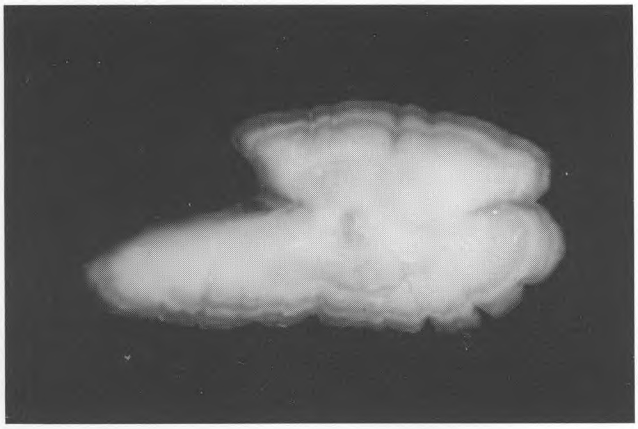
– age group 4, fish length 26.5 cm, 1984 year-class; infected by Anisakis nematode;



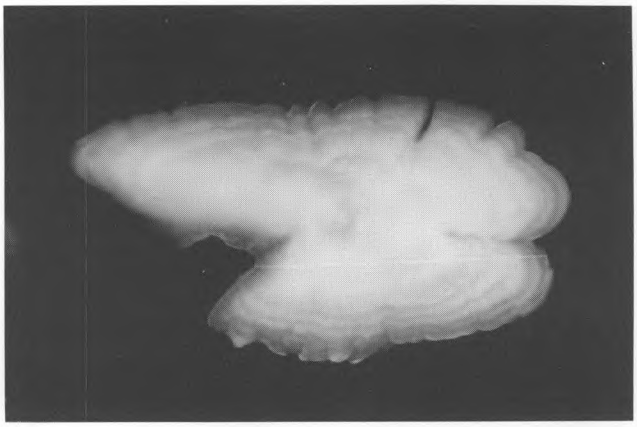
– age group 4, fish length 21.0 cm, 1984 year-class;



– age group 6, fish length 25.5 cm, 1982 year-class;

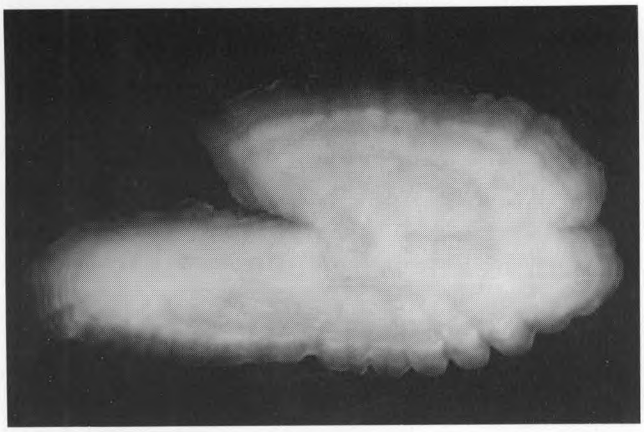


– age group 4, fish length 23.0 cm, 1984 year-class;

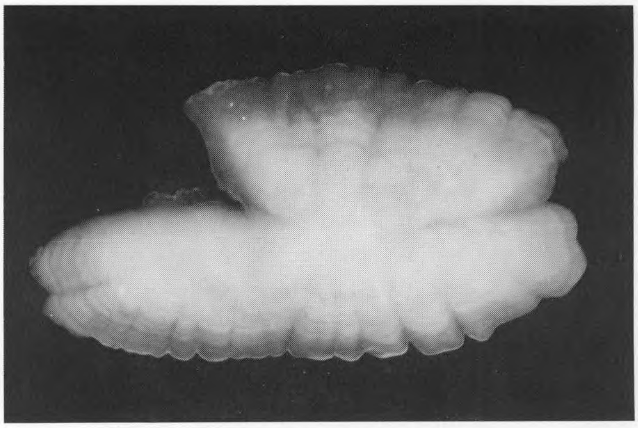


– age group 6, fish length 22.5 cm, 1982 year-class; otoliths may be referred to open sea herring;

Continuation **Fig. 8**

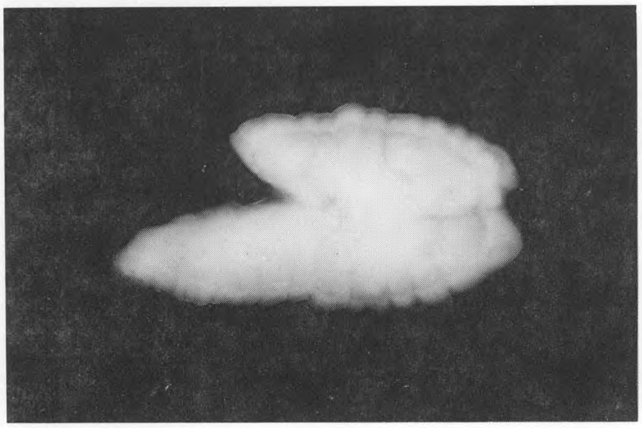


– age group 8, fish length 27.0 cm, 1980 year-class;

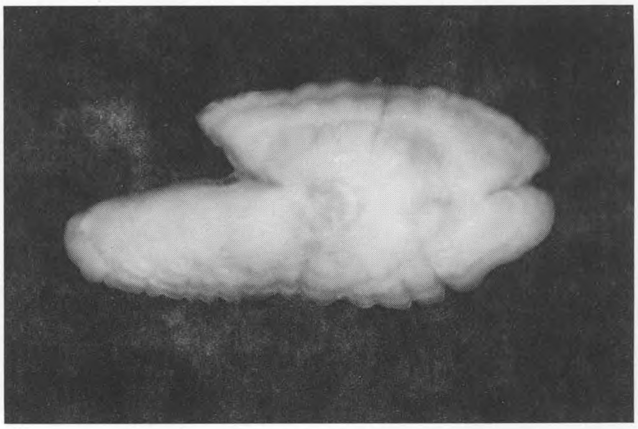


– age group 9 (8), fish length 23.5 cm, 1979 year-class, otoliths may be referred to open sea herring or even to gulf herring.

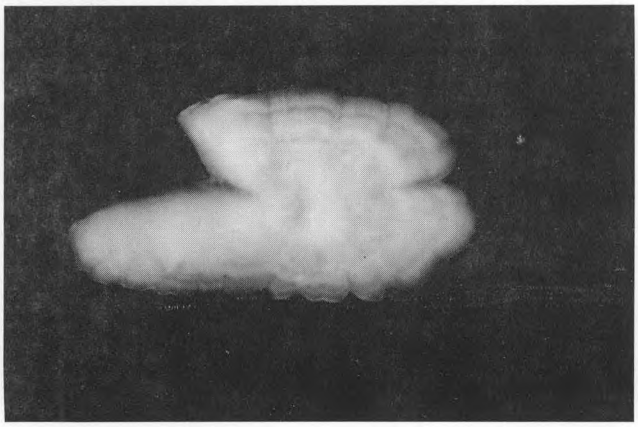
Fig. 9
Herring otoliths from the spawning region of the Vistula Bay



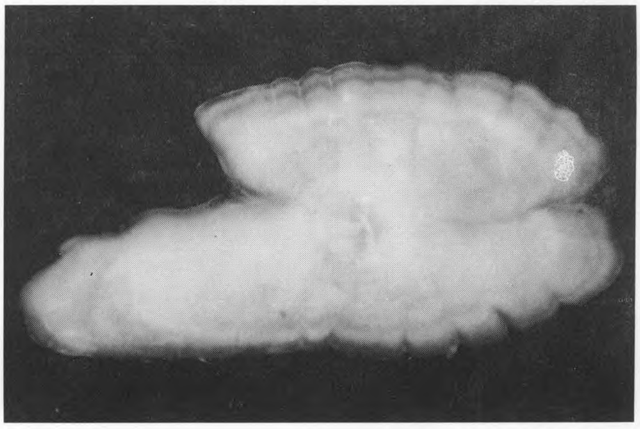
– age group 2, fish length 18.5 cm, 1985 year-class;



– age group 3, fish length 18.6 cm, 1984 year-class;

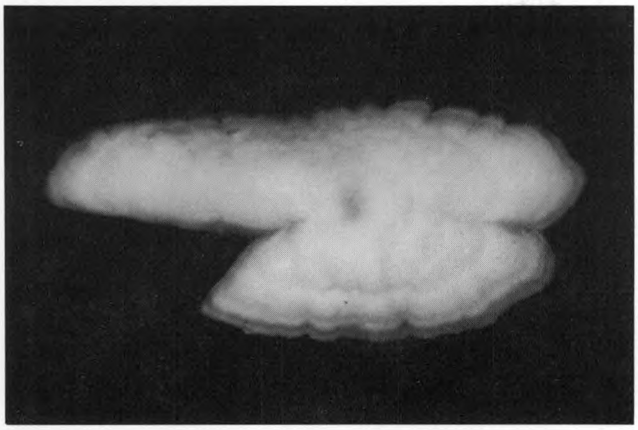


– age group 3, fish length 16.5 cm, 1984 year-class;

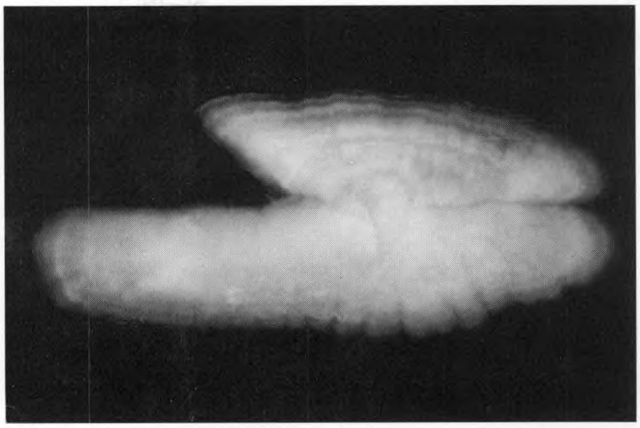


– age group 3, fish length 20.5 cm, 1984 year-class;

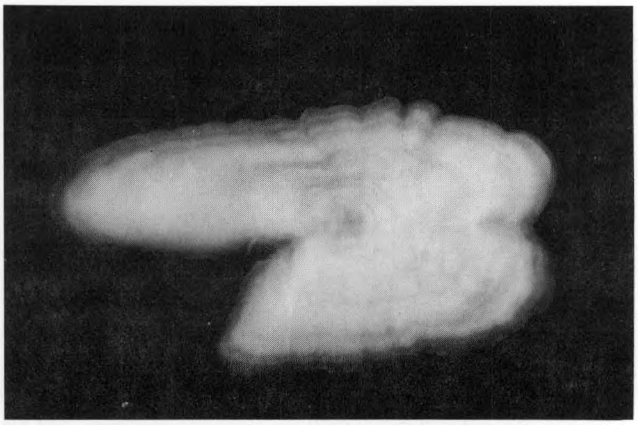
Continuation **Fig. 9**



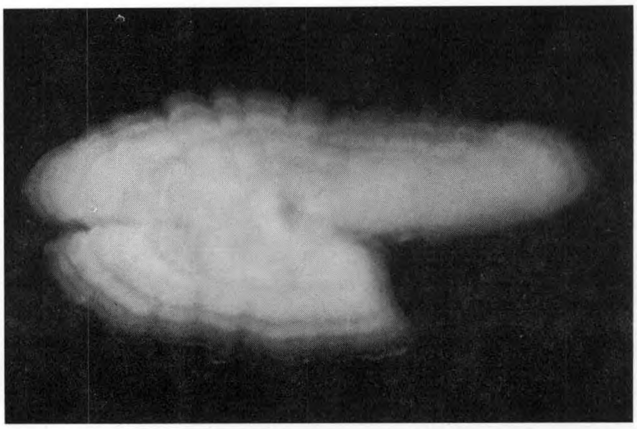
– age group 4, fish length 21.4 cm, 1983 year-class;



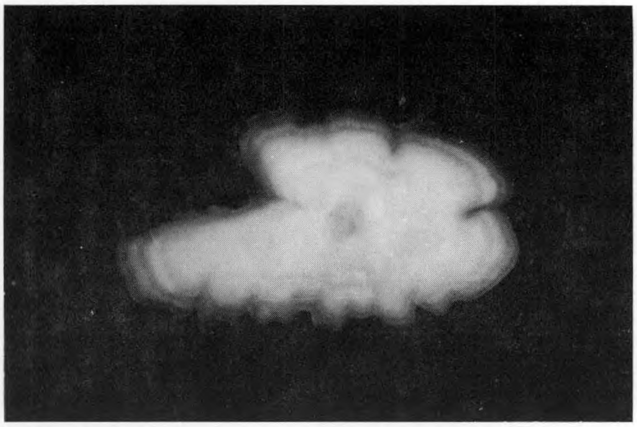
– age group 5, fish length 25.8 cm, 1982 year-class; otolith shape is not typical;



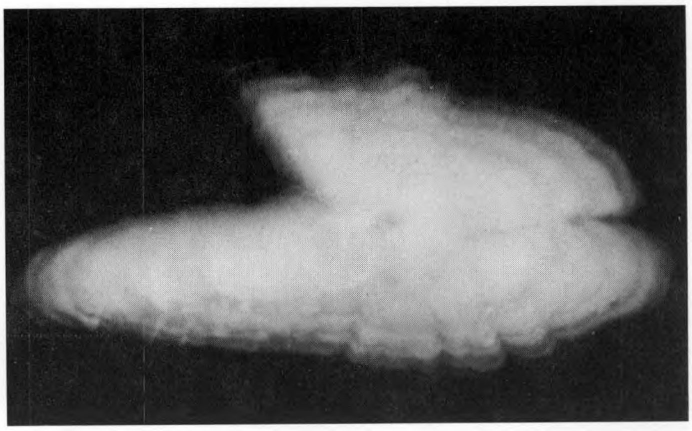
– age group 5, fish length 25.1 cm, 1982 year-class;



– age group 6, fish length 25.4 cm, 1981 year-class;

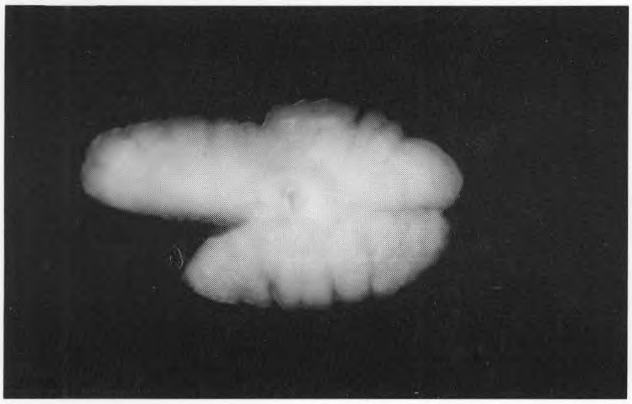


– age group 5, fish length 15.2 cm, 1982 year-class; otoliths may be referred to open sea herring or even to gulf herring;



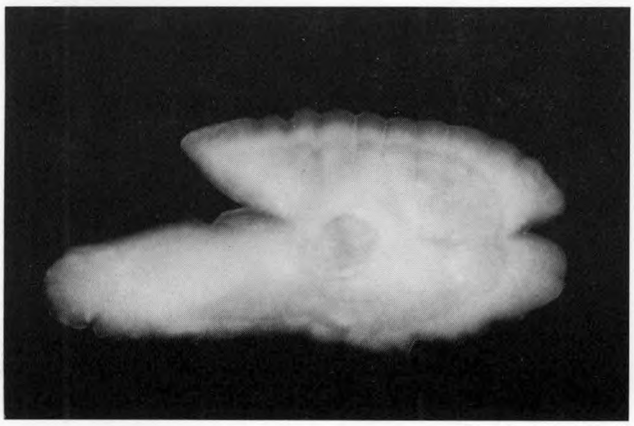
– age group 6, fish length 23.4 cm, 1981 year-class, otolith shape is not typical.

Fig. 10
Herring otoliths from the spawning region of Pionersk-Klaipeda

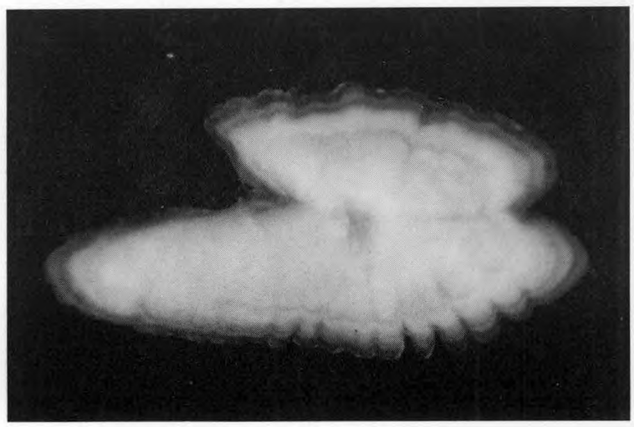


– age group 1, fish length 13.3 cm, 1986 year-class;

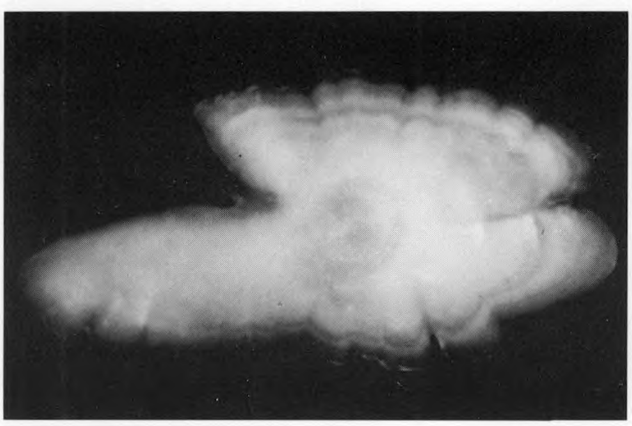
– age group 3, fish length 20.4 cm, 1984 year-class;



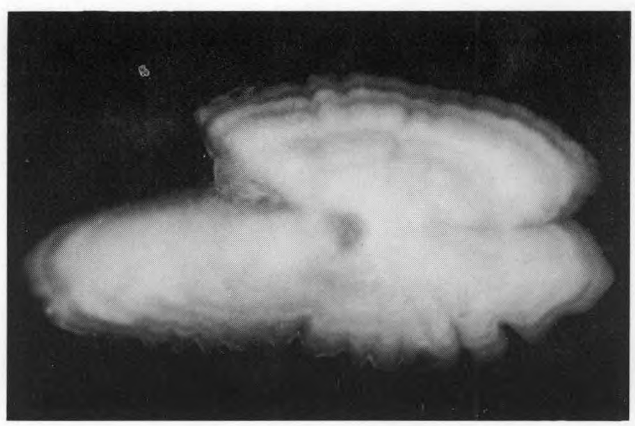
– age group 2, fish length 19.3 cm, 1985 year-class;



– age group 4, fish length 22.0 cm, 1983 year-class;

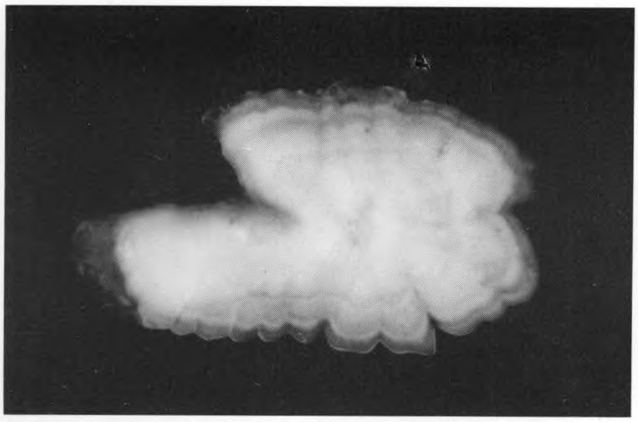


– age group 2, fish length 17.2 cm, 1985 year-class;

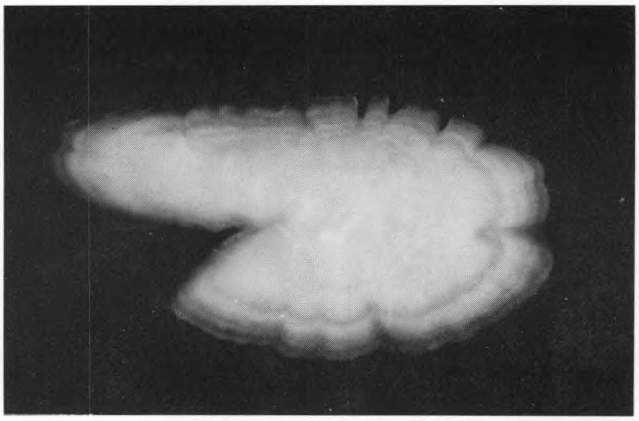


– age group 4, fish length 23.0 cm, 1983 year-class;

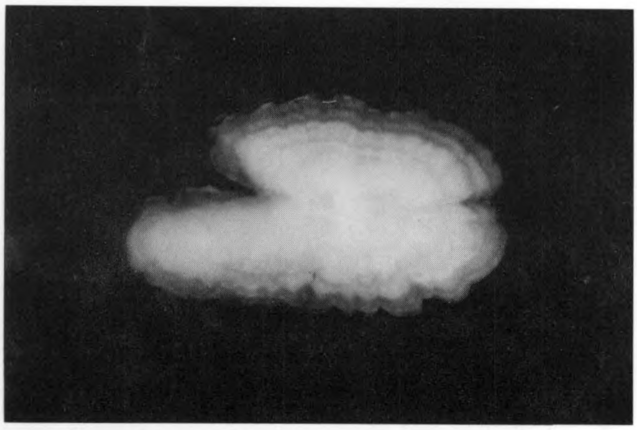
Continuation **Fig. 10**



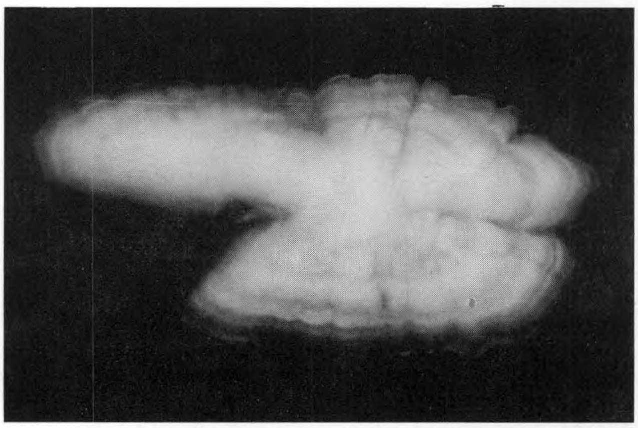
– age group 4, fish length 16.8 cm, 1983 year-class; otoliths can be referred to gulf herring (from northern Baltic);



– age group 5, fish length 23.4 cm, 1982 year-class;

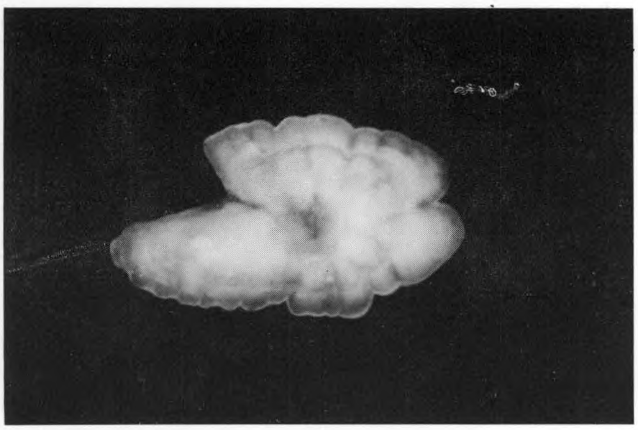


– age group 4, fish length 16.7 cm, 1983 year-class; otolith can be referred to gulf herring (from northern Baltic);

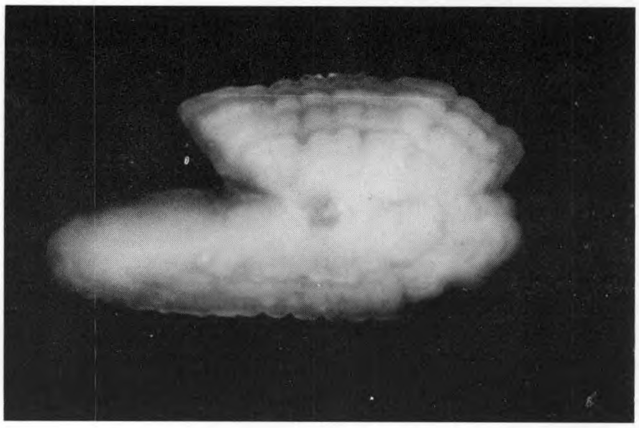


– age group 6, fish length 26.0 cm, 1981 year-class.

Fig. 11
Herring otoliths from the spawning region near the Estonian Islands (North-Eastern part of ICES Subdivision 29)

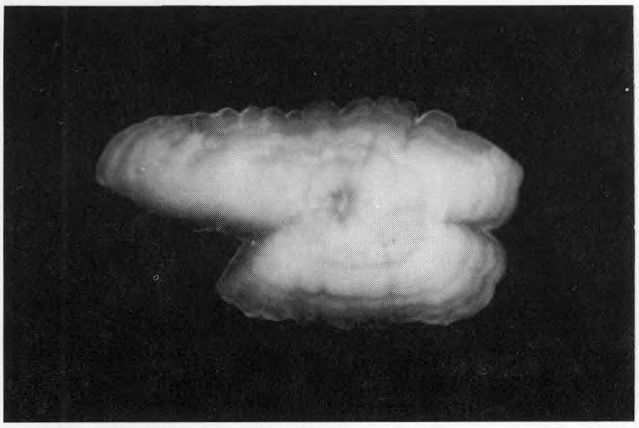


– age group 2, fish length 13.6 cm, 1986 year-class;



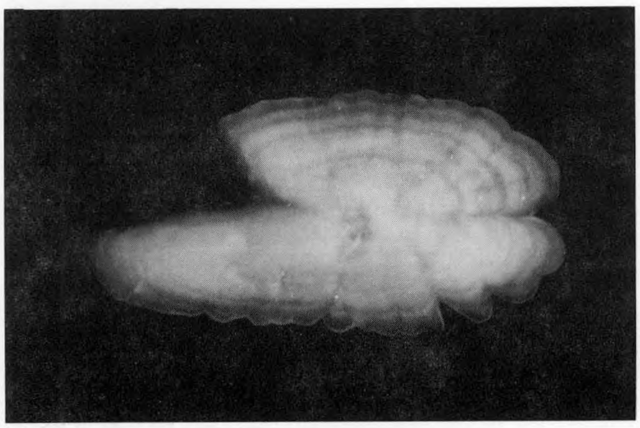
– age group 4, fish length 15.6 cm, 1984 year-class;

Continuation **Fig. 11**

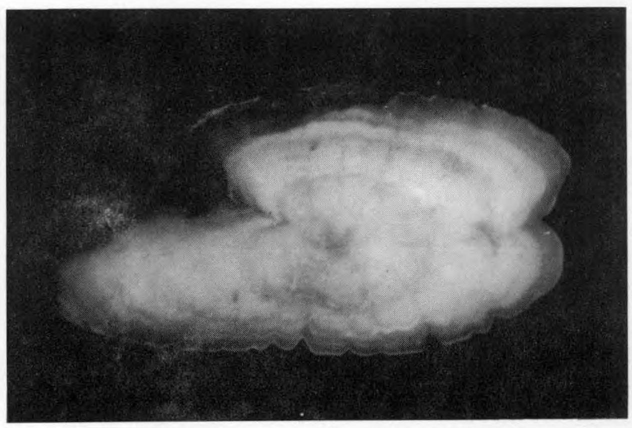


– age group 5, fish length 19.3 cm, 1983 year-class;

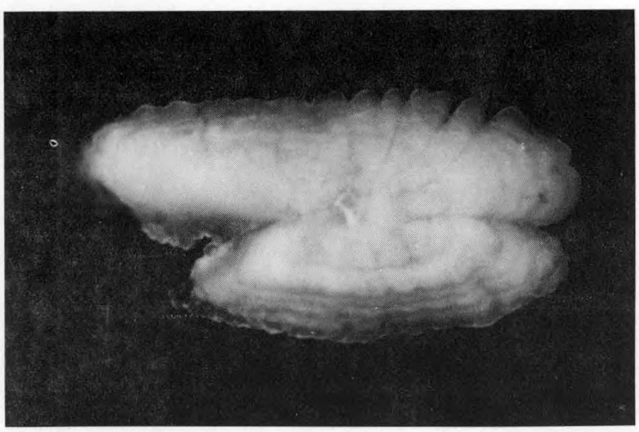
– age group 7, fish length 21.0 cm, 1981 year-class;



– age group 5, fish length 18.1 cm, 1983 year-class;

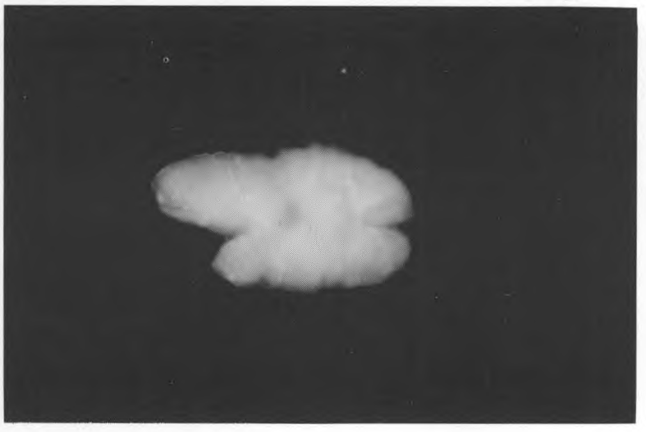


– age group 7, fish length 19.1 cm, 1981 year-class, anterostrum is partially hyalined

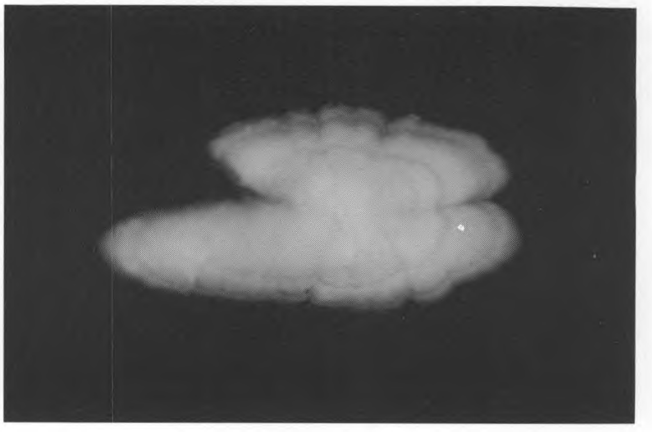


– age group 6, fish length 18.9 cm, 1982 year-class;

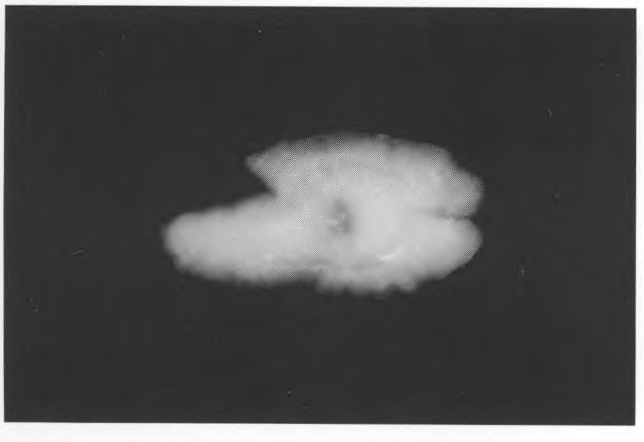
Fig.12
Herring otoliths from the spawning region of the Gulf of Riga



– age group 1, fish length 10.9 cm, 1987 year-class;

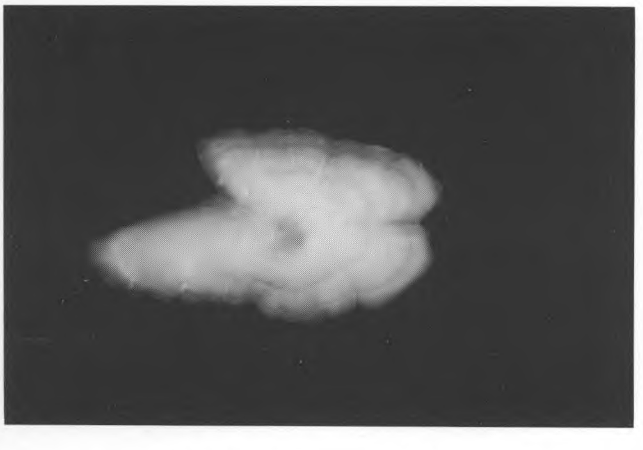


– age group 3, fish length 16.4 cm, 1985 year-class;

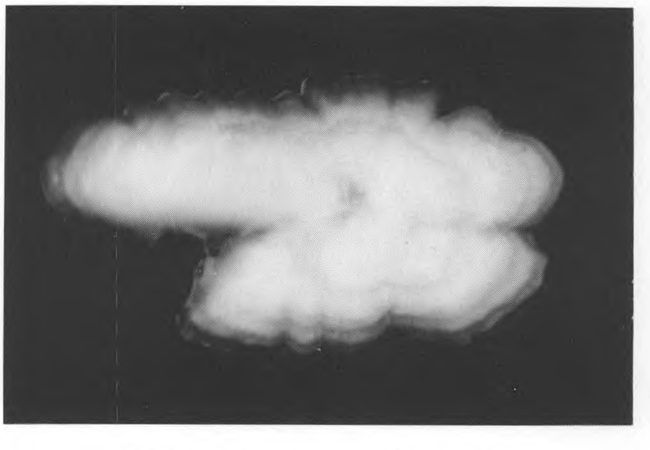


– age group 2, fish length 11.7 cm, 1986 year-class;

– age group 4 (5), fish length 14.4 cm;

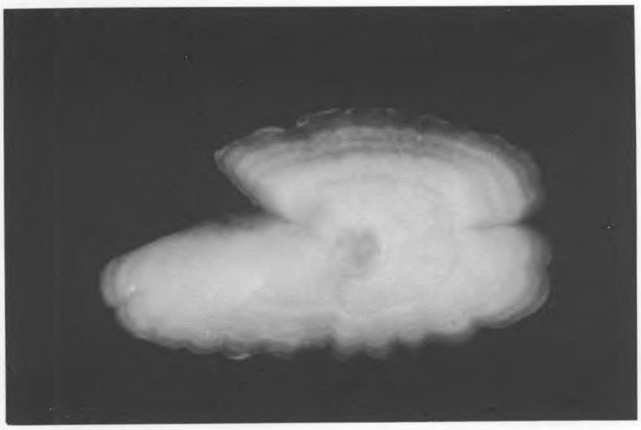


– age group 3, fish length 12.9 cm, 1985 year-class;

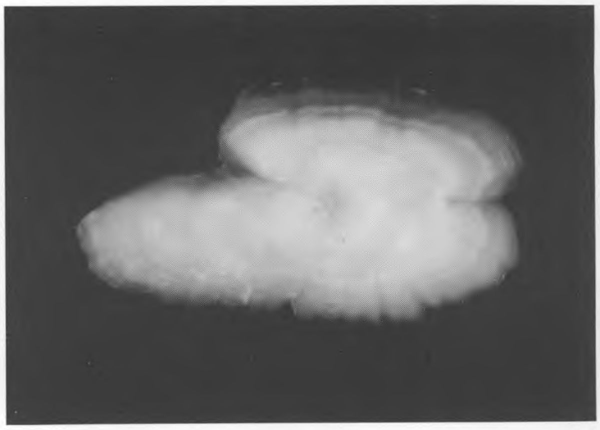


– age group 5, fish length 15.0 cm, 1983 year-class;

Continuation **Fig. 12**



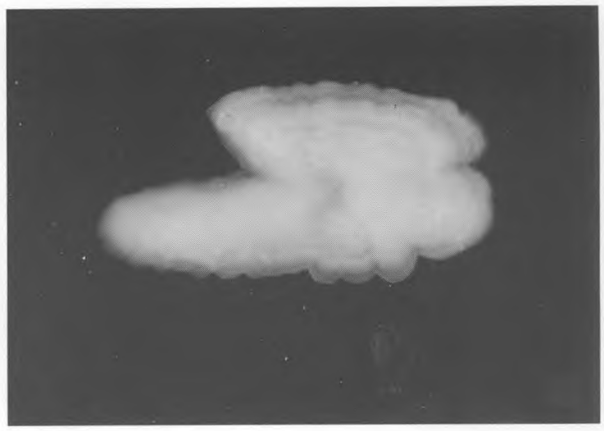
– age group 6, fish length 19.4 cm, 1982 year-class;



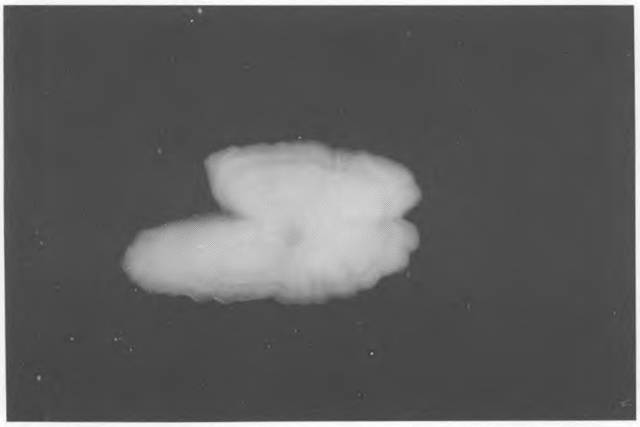
– age group 7 (8), fish length 19.2 cm.

Fig. 13
Herring otoliths from the spawning region of the Gulf of Finland (Eastern part).

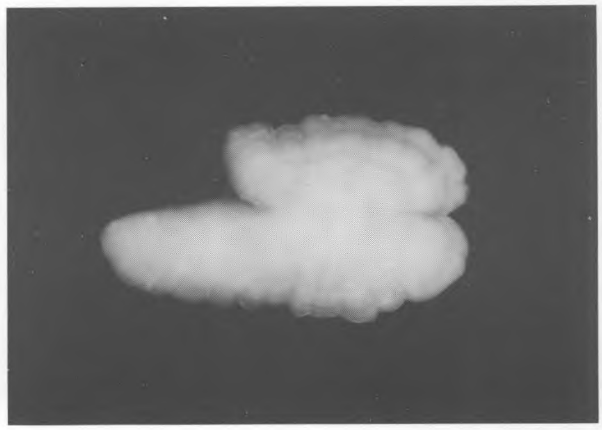
– age group 1, fish length 9.2 cm, 1988 year-class;



– age group 3, fish length 14.7 cm, 1986 year-class;

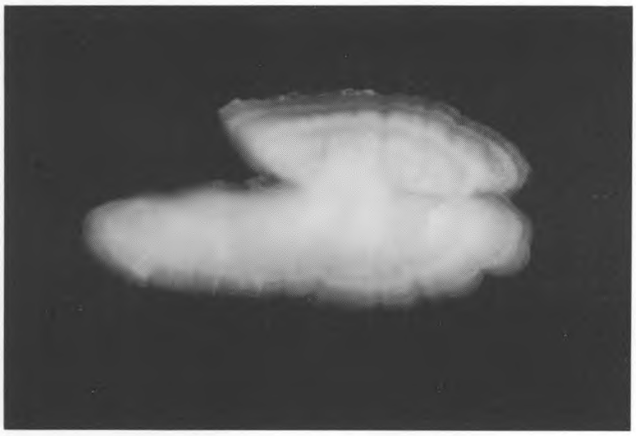


– age group 2, fish length 14.1 cm, 1986 year-class;

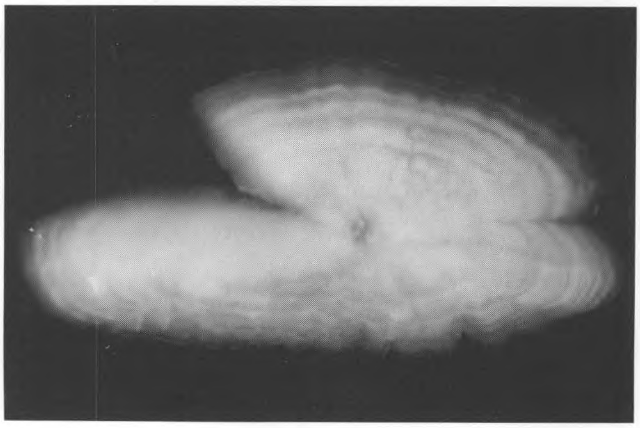


– age group 3, fish length 14.6 cm, 1986 year-class;

Continuation **Fig 13**

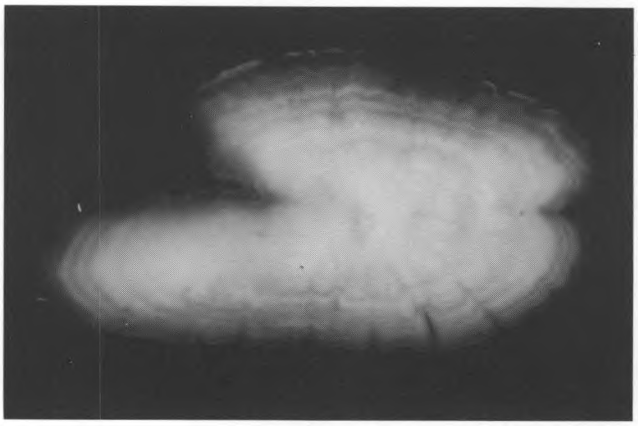


– age group 4, fish length 15.9 cm, 1984 year-class;



– age group 7 (8), fish length 21.6 cm;

– age group 6, fish length 22.3 cm, 1982 year-class;



– age group 8, fish length 22.0 cm, 1980 year-class

3.5. Vistula Bay

Statistical parameters of herring otolith morphometric features are given in Table 6, photographs of otoliths are shown in Fig. 9.

Table 6
Statistical parameters of Baltic herring otoliths from the Vistula Bay (M is average, δ is standard deviation). Designations are given in 2.1.

Parameters	Age group							
	2		3		4		5	
	M	δ	M	δ	M	δ	M	δ
TOL	3.17	0.13	3.52	0.17	3.91	0.18	4.05	0.30
TOW	1.54	0.05	1.69	0.06	1.83	0.08	1.92	0.11
RmL	1.17	0.11	1.25	0.11	1.44	0.12	1.48	0.15
OW_1	1.2	0.04	1.19	0.04	1.20	0.06	1.18	0.06
R_1	1.02	0.06	1.04	0.06	1.05	0.07	1.00	0.07
R_2	1.37	0.08	1.38	0.09	1.31	0.10	1.40	0.12
R_3	–	–	1.56	0.11	1.49	0.09	1.60	0.10
R_4	–	–	–	–	1.60	0.12	1.70	0.11
R_5	–	–	–	–	–	–	1.77	0.09
$\frac{TOL}{TOW}$	2.07	0.09	2.09	0.08	2.14	0.10	2.10	0.10
$\frac{RmL}{TOL} \cdot 100$	36.8	2.2	36.3	2.3	36.5	2.7	35.8	3.2
$\frac{R_2-R_1}{R_1} \cdot 100$	33.8	3.4	33.3	4.5	35.4	5.5	39.7	6.2
$\frac{R_3-R_2}{R_1} \cdot 100$	–	–	17.5	3.9	16.7	3.4	20.0	4.1
$\frac{R_4-R_3}{R_1} \cdot 100$	–	–	–	–	10.7	2.4	10.1	3.6
$\frac{R_5-R_4}{R_1} \cdot 100$	–	–	–	–	–	–		

3.6. Pionersk-Klaipeda

Statistical parameters of herring otolith morphometric features are given in Table 7, photographs of otoliths are shown in Fig. 10.

Table 7
Statistical parameters of Baltic herring otoliths from the Pionersk-Klaipeda region (M is average, δ is standard deviation). Designations are given in 2.1.

Parameters	Age group					
	2		3		4	
	m	δ	M	δ	M	δ
TOL	3.30	0.16	3.78	0.21	4.02	0.27
TOW	1.63	0.07	1.81	0.10	1.93	0.09
RmL	1.25	0.12	1.40	0.13	1.49	0.14
OW_1	1.24	0.06	1.22	0.08	1.19	0.06
R_1	1.02	0.09	1.04	0.09	0.98	0.11
R_2	1.40	0.09	1.42	0.09	1.38	0.13
R_3	–	–	1.65	0.10	1.58	0.14
R_4	–	–	–	–	1.73	0.13
$\frac{TOL}{TOW}$	2.02	0.10	2.09	0.11	2.09	0.12
$\frac{RmL}{TOL} \cdot 100$	37.8	3.1	36.9	2.4	37.1	2.5
$\frac{R_2-R_1}{R_1} \cdot 100$	37.5	9.7	37.1	10.3	42.1	14.7
$\frac{R_3-R_2}{R_1} \cdot 100$	–	–	21.6	6.9	20.8	8.3
$\frac{R_4-R_3}{R_1} \cdot 100$	–	–	–	–	15.4	5.03

3.7. ICES Subdivision 29, near Estonian Islands

Statistical parameters of herring otolith morphometric features are given in Table 8, photographs of otoliths are shown in Fig. 11.

Table 8
Statistical parameters of Baltic herring otoliths from the North-Eastern part of ICES Subdivision 29 (M is average, δ is standard deviation).
Designations are given in 2.1.

Parameters	Age group							
	2		3		4		5	
	m	δ	M	δ	M	δ	M	δ
TOL	2.81	0.28	3.21	0.25	4.43	0.26	3.67	0.30
TOW	1.47	0.09	1.63	0.09	1.75	0.10	1.87	0.11
RmL	1.00	0.16	1.13	0.16	1.22	0.14	1.31	0.16
OW_1	1.01	0.15	1.05	0.11	1.07	0.08	1.06	0.07
R_1	0.81	0.16	0.87	0.09	0.86	0.09	0.83	0.10
R_2	1.24	0.15	1.25	0.09	1.21	0.08	1.21	0.09
R_3	–	–	1.43	0.10	1.38	0.10	1.38	0.11
R_4	–	–	–	–	1.51	0.12	1.51	0.13
R_5	–	–	–	–	–	–	1.62	0.14
$\frac{TOL}{TOW}$	1.90	0.10	2.00	0.20	2.01	0.11	2.03	0.09
$\frac{RmL}{TOL} \cdot 100$	35.5	2.8	35.2	3.0	35.4	2.4	35.7	2.6
$\frac{R_2-R_1}{R_1} \cdot 100$	55.7	19.5	44.9	11.1	40.6	12.3	47.6	15.7
$\frac{R_3-R_2}{R_1} \cdot 100$	–	–	21.5	6.8	20.8	8.0	20.8	7.5
$\frac{R_4-R_3}{R_1} \cdot 100$	–	–	–	–	14.9	4.4	17.0	7.4
$\frac{R_5-R_4}{R_1} \cdot 100$	–	–	–	–	–	–	13.3	4.2

3.8. Gulf of Riga

Statistical parameters of herring otolith morphometric features are given in Table 9, photographs of otoliths are shown in Fig. 12

Table 9
Statistical parameters of Baltic herring otoliths from the Gulf of Riga (M is average, δ ist standard deviation).
Designations are given in 2.1.

Parameters	Age group							
	2		3		4		5	
	M	δ	M	δ	M	δ	M	δ
TOL	2.43	0.13	2.77	0.17	2.97	0.18	3.14	0.23
TOW	1.26	0.06	1.41	0.08	1.52	0.11	1.60	0.10
RmL	0.84	0.07	0.96	0.08	1.02	0.10	1.06	0.13
OW1	0.89	0.08	0.91	0.08	0.93	0.08	0.93	0.06
R_1	0.69	0.08	0.69	0.08	0.70	0.07	0.71	0.07
R_2	1.04	0.07	1.07	0.07	1.01	0.08	1.07	0.09
R_3	–	–	1.18	0.07	1.20	0.09	1.20	0.11
R_4	–	–	–	–	1.26	0.08	1.29	0.13
R_5	–	–	–	–	–	–	1.33	0.14
$\frac{TOL}{TOW}$	1.90	0.09	1.90	0.07	1.90	0.12	1.96	0.11
$\frac{RmL}{TOL} \cdot 100$	34.8	2.1	34.6	2.0	34.3	2.2	33.6	2.7
$\frac{R_2-R_1}{R_1} \cdot 100$	51.5	14.2	57.8	18.2	54.1	17.2	50.6	13.2
$\frac{R_3-R_2}{R_1} \cdot 100$	–	–	16.3	7.3	18.3	4.6	18.5	5.0
$\frac{R_4-R_3}{R_1} \cdot 100$	–	–	–	–	8.3	3.4	12.1	3.8
$\frac{R_5-R_4}{R_1} \cdot 100$	–	–	–	–	–	–	5.7	2.7

3.9 Gulf of Finland

Statistical parameters of herring otolith morphometric features are given in Table 10, photographs of otoliths are shown in Fig. 13

Table 10
Statistical parameters of Baltic herring otoliths from the Eastern part of the Gulf of Finland (M is average, δ is standard deviation).
Designations are given in 2.1.

Parameters	Age group							
	2		3		4		5	
	m	δ	M	δ	M	δ	M	δ
TOL	2.72	0.29	3.06	0.19	3.24	0.15	3.33	0.15
TOW	1.40	0.05	1.61	0.09	1.69	0.08	1.76	0.06
RmL	0.94	0.08	1.06	0.10	1.14	0.12	1.18	0.11
OW_1	0.99	0.09	0.96	0.09	1.00	0.07	0.99	0.06
R_1	0.78	0.08	0.74	0.08	0.79	0.12	0.79	0.09
R_2	1.13	0.05	1.16	0.10	1.17	0.09	1.15	0.06
R_3	–	–	1.33	0.10	1.33	0.09	1.29	0.07
R_4	–	–	–	–	1.43	0.10	1.41	0.10
R_5	–	–	–	–	–	–	1.48	0.10
$\frac{TOL}{TOW}$	1.9	0.2	1.9	0.1	1.9	0.1	1.9	0.08
$\frac{RmL}{TOL} \cdot 100$	34.6	3.4	36.2	2.2	35.2	2.6	35.3	2.8
$\frac{R_2-R_1}{R_1} \cdot 100$	45.7	14.1	58.4	21.1	49.2	17.7	47.5	15.6
$\frac{R_3-R_2}{R_1} \cdot 100$	–	–	22.8	8.6	28.8	10.4	17.1	5.1
$\frac{R_4-R_3}{R_1} \cdot 100$	–	–	–	–	12.3	6.2	15.3	6.2
$\frac{R_5-R_4}{R_1} \cdot 100$	–	–	–	–	–	–	9.1	3.9

References

1. БАТАЛЬЯНЦ, К.Я.:
О происхождении внутривидовой дифференциации балтийской салаки Clupea harengus membras L.
Вопросы ихтиологии.- 1965.- Т.5,вып.1/34/.- С.46-57.

2. БАТАЛЬЯНЦ, К.Я.:
Историческое прошлое сезонных рас сельди Clupea harengus L.в свете современных представлений.
Зоологический журнал.-1972.-Т.51,вып.2.- С.237-241.

3. БИРЮКОВ, Н.П.:
Сельди Балтийского моря. -
Калининград. - 1970. - 201 с.

4. ОЯВЕЕР, Э.А.:
О различении сезонных рас салаки северо-восточной части Балтийского моря по отолитам.
Известия АН ЭССР. Сер.биол..-1962.-№3.-С. 193-207.

5. ОЯВЕЕР, Э.А.:
Балтийские сельди. -
М.:Агропромиздат, - 1988.- 203 с.

6. РАННАК, Л.:
Биологические группировки сельди по типам отолитов.
Известия АН ЭССР, Сер.биол.-1967.-Т.16/1.

7. ФЕТТЕР, М., АПС, Р., КРУМИНЯ Р.:
О морфологической изменчивости отолитов годовиков весенней сельди Балтийского моря.
Fischerei-Forschung, Rostock 26 (1988) 2.,S.24-28.

8. ALTNÖDER, K.:
Die Frühjahrs- und Herbstheringe von Rügen.
Ber. Dtsch. Komm. Meeresforsch., 1949, 11, S. 247–257.

9. ANWAND, K.:
Das Wachstum der Frühjahrs- und Herbstheringe aus den Gewässern um Rügen.
Zeitschrift für Fischerei und deren Hilfswiss., XI, N. F. (1962-1963), S. 201–209.

10. ANWAND, K.:
Vergleichende Untersuchungen an den Frühjahrs- und Herbstheringen aus den Gewässern um Rügen.
Zeitschrift für Fischerei und deren Hilfswiss., XI, N. F. (1962–1963), 211-249.

11. BIESTER, E.:
Der Frühjahrshering Rügens – seine Rolle in der Fischerei der Ostsee und in den Übergangsgebieten zur Nordsee.
Rostock, Univ., SBI, Diss. B, 1979.

12. ELWERTOWSKI, J.:
Materiały do poznania podstaw biologicznych rybołowstwa śledziowego na Pomorzu Zachodnim.
Prace Morsk. Inst. Ryb. w Gdyni, 7, Wyd Komunjkacyjne, Warszawa, 1954.

13. FETTER, M., OJAVEER, E.:
Assessment of the Eastern Baltic herring Stocks by Hydroacoustic Method.
ICES, C. M. 1988/J:11 B. F. C.

14. GROTH, B.; APS, R.; PAAT, A.; UDER, Y.:
The shape of adult herring otoliths in the Western Baltic.
ICES, C. M. 1988 J:25 B. F. C.

15. GRYGIEL, W.:
Differences in morphology and growth of otoliths of juvenile herring taken on various fishing grounds in the Southern Baltic.
ICES, C. M. 1984/J:25.

16. GRYGIEL, W.:
Southern Baltic herring: some remarks on morphological structure of its otoliths.
ICES, C. M. 1987/J:4, B. F. C.

17. HESSLE, Chr.:
The herring along the Baltic coast of Sweden.
Publ. de Circouste, 1925, 89, pp. 1–57.

18. KOMPOWSKI, A.:
Types of otoliths of Southern Baltic herring.
ICES, C.M. 1969/12.

19. KOMPOWSKI, A.:
Typy otolitow sledzi poludniowego Baltyku.
Prace MIR 16 (1971) Seria A, S. 109–141.

20. LINNAEUS, C.:
Systema naturae per regna tria naturae, secundum classes, ordines, genera, species cum characteribus, differentiis, synonimys, locis.
Editio decima, reformata, Tom I, Laurentii Salvi, Holmiae (1758), 824.

21. LUNDBECK, J.:
Vom Strömling.
Mitt. Dtsch. Seefisch. Ver., 1930, Bd. 46, No. 7, 310–335.

22. MESSIEH, S. N.:
Use of otoliths in identifying herring stocks in the Southern Gulf of St. Lawrence and adjacent waters.
J. Fish. Res. Board Canada, 1972, vol. 29, 8, pp. 1113–1118.

23. MESSIEH, S. N.:
Growth of the otoliths of young herring in the Bay of Fundy.
Trans. Am. Fish. Soc. k (1975) 4, pp. 770–772.

24. OJAVEER, E.:
Herring otoliths Investigations in the North-Eastern Baltic.
ICES C.M., 1962, Herring Committee, No. 134.

25. OJAVEER, E.; EVTJUKHOVA, B.; RECHLIN, O.; STRZYZEWSKA, K.:
Results of investigation of population structure and otoliths of Baltic spring spawning herring.
ICES, C.M. 1981 J:19, B.F.C.

26. OJAVEER, E.:
Influence of temperature, salinity and reproductive mixing of Baltic herring groups on its embryonal development.
Rapp. p.-v. Reun. Cons. int. Explor. Mer., 1981, 178, pp. 409–415.

27. OJAVEER, E.:
On population structure of pelagic fishes in the Baltic Sea.
ICES, 1988, Bal/No. 43.

28. OTTERLIND, G.:
On them migration of the Baltic herring.
ICES, Herr. Ctee, 121. C.M., 1961.

29. OTTERLIND, G.:
Sillens / strömmingens vandringsvanor vid svenska syd-och Ostkusten.
Ostkusten, 1962, 34 (1), 15–21.

30. OTTERLIND, G.:
On the Öresund herring and related population problems.
Medd. fr. Havsfiskelab., Lysekil (1987), 322.

31. POPIEL, J.:
Z biologiissledzi baltyckich.
Prace Morsk. Inst. Ryb. w Gdyni, Wyd. Komunikacyjne, Warszawa (1955), 8.

32. POPIEL, J.:
Some remarks on the Baltic herring.
ICES, Herr. Ctee. att.: Baltic-Belt S. Ctee, 68, C.M., 1964.

33. POPIEL, J.:
Differentiation of the biological groups of herring in the Southern Baltic.
Rapp. P.-v. Reun. Cons. int. Explor. Mer., 1958, v. 143, II, 114–121.

34. RAUCK, G.:
The structure of the otoliths from the Baltic herring a helpful means for separation of biological groups.
ICES, C.M., 1965, No. 39, Herr. Cttee.

35. SCHNEIDER, G.:
Die Clupeiden der Ostsee.
Rapp. P.-v. Reun. Cons. int. Explor. Mer., 1908, v. 9, S. 66–111.

36. WYSZYNSKI, M., KÄSTNER, D.:
Agreements of age interpretation and population identity based on age reading of otoliths of herring (Clupea harengus L.) in the Southern Baltic – subdivisions 24, 25, 26.
ICES, C.M. 1985/J:23 B.F.C.

37. WYSZYNSKI, M.:
Influence of thermal environmental conditions on certain aspects of the biology of herring (Clupea harengus membras L.) in the Central Baltic.
ICES Symposium Bul., 54, 1988.

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