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Types of Otoliths of Southern Baltic Herring

by

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Introduction

The complicated geological past, and the great variety of environmental conditions in the Baltic, have resulted in a great number of local herring stocks in this sea. On the basis of some common features, a number of larger groups can be distinguished among them. The practice most frequently adhered to now is to divide herring in two seasonal races: the spring-spawning race and the autumn-spawning race. The spring herring is further differentiated into coastal herring (most frequent in the Southern Baltic) and marine herring (most frequent in the Central Baltic).

Since the catch is very often found to be a mixture of the three groups, it would be worthwhile having a quick and simple means of identifying herring belonging to the individual groups.

This means is furnished by the study of differences in the structure of otoliths. This problem has already been tackled by a number of authors, beginning with Jenkins (1902). They have found constant differences in the structure of the nucleus, the width of the individuals' growth zones and the shape of otoliths in the various groups. According to Parrish and Sharman (1958), most of the differences are of a phenotypic nature and reflect the differences in the growth and metabolism of the early stages of herring born in various places and in various seasons.

Kändler (1942) and Popiel (1955) have found that the various Baltic herring groups can also be identified by means of their otoliths. Detailed studies of the problem have been made by Rauck (1965) and Anwand (1963) for the Western Baltic and by Ojaveer (1962a and b) and Rannak (1967) for the North-East and Central Baltic. The object of this paper is to relate this problem to the Southern Baltic.

Material and Methods

The study is based on otoliths from 2,399 herring from the Gdańsk Bay and 2,298 from the Bornholm Basin (deep-sea trawling in feeding grounds) and from 1,066 herring from coastal fisheries (set gill-net catches in spawing grounds).

The material was collected from 1962 to 1964 by the Sea Fisheries Institute of Gdynia and made available to the author by Professor J. Popiel and Dr. K. Strzyzewska.

A detailed microscopic study of all the otoliths made it possible to differentiate three recurrent structural types. An attempt was then made at a quantitative formulation of the differences between the various types by measuring the diameter of the nucleus and the radii of the individual growth zones by means of a microscope fitted with a micrometer screw. The growth zones were measured in the nucleus-postrostrum distance. The diameters of the nucleus were measured, including the "transitional zone" as described by Postuma (1959).

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Otolith Types

I. Otoliths relatively large, considerably elongated, having a long rostrum. The nucleus usually small. The winter rings narrow. The first growth zone relatively large. The excisura minor well developed. The excisura major sharply indented but shallow. The line through the excisura minor and nucleus parallel to the longitudinal axis of the otolith (Figure 1).

II. Otoliths relatively large but not so elongated as Type I, the first growth zone being relatively small. The number of growth zones usually considerably smaller than in Type I. Other features as in Type I.

The Type II otoliths can be further subdivided as follows:

IIA. Otoliths large, of regular shape and long rostrum. The nucleus small or medium-sized. The winter rings wider than in Type I. The first growth zone small, the next wide and gradually decreasing (Figure 1).

IIB. Otoliths large and bulky, having a rough surface and irregular shape. The nucleus small or medium-sized, usually poorly visible due to the overlying opaque substance. The first growth zone small, the second relatively large, the next as in Subtype IIA (Figure 1).

IIC. Otoliths similar to subtype IIA but differing in the second and third (and sometimes also fourth) growth zones being much wider than the following ones (Figure 1).

III. Otoliths smaller than in the previous types. In young herring, the nucleus large and transparent; in older herring, the nucleus often covered by an opaque substance which makes it quite invisible. The first growth zone relatively large. The excisura minor weakly marked and very often not marked at all. The line through the excisura minor and nucleus at an angle to the longitudinal axis. The excisura major deep, often characteristically rounded, in young herring in particular (Figure 1).

From the results of the studies listed in the Introduction it seems very likely that the above-mentioned types correspond to herring of various origin, living in the Southern Baltic. A more exact picture of the problem requires a detailed analysis of the structural differences in the otoliths in question.

Otolith Size

During the microscopic observations it has been found that Type III otoliths are usually smaller than Types I and II in fish of the same size. The fish size/otolith size relation has been studied in 2,859 herring. From the results shown in Figures 2 and 3, it follows that for fish in excess of 15 cm length it is a straight-line function. The lines expressing this relation pass above the origin of co-ordinates; this can only be explained by the fact that in young herring the function is not a straight line but a curve. The same has been found in some North Sea herring groups (Hempel, 1959; Bohl, 1962; Wood, 1962). In herring belonging to the same length class, the greatest otoliths are those in Types I and II, and the smallest are those in Type III.

Size and Structure of the Nucleus

Both the size and transparency of the nucleus are highly variable. The greatest percentage of transparent nuclei (29.5%) can be found in Type III while in Types I and II the figures are much lower (5.6 to 9.5%). However, each type comprises a great number of nuclei of intermediate transparency (Table 1).

Type III comprises much largernuclei than Types I and II. The nucleus diameter is highly variable in all the types. It follows from these data that the size and structure of the nucleus can only be considered as auxiliary features in the identification of herring from various groups.

Size of the First Growth Zone

The curve in Figures 4 and 5 represent the frequency of occurrence of herring with various radii of the first growth zone (V_1).

Feeding Seasons.

The herring which prevailed in the spring-summer feeding season in 1963 and 1964 (especially in the first half of the season) were those with high V_1 values. These were chiefly herring with Type III otoliths. Towards the end of the season fish with small V_1 values and Type II otoliths appeared in the feeding grounds. In the summer-autumn season the latter prevailed in the catch, those with high V_1 values (Types III and I) forming an admixture which is represented by the second, lower peak in the curves.

Spawning Seasons.

Spring. The individuals prevailing in the spawning grounds were those with high V_1 values, chiefly with Type I otoliths (Figure 5). Sometimes, there was an admixture with low V_1 values and Type II otoliths. The latter forms a distinct peak in the curves, in particular for the Rowy, Kuźnica and Orłowo areas.

Autumn. In the material available to the author, only two samples (Rowy, 3rd October 1962, and Mrzezyno, 29th September 1964) could, judging from the maturity of gonads, be considered to come from autum herring spawning grounds. In both cases the herring in question had otoliths with a high V_1, almost all of them from Type III. Samples from the Rewa (11th October 1963) and Gdynia (20th October 1963) areas, though they come from set gill-net catches in the coastal area, resemble the summer-autumn feeding season with their curves and age distribution. The herring which prevailed there were spring herring with low V_1 (Type II otoliths).

It can be seen from the above dates that the occurrence of herring with large or small first growth zones in their otoliths is strictly related to the fishing seasons and feeding or spawning grounds. It is also related to the prevalence, in the given seasons and areas, of fish with various otolith types. The data seem to confirm the supposition that the otolith types listed above correspond to herring of various origins. It should now be investigated whether the size of the first growth zone changes with age or, in other words, to what an extent this size is affected by the fluctuations of the growth-rate over the individual years, and by the recruitment to the stock.

From Figure 6 it can be seen that there are considerable differences in the average size of the first growth zone between the individual age groups. This is probably due to the differences in environmental conditions in the years when the zones were formed, e.g., nourishment conditions and the length of the intensive nourishment period during the first year of life of the various year-classes. In all the otolith types, the V_1 value is slightly higher in the youngest age groups than in the older groups. This can very likely be due to the way in which the stock is recruited. It is well known that individuals having a higher growth-rate, i.e., achieving a greater length in the early years of their life, enter the adult stock at an earlier age than those having a lower growth-rate. In the older age groups of herring with Type I and III otoliths, no appreciable relation can be found between the age and the size of the first growth zone, while in herring with Type II otoliths, a slight increase of the zone can be seen, starting from Group 7. It also follows from the above-mentioned drawings that the average value of V_1 in Type II is always much lower than in Types I or III.

Growth of Otoliths

Figures 7 and 8 show the average growth-rates of the individual otolith types based on the measurements of growth zone radii in 2,895 herring. It can be seen that each of the three types of otoliths found in Southern Baltic herring is charcterised by a completely different growth-rate. The growth curves plotted for otoliths of the same type in fish from various samples and areas are very similar in form and can to a great extent be superimposed. The shape of these curves seems to be a constant feature of a given otolith type. The lowest growth-rate is found in Type II. The curves for Types IIA and IIB are nearly the same. A higher growth-rate, in particular in the first three years, can be seen in Type I. The latter type is prevalent in ripening herring caught in spring in littoral spawning grounds.

In the first age group, the size of otoliths is similar to that of Type III; in the older groups, however, Type I otoliths are larger. It is interesting to note that the largest otoliths found in the North Sea herring are also those from individuals caught in spring in coastal spawning grounds (Wood, 1962).

Occurrence of Otolith Types

a) Otolith Types in Spring and Autumn Herring

Adult herring caught in the Southern Baltic can, in general, be divided into spring and autumn groups on the basis of maturity of their gonads. This feature has been used to assess which otolith types are characteristic of each of the two seasonal races. The investigation was based on otoliths from 5,763 herring. First an attempt was made to ascribe each otolith to one of the types listed above. 135 otoliths defied classification and were omitted from this and further analyses.

Table 2 shows the quantitative and percent occurrence of the various otolith types in spring and autumn herring. Type III as distinctly separate, is juxtaposed to Types I and II which are grouped together on account of the many features they have in common.

From among 3,879 herring defined as spring herring, 3,823 (i.e., 98.56%) had Type I and II otoliths while from among 1,748 herring defined as autumn herring, as many as 1,620 (i.e., 92.62%) had Type III otoliths. Thus, Types I and II are characteristic of spring herring while Type III is characteristic of autumn herring.

b) Otolith Types in Herring Caught in Various Fishing Grounds and in Various Seasons

Spring. The herring prevailing in the deep-sea fisheries both in the Gdańsk and in the Bornholm Basin were those having the characteristic Type III otoliths, as has already been said, of the autumn herring (Figure 9). In the Bornholm Basin they amounted to 74.1% and in the Gdańsk Bay to 68.5% of all the herring studied. The remaining herring had Type I and II otoliths characteristic of spring herring. This conforms well to the results obtained by Popiel (1955, 1958 and 1964) and Popiel and Elwertowski (1959) who have found that the spring-summer catch consists chiefly of feeding autumn herring and comprises only a small admixture of spring herring just before or after spawning. Another conformity to be seen here is that to the results of the analysis of frequency of herring having various sizes of the first growth zone. Thus, the herring prevailing in the spring-summer season were those with high V_1 values, with Type III otoliths, i.e., autumn herring, which can be clearly seen as the peaks in the curves. Also, the age structure of the herring with Type III otoliths conforms to that of the autumn herring caught at the same time (Popiel and Strzyzewska, 1968). All of these facts confirm the statement that Type III otoliths are characteristic of autumn herring.

The catch by means of set gill-nets in coastal spawning grounds consisted mainly of herring with Type I otoliths. They ranged from 52.3% (Rowy, average from 1962 to 1964) to 100% (Vistula Firth, 24th May 1965) of the catch. Thus, Type I otoliths seem to be characteristic of herring spawning off the Polish shores in spring. The admixture of herring having Type III otoliths consists of autumn herring some of which can usually be found among spawning spring herring (Strzyzewska, 1967; Wiczkowski, 1961; Buss, 1964). Besides, in spring spawning grounds, in particular in the Rowy area, there is sometimes a considerable admixture of herring having Type II otoliths. This will be explained further on.

Autumn. The herring prevailing in the summer-autumn catch from deep-sea trawling were those with Type II otoliths (76.3% in the Gdańsk Bay; 68.8% in the Bornholm Basin). Herring with Type I otoliths were relatively scarce (4.6% in the Bornholm Basin; 8.9% in the Gdańsk Bay). Type III otoliths were slightly more numerous in the Bornholm Basin (24.7%) while in the Gdańsk Bay they were found in 12% of the fish studied. This admixture with Type III otoliths consists of autumn herring which have not yet spawned or are already spent. Autumn herring are more numerous in the Bornholm Basin (Popiel and Elwertowski, 1959; Popiel, 1964) which accounts for the greater number of herring with Type III otoliths in that area.

It is now time to deal with herring with Type I and II otoliths, i.e., spring herring. It has already been said that Type I is characteristic of the herring spawning in spring off the southern coast of the Baltic. Their small share in the catch during the summer-autumn feeding season can be accounted for by the fact that the stocks are not large. Besides, from 1954 to 1965 their number decreased both in the Eastern and Western Baltic (Biriukow and Sieletskaja, 1958; Strzyzewska, 1967). Most spring herring caught in feeding grounds in the summer-autumn season had Type II otoliths. The fish having this type are relatively old. The herring which prevailed in 1962 to 1964 were of the 1955, 1957 and 1959 year-classes. This conforms to the results obtained by Popiel and Strzyzewska (1968).

Thus, Type II otoliths can be found in most spring herring feeding in the Southern Baltic in the summer-autumn season. These fish differ from the spring spawners from the Polish coast in having a lower growth-rate, a larger head, a longer life cycle, as well as in the average number of vertebrae and gill rakers, (Popiel, 1955 and 1964). As suggested by Popiel (1955, 1958 and 1964) and Elwertowski (1954) and confirmed by a tagging experiment off the Swedish coast (Otterlind, 1961), the majority of these herring come to the Southern Baltic from the Central Baltic. That these are herring other than those spawning off the Polish coast can also be seen from a comparison of the curves representing the frequency of herring with various V_1 values from the summer-autumn season, (Figure 4) with the corresponding curves plotted for spring spawners from coastal fisheries (Figure 5). In the former case, the main peak is formed by herring with low V_1 values, with Type II otoliths, while in the latter case by herring with high V_1 values, with Type I otoliths. Another, distinctly separate peak sometimes found in spring spawning grounds and formed by Type II herring (Figure 5) as well as the age composition of spawning herring tend to confirm Strzyzewska's supposition (1967) that, at least in some years, some slow-growth herring from the Central Baltic may stay in the Southern Baltic after the feeding season until spring to spawn there together with coastal spring herring populations. Some more light could be thrown on this hypothesis by investigations of meristic features in herring with Type I and II otoliths.

The occurrence of various otolith types in herring caught in autumn in coastal spawning grounds has already been interpreted when discussing the V_1 values. This is in accordance with the conclusion that Type III otoliths are characteristic of autumn spawners.

Final Remarks

Results very close to those reached by this paper have been obtained by Rauck (1965), who dealt with the Western Baltic and, partly, with the Central Baltic, and by Ojaveer (1962a and b) and Rannak (1967) who studied the use of otoliths in identification of various herring groups in the North-East and Central Baltic.

Summing up the results of this paper and comparing them with those obtained by other authors, the following conclusions can be drawn:

1. From among the three otolith types distinguished in this paper, Type I is the most frequent in coastal spring-spawning herring spawning off the southern coast of the Baltic. Type II is characteristic of marine spring herring. Three subtypes can be distinguished within Type II which seems to result from the fact that marine herring found in the Southern Baltic feeding grounds are a mixture of various populations. Type III is characteristic of autumn herring.

2. Otolith types can be of use in identifying herring belonging to the three groups living in the Southern Baltic: coastal spring herring, marine spring herring and autumn herring.

3. Studies of otoliths tend to confirm Strzyzewska's supposition that, at least in some years, some marine spring herring may stay in the Southern Baltic after the summer-autumn feeding season until spring to spawn there together with coastal spring herring.

4. The analysis of the occurrence of herring with various sizes of the first growth zone in otoliths may be of great use in studying the share of marine spring herring, coastal spring herring and autumn herring in the catch.

5. Marine spring herring can be distinguished from coastal spring herring and from autumn herring by comparing the sizes of the first growth zones in their otoliths.

6. The shape of otolith growth-rate curves seems to be characteristic of herring belonging to the given group.

7. The otolith radius/fish length relation is a straight line function for herring 15-30 cm in length, i.e., those found in the catch.

8. The considerable shift from the origin of co-ordinates of the regression lines representing the otolith radius/fish length relation suggests that in young Southern Baltic herring this relation is not a straight line but a curve.

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Table 1. The occurrence of herring with the different transparency of the otolith nucleus.x)

Otolith Type	0		OH		HO		H		Total	
	n	%	n	%	n	%	n	%	n	%
I	93	21,9	227	53,5	79	18,7	25	5,9	425	100,0
II A	296	26,5	493	44,1	222	19,9	107	9,5	1118	100,0
II B	118	32,8	169	46,8	53	14,8	20	5,6	361	100,0
III	268	25,5	291	27,6	183	17,4	310	29,5	1052	100,0

x) 0 = opaque; OH = opaque-hyaline; HO = hyaline-opaque; H = hyaline

Table 2. The occurrence of I, II, and III otolith types in spring- and autumn-spawning herring of the Southern Baltic from 1962 to 1964.

Seasons	SPRING SPAWNING						AUTUMN SPAWNING						Unidentified	Total
	III		I and II		Spring-spawning total		III		I and II		Autumn-spawning total			
	n	%	n	%	n	%	n	%	n	%	n	%		
	Trawl catches in open sea feeding grounds - Bornholm Basin													
Spring-Summer	10	5,5	154	94,5	164	100,0	546	95,6	25	4,4	571	100,0	15	750
Summer-Autumn	21	1,9	1114	98,1	1135	100,0	362	93,3	22	6,7	384	100,0	29	1548
	Trawl catches in open sea feeding grounds - Gdańsk Bay													
Spring-Summer	3	3,4	86	96,6	89	100,0	271	92,2	23	7,8	294	100,0	17	400
Summer-Autumn	17	1,1	1669	98,9	1686	100,0	225	86,9	34	13,1	259	100,0	54	1999
	Set gill-net catches in coastal spawning grounds													
Spring	5	0,8	751	99,2	756	100,0	27	62,3	15	37,7	42	100,0	12	810
Autumn	-	-	49	100,0	49	100,0	189	95,0	10	5,0	199	100,0	8	256
Total	56	1,4	3823	98,6	3879	100,0	1620	92,6	129	7,4	1748	100,0	135	5763

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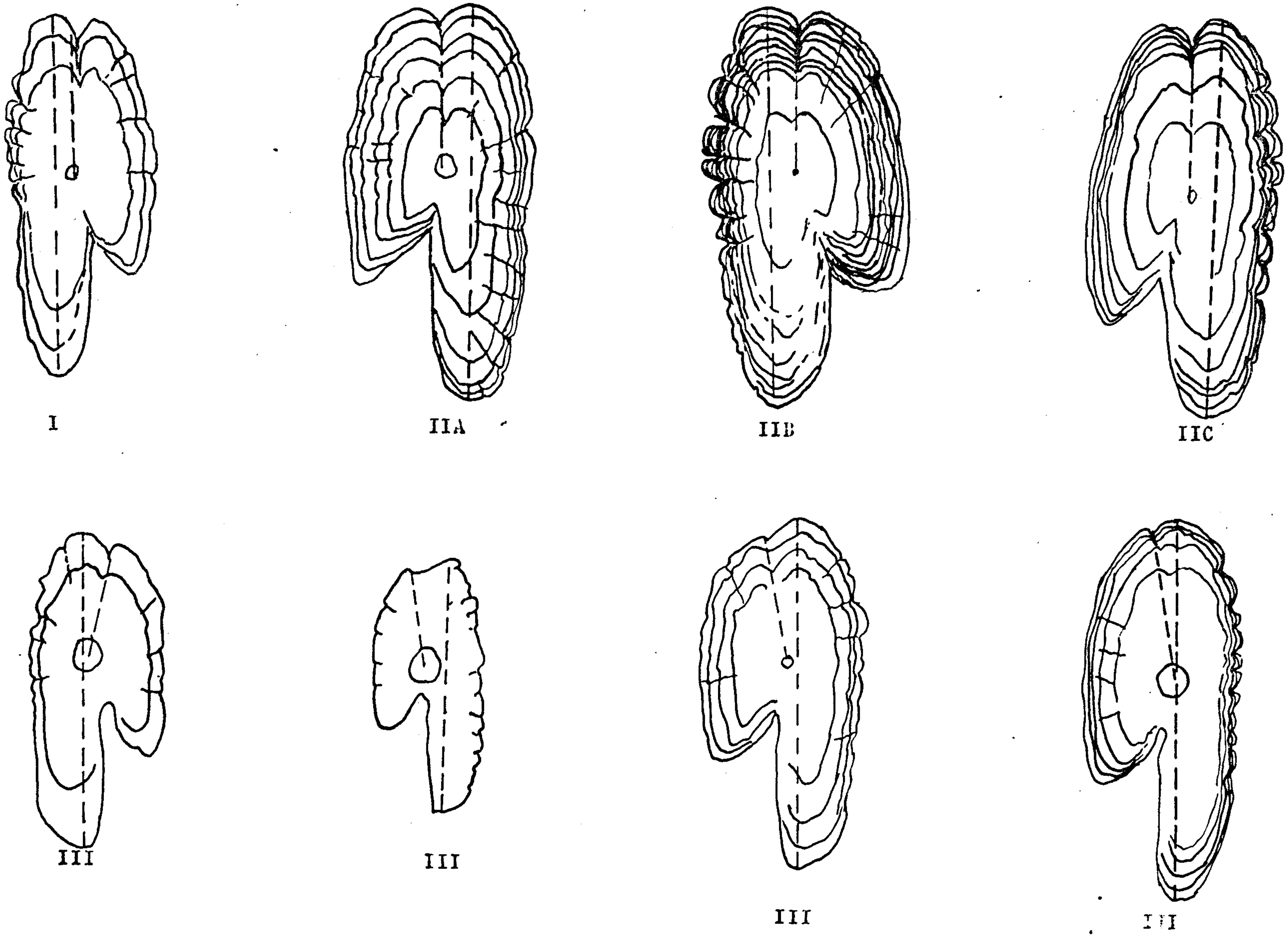
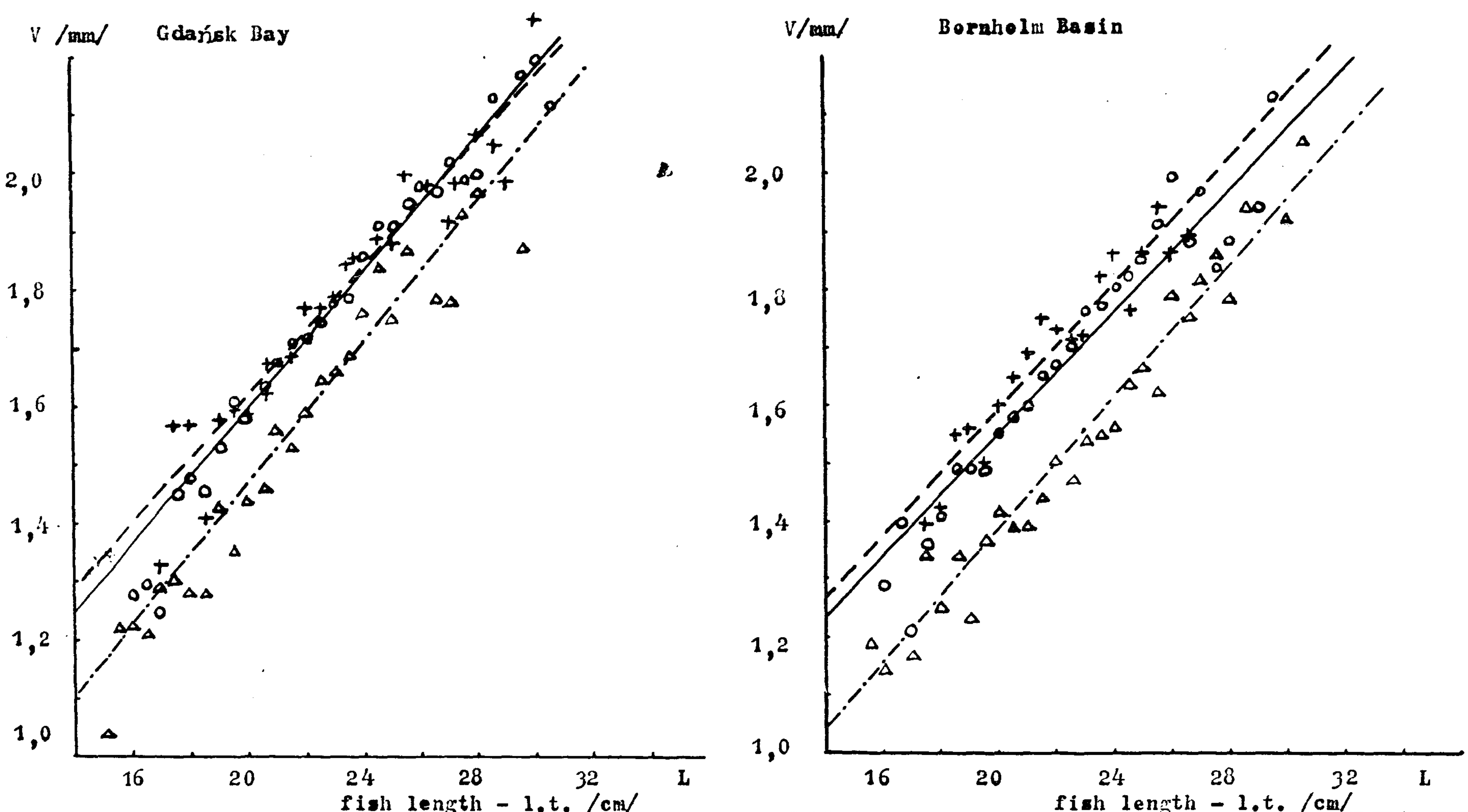


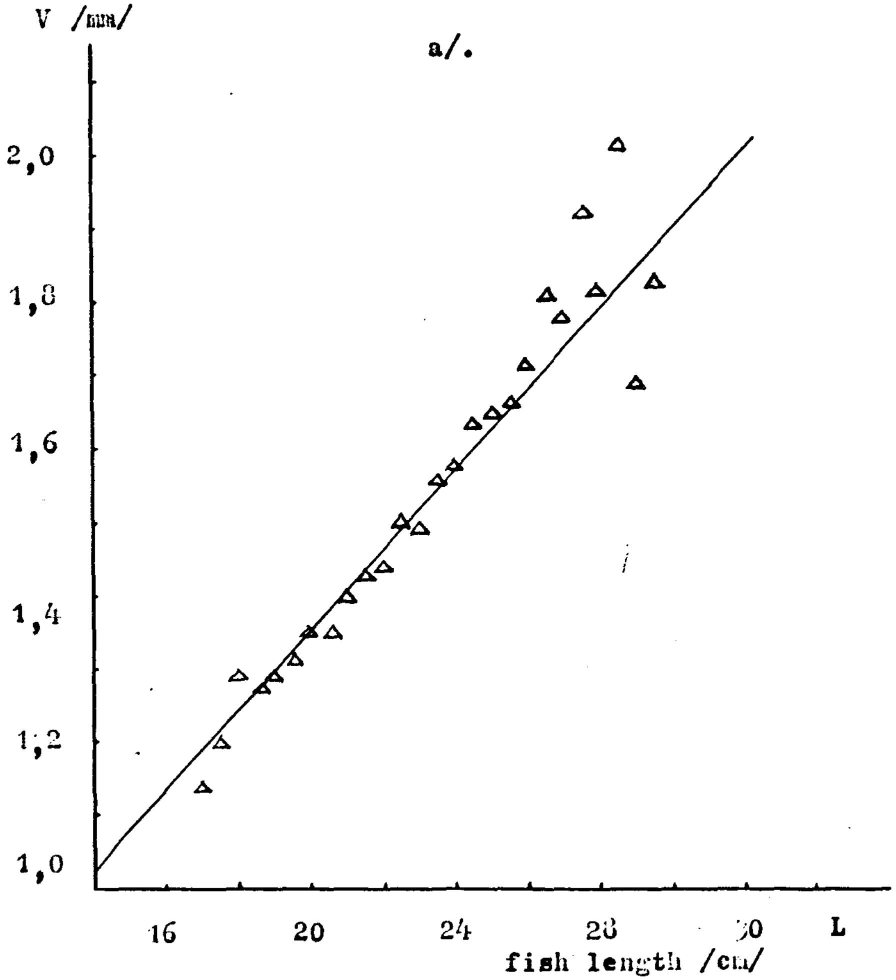
Fig. 1. The otolith types of Southern Baltic herring

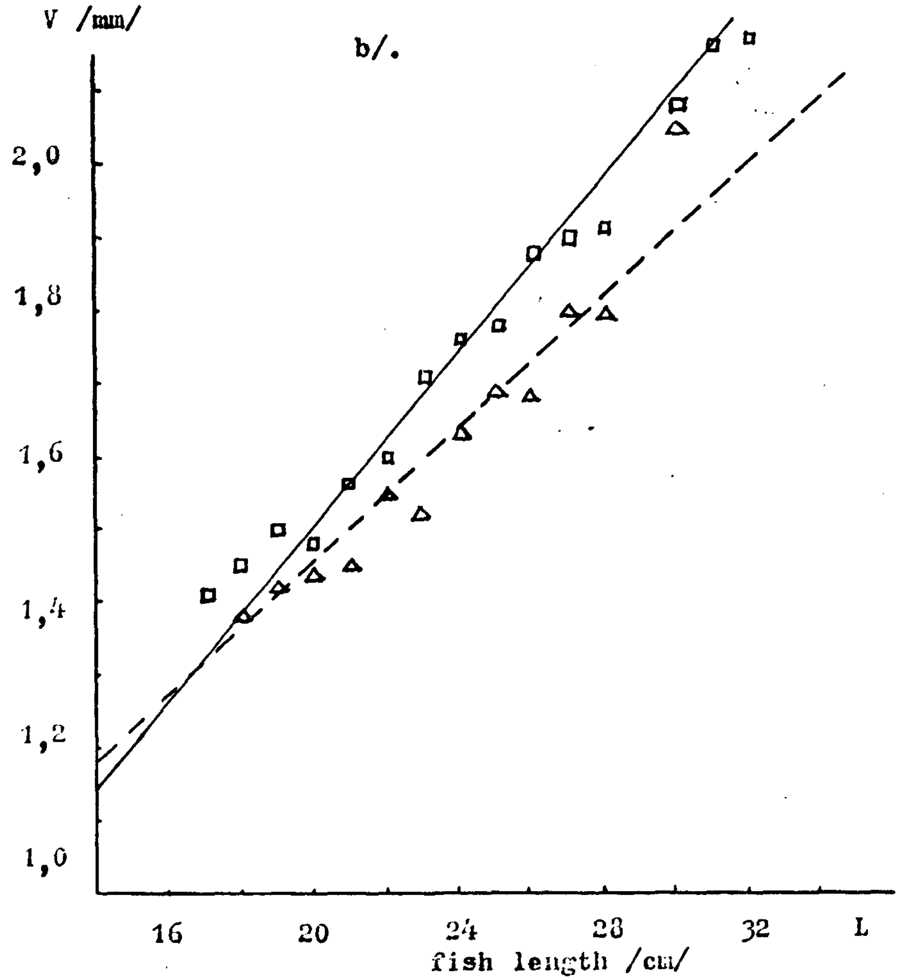
Fig. 2. The relationship between fish size and otolith size. Summer-autumn seasons 1963 and 1964.



otolith type	correlation coefficient	regression equation	empiric data	otolith type	correlation coefficient	regression equation	empiric data
IIA	0,797	V = 0,058L + 0,436 ———	o	IIA	0,900	V = 0,0529L + 0,491 ———	o
IIB	0,962	V = 0,0556L + 0,503 - - -	+	IIB	0,971	V = 0,0541L + 0,509 - - -	+
III	0,993	V = 0,061L + 0,245 -·-·-	Δ	III	0,978	V = 0,0574L + 0,231 -·-·-	Δ

Fig. 3. The relationship between fish size and otolith size. a/. spring summer season 1963 and 1964 of Bornholm Basin, b/. herring caught by means of set gill-nets on spawning grounds near Rewy and Mrzeżyno /III otolith type/ and in regions of Orłowo, Rewy, Kuźnica, Pomeranian Bay and Vistula Firth /I otolith type/.





otolith type	correlation coefficient	regression equation	empiric data
III	0,864	V = 0,0541L + 0,277	△

otolith type	correlation coefficient	regression equation	empiric data
III	0,920	V = 0,046L + 0,534 – – –	△
I	0,951	V = 0,061L + 0,274 ——	□

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Figure 4.

The occurrence of herring with the different V_1 value according to the particular otolith types.

Bornholm Basin

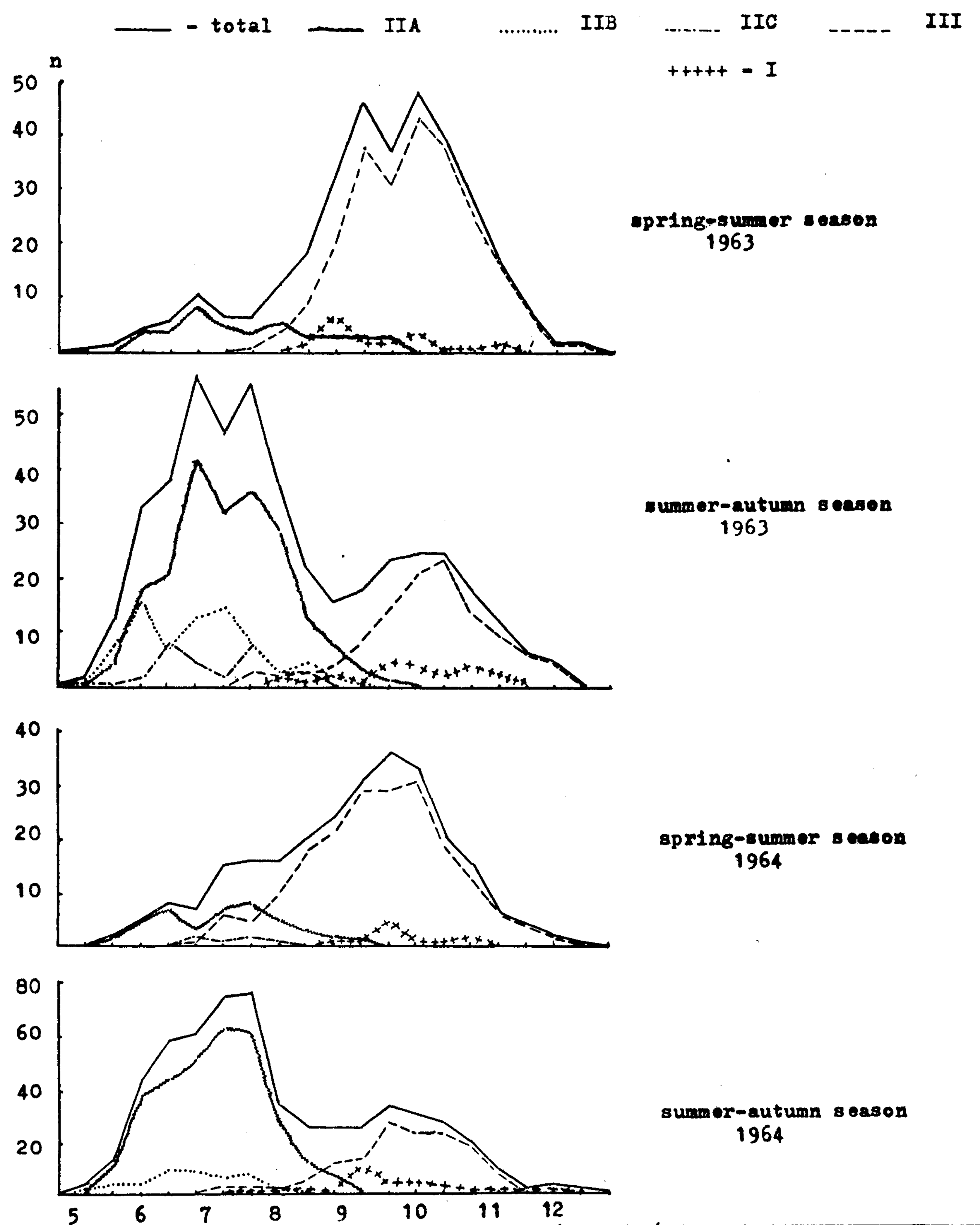

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Figure 5. The occurrence of herring with the different V_1 value. Coastal fishing grounds.

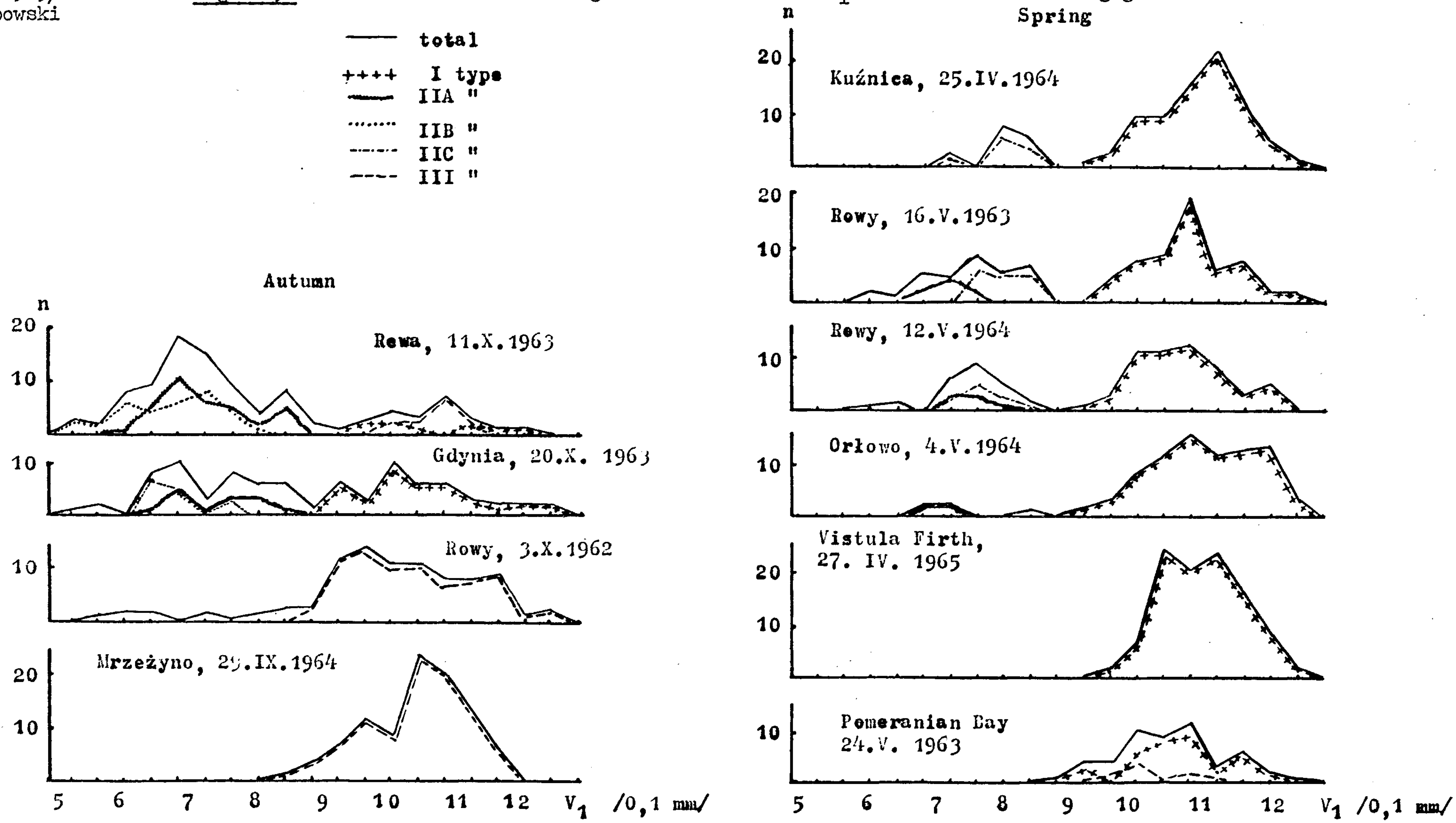

Figure 6. Mean V_1 value according to particular age-groups.

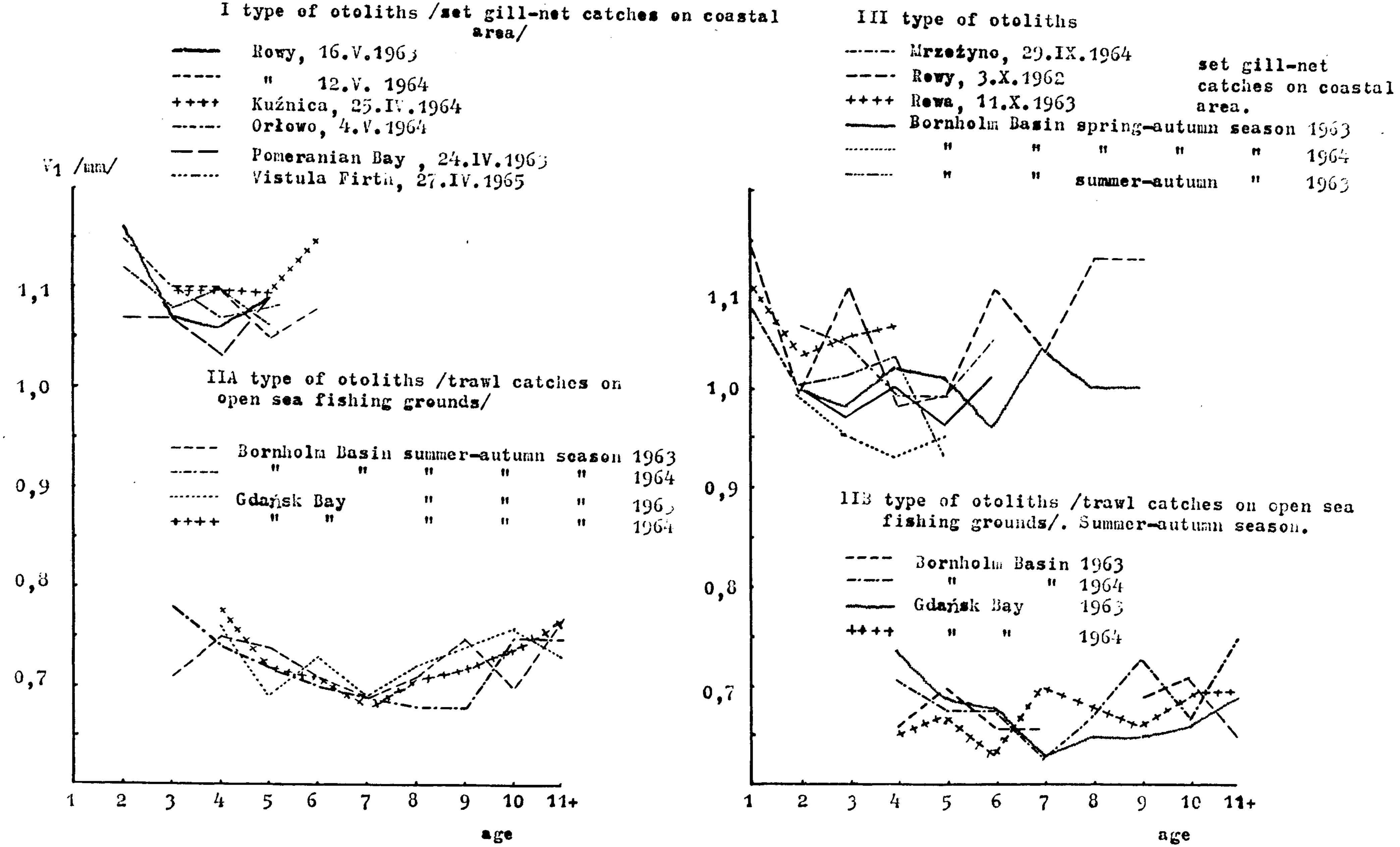

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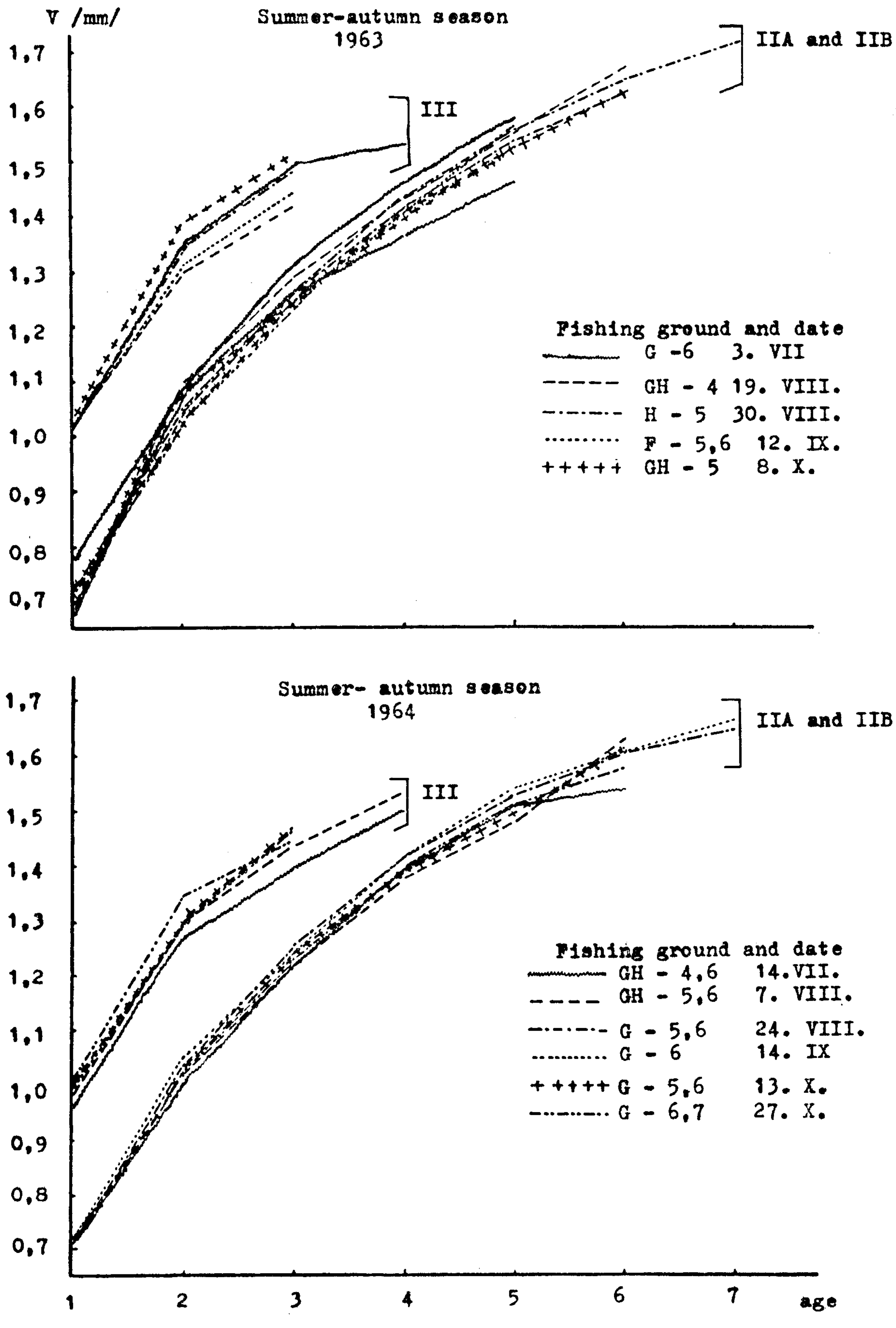
Figure 7. The growth of otoliths of herring from the Bornholm Basin.



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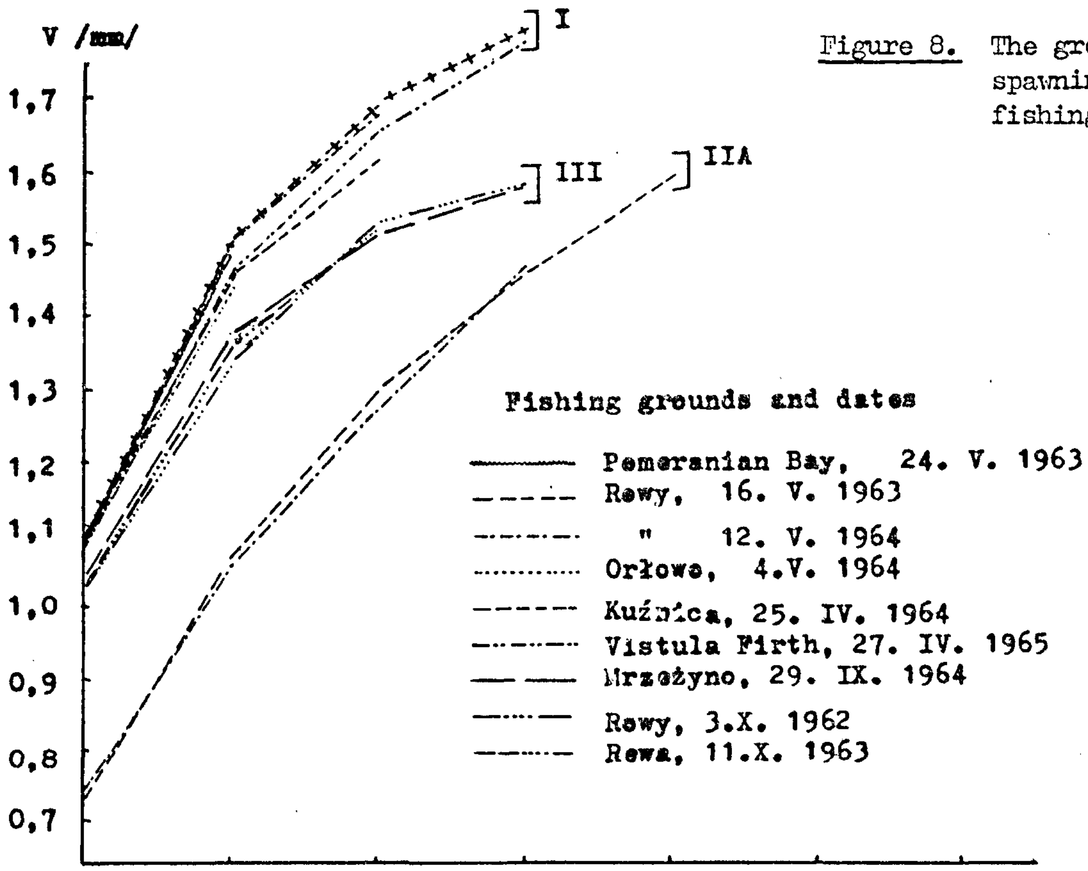

Figure 8. The growth of otoliths of spawning herring from coastal fishing grounds.

C.M.1969/H:12
Kompowski

Figure 9.

The occurrence of herring with the different otolith types in Southern Baltic Sea in 1962 - 1964. The feeding area are presented by large circles and the spawning grounds by small ones.