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A COMPARATIVE ANALYSIS OF SOME ANATOMICAL ELEMENTS WITH REGARD TO THEIR RELEVANCE TO THE AGE AND GROWTH RATE DETERMINATION IN GREENLAND HALIBUT, *Reinhardtius hippoglossoides* (WALBAUM)

PORÓWNAWCZA ANALIZA PRZYDATNOŚCI RÓŻNYCH ELEMENTÓW ANATOMICZNYCH DO OZNACZANIA WIEKU I TEMPA WZROSTU HALIBUTA NIEBIESKIEGO *Reinhardtius hippoglossoides* (WALBAUM)

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The present paper evaluates the applicability of various anatomical parts of fish to age determinations and growth rate calculations. Additionally, the results of attempts to improve the conspicuousness of seasonal zones by calcination and staining are presented.

INTRODUCTION

The biology of Greenland halibut has not been treated to any greater detail so far, regardless of the fact that the species is of considerable importance to both the ICNAF and ICES regions fisheries. The hitherto-published papers deal mainly with catches, taxonomy, and geographic distribution of the species. The lack of more comprehensive biological treatment is associated with difficulties encountered in methodology of the age and growth rate determinations. Even Smidt (1969) in his extensive monographic study on the biology of Greenland halibut off Greenland offers no definite solution of the problem. The workers attempting so far to determine the Greenland halibut age and growth rate have all used otoliths, except for Milinskij (1944) who worked with scales. However, it is very difficult to read the age from otoliths due to their irregular structure, deeply incised edges and many secondary zones, their number increasing with fish length (Smidt, op. cit.). The age of young fishes, in spite of their best-readable otoliths, can be determined only in less than 50% individuals. The readability of otoliths deteriorates with fish growth: only 12% of the otoliths of 60–80 cm long fish individuals can be used for age determinations, 4 and 0% being found in 80–100 and more than 100 cm long fishes, respectively. Therefore the author discussed limited his activities to determining the fish age up to the twelvth year only. Also Paschen (1968) stated the percentage of readable otoliths in Greenland halibut off Iceland as ca 30%.

Thus the present paper was aimed at finding some more convenient method for age and growth rate determinations, which has a considerable bearing on setting a biological basis for the commercial exploitation of the species.

MATERIALS AND METHODS

Materials

The materials to be treated here were collected in 1971 and 1972 from 2 North Atlantic regions, namely from the New Foundland and Barents Sea fishing grounds. 603 specimens were examined. All the specimens supplied scales and otoliths, and additionally vertebrae, opercular bones, and fin rays were taken out of 86 individuals. In 353 specimens the scales were picked out from 12 different spots on the body surface in order to find the place with scales of most conspicuous structure of annual zones as well as of the radius – fish length ratio most suitable for the growth rate back calculations. The data collected are summarized in detail in Table 1.

Methods

Frozen Greenland halibut individuals were brought to the laboratory where the body length (l.t.) measurements with a 1 cm accuracy were performed on thawed fish.

Attempts were made to increase the readability of some anatomical parts through alizarin-staining (vertebrae and otoliths) and calcination (otoliths). For calcination, the otoliths were placed on a heat-resistant glass dish and heated with a burner. The calcinated otoliths were then transferred to a small vessel placed against dark background, poured over with alcohol and scanned in incident light of a Zeiss measuring microscope. The same microscope was used in transmitted lightscanning of scales and measurements of annuli.

The regression equations and correlation coefficients were calculated according to formulae given by Romanowski (1952).

Table 1

Summary of data on material collected in 1971 and 1972

No.	Region of capture	Date of capture	Geographic co-ordinates	Number of fish examined	Elements taken				
					Scales	Otoliths	Vertebrae	Opercular bones	Fin rays
1	New Foundland	19.04.71.	46°08′N–51°00′W	82	82	82	–	–	–
2	sub – area	08.04.72.	50°04′N–52°47′W	98	98	98	86	86	86
3	fishing grounds	17.09.72.	51°35′N–54°00′W	250	250	250	–	–	–
4	Barents Sea	19.11.71	72°48′N–15°17′E	173	173	173	–	–	–

RESULTS

Age determinations

Otoliths, scales, vertebrae, opercular bones, and fin rays were used in the Greenland halibut age determinations. Opercular bones and fin rays, owing to their delicate structure and poor readability, turned out to be unsuitable for this task. Otoliths and vertebrae, without any special treatment applied, were not fulfilling the requirements of a proper age reading either. Calcination of otoliths increases their readability a little due to differences in chemical composition of opaque and hyaline zones (Dennevig, 1956). The fact that calcination is at times highly advantageous for the otolith readability has been stated by Krzykawski and Romański (1972) in their report on studies on whiting. Alizarin-staining of vertebrae and otoliths proved successful only in the first. However, the most suitable material for the Greenland halibut age and growth determination was found in scales. They are sufficiently readable in most fishes examined, while readable otoliths are possible to obtain only from some, rather young, individuals, and the vertebrae, because of a laborious treatment necessary for the determination, cannot serve to determine the age of any greater number of fishes. A comparison of a scale, alizarin-stained vertebra, and otolith, taken from the same individual, is seen on Fig. 1. Such comparison, made for 86 specimens, showed the age read from otoliths to be one year, or even two years higher than that read from the other two elements. Presumably this is associated with the presence of secondary zones revealed by Smidt (1969).

In the age determinations from scales, the number of annuli, visible as zones of close circuli, was taken as a guideline. An annulus was recognized on the outer border of the zone (Figs. 2, 3, 4, 5). Apart from the true annuli, false ones were found to occur on Greenland halibut scales. The nomenclature of these annuli was adopted after Čugunova (1959). In the material examined, one of the most frequently found false annuli was a juvenile ring seen as a border between the zones of close circuli near the centre and the zone of more loosely spread circuli placed off the centre. More rare was a so-called double ring situated very close to another ring, as well as a partial ring shown only on a part of a scale.

Growth rate determination

In order to test the applicability of scales to growth rate determination, they were collected at 12 spots on the body surface from 173 fish specimens obtained from the Barents Sea fishing grounds, and from 180 ones from the New Foundland fishing grounds (Fig. 6). A relationship between the Greenland halibut total body length (l.t.) and an oral radius of the scale from a given spot was also calculated. When choosing the longer (oral) radius to be used in growth rate calculations, decisive was the fact that the annuli there are displaced farther apart, therefore they are more conspicuous. Moreover, pigment cells are very frequent in the caudal part, whereby a proper interpretation of annuli from this part is difficult.

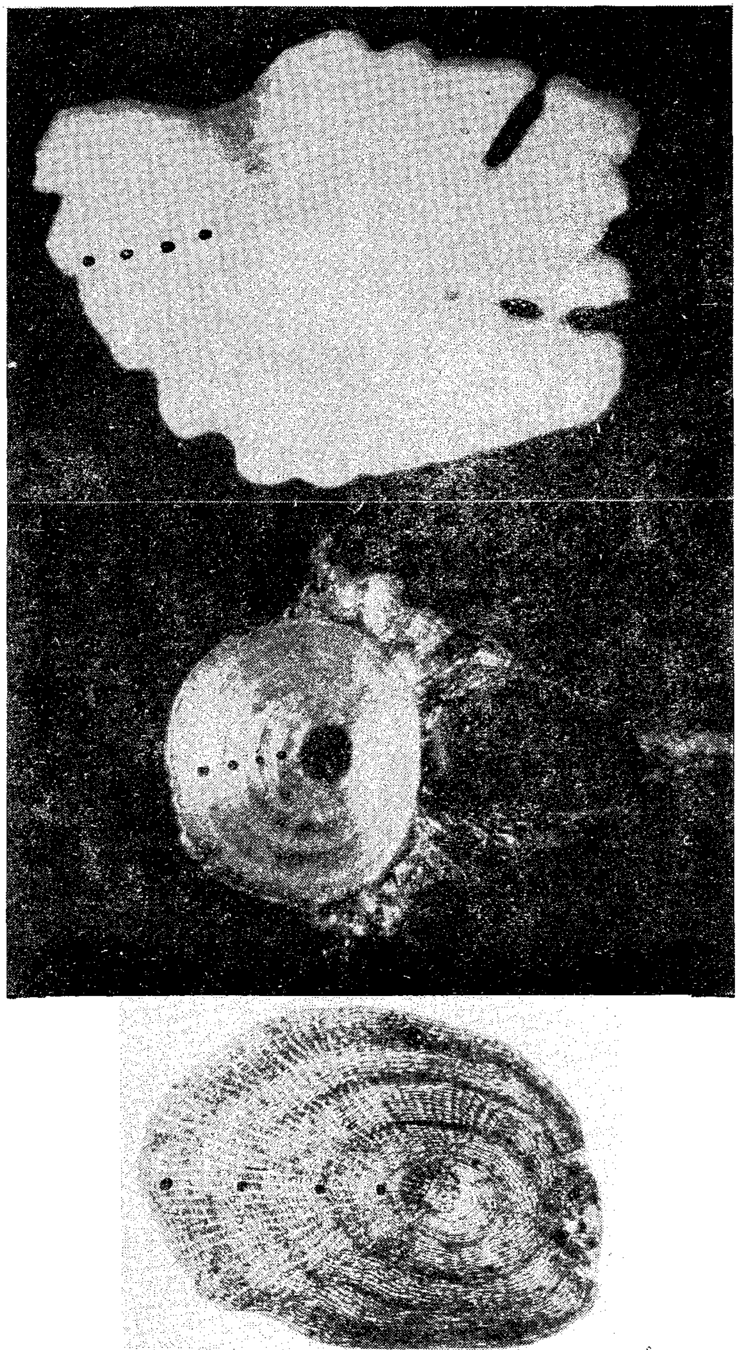

Fig. 1. Otolith, vertebra, and scale of a 4+ –years-old Greenland halibut of 43 cm length (l.t.) (Phot. by C. Nagięć)

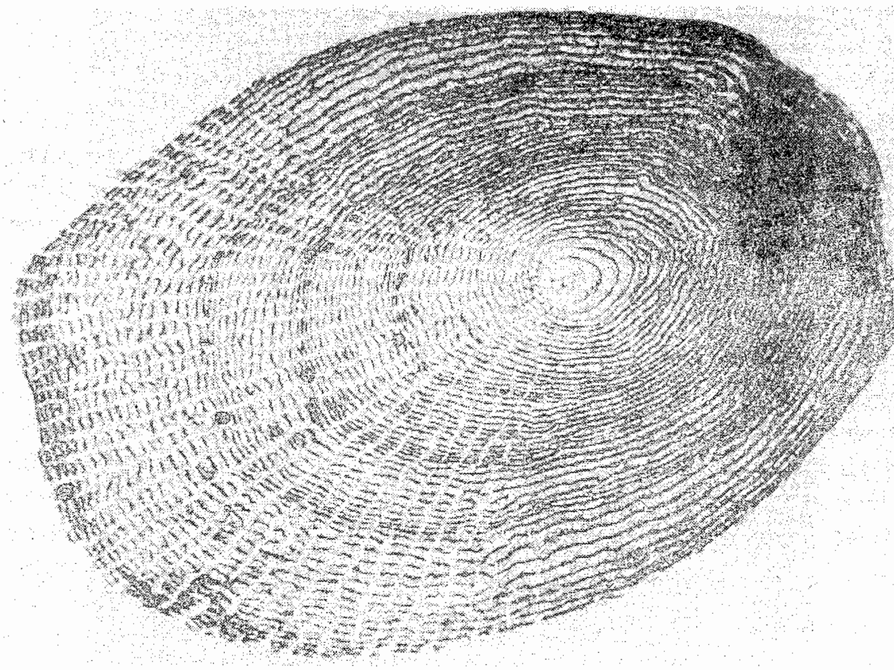

Fig. 2. Scale of a 4-years-old Greenland halibut of 37 cm length (l. t.) (Phot. by C. Nagięć)

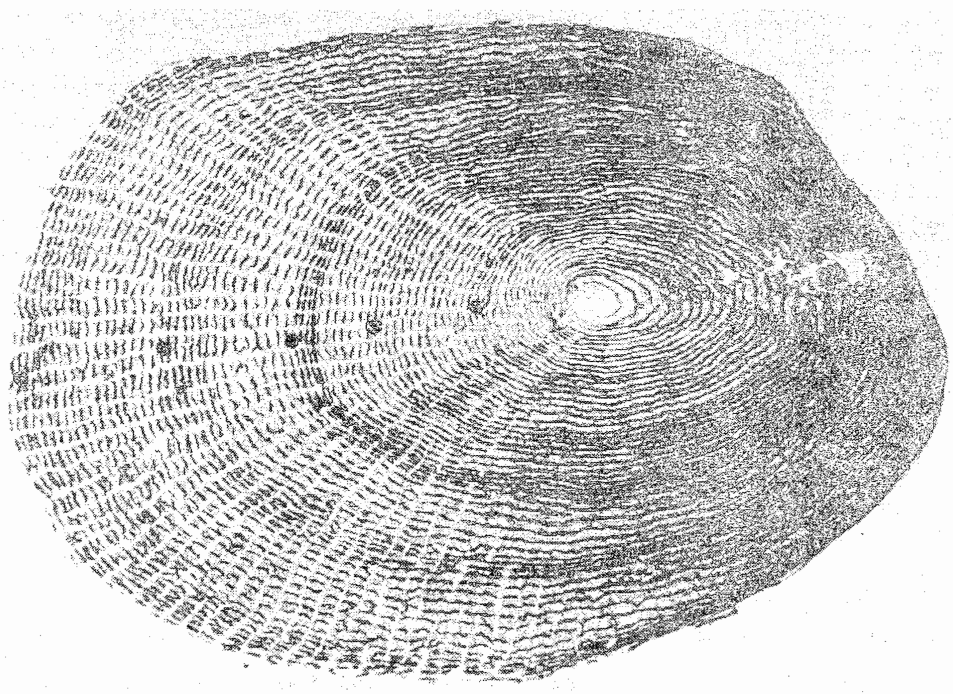

Fig. 3. Scale of a 5-years-old Greenland halibut of 44 cm length (l. t.) (Phot. by C. Nagięć)

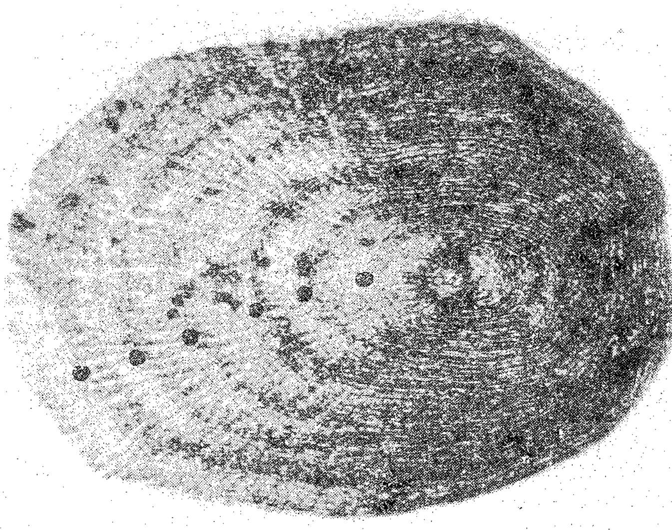

Fig. 4. Scale of a 6+-years-old Greenland halibut of 54 cm length (l. t.) (Phot. by C. Nagięć)

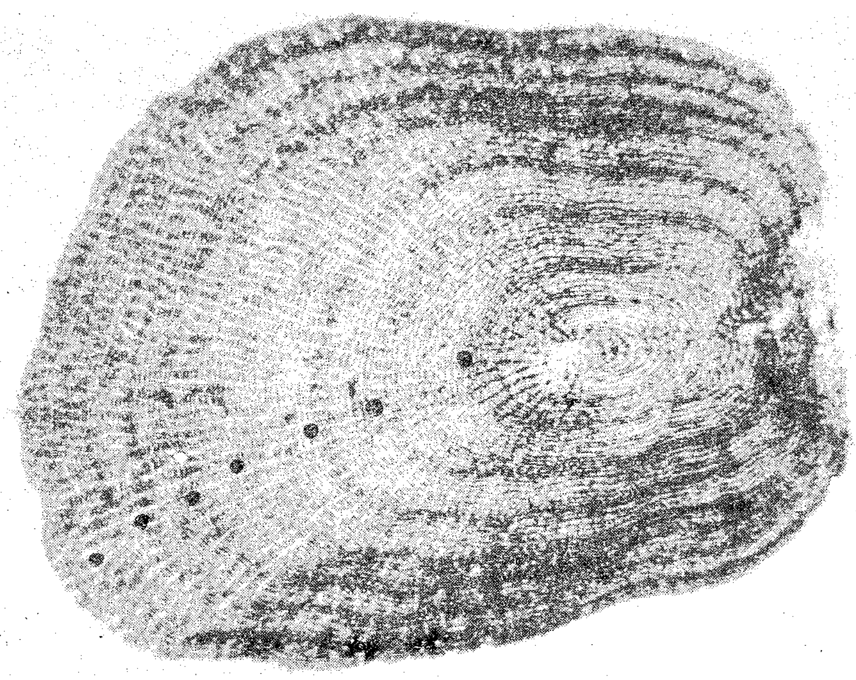

Fig. 5. Scale of a 7+-years-old Greenland halibut of 59 cm length (l. t.) (Phot. by C. Nagięć)

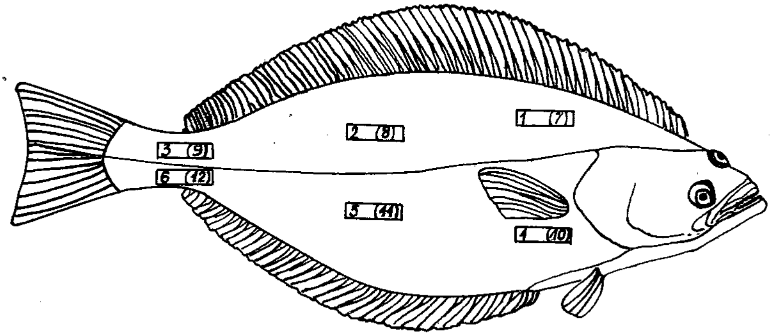

Fig. 6. Spots for collecting Greenland halibut scales for oral radius (r. or.) – total length (l. t.) relationship analysis. Figures in parentheses define analogous spots on blind side

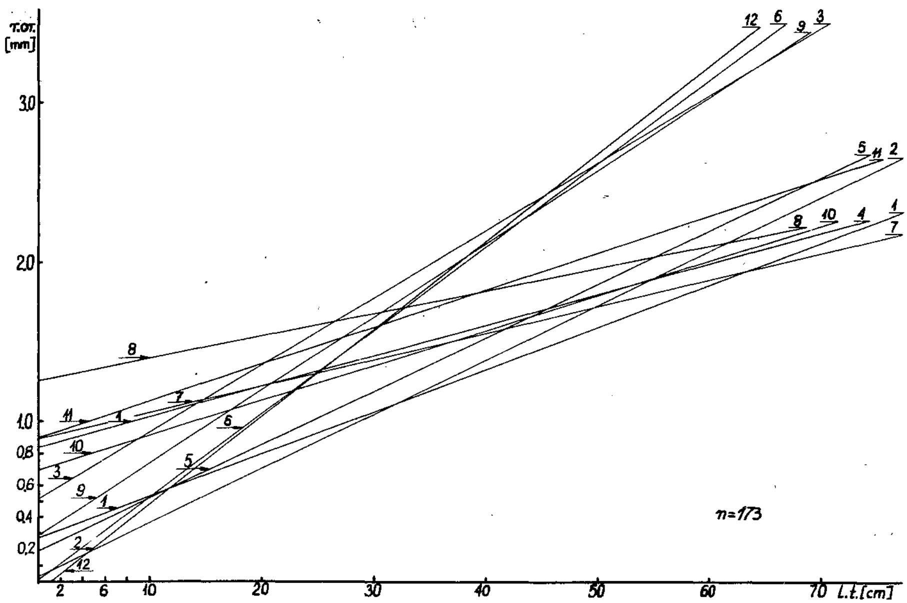

Fig. 7. Total length (l. t.) – scale oral radius (r. or.) relationship for 12 spots on Greenland halibut body from Barents Sea fishing grounds

A linear relationship was found between the oral radius length for all the 12 spots and the total length (l.t.) of Greenland halibut (Figs. 7 and 8). Correlation coefficients and regression equations, calculated for 12 chosen places from the Barents Sea material, are presented in Table 2. Fig. 7 shows a graph representing the relationship studied. As it is seen from Table 2, the highest correlation coefficients are observed for scales taken from the following spots: 3, 5, 6, 9, and 12, the spots 3, 6, 9, and 12 being placed in the caudal part of the fish body. At the same time the regression lines drawn for the caudal scales

Table 2

Relationships between total length (l.t.) and scale oral redius for 12 spots on Greenland halibut body for Barents Sea fishing grounds

Spot of scale collection	Correlation coefficient	Regression equation
1	0.633	y = 0.0265x+0.27
2	0.678	y = 0.0340x+0.03
3	0.810	y = 0.0422x+0.52
4	0.615	y = 0.0192x+0.84
5	0.758	y = 0.0334x+0.20
6	0.779	y = 0.0521x+0.01
7	0.534	y = 0.0167x+0.87
8	0.379	y = 0.0140x+1.26
9	0.734	y = 0.0458x+0.28
10	0.521	y = 0.0218x+0.70
11	0.562	y = 0.0235x+0.88
12	0.848	y = 0.0542x−0.06

differ in their slope from the remaining ones, which is associated with their larger sizes. Moreover, the lines as opposed to most of the others, cross the y-axis closer to the origin. Since the caudal scales are the largest, their annuli are observed to be most conspicuous. The scale size was found to decrease towards the head, which holds true for all fish caught in various regions.

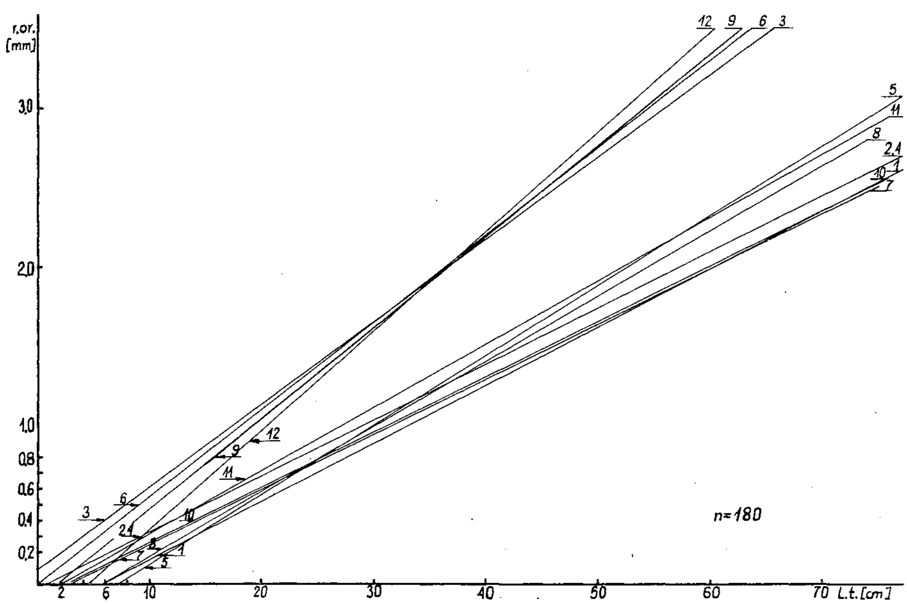

Fig. 8. Total length (l. t.) – scale oral radius (r. or.) relationship for 12 spots on Greenland halibut body from New Foundland fishing grounds

Table 3

Relationships between total length (l.t.) and scale oral radius for 12 spots on Greenland halibut body for New Foundland sub-area fishing grounds

Spot of scale collection	Correlation coefficient	Regression equation
1	0.866	y = 0.0365x–0.21
2	0.923	y = 0.0353x–0.02
3	0.897	y = 0.0519x+0.10
4	0.892	y = 0.0353x–0.02
5	0.877	y = 0.0439x–0.31
6	0.893	y = 0.0548x
7	0.878	y = 0.0347x–0.10
8	0.897	y = 0.0410x–0.24
9	0.893	y = 0.0570x–0.10
10	0.904	y = 0.0346x–0.08
11	0.897	y = 0.0400x–0.08
12	0.950	y = 0.0629x–0.29

Table 3 contains data analogous to those in Table 2, concerning the New Foundland sub-area fishes. The pattern of the oral radius – fish length relationship is presented in Fig. 8. As can be seen from Table 3 and Fig. 8, again the highest correlation coefficients are to be found, in general, in scales of the caudal part of the body, while the course of regression lines corresponding to this part of the body is similar to that observed in the Barents Sea fishes. The correlation coefficients computed for the caudal part of the body (Tables 2 and 3) ranged within 0.734–0.950, which is indicative of a significant or very strong (Guilford, 1960) relationship between the Greenland halibut total length and oral radius of a scale from this part of the body.

The comparisons made show the caudal scales (spots 3, 6, 9, and 12) to be readable to the highest degree; the scales are almost equally suitable to both the age and growth rate determinations. In view of the above-mentioned finding of different size and readability of scales derived from various parts of the fish body, it is very important to follow the procedure of obtaining scales from the strictly defined spot. Scales obtained from above the lateral line in the caudal part of the eye side of the body (spot 3) were adopted as a basis for the ensuing determinations. The least amount of regenerated scales was found at this spot. Thus the relationship between the Greenland halibut total length (l.t.) and oral radius of its caudal scale (r.or.) (spot 3) was additionally calculated from the enlarged material (430 individuals) obtained from the New Foundland fishing grounds, where the body length varied from 13 to 81 cm. The relationship is presented in Fig. 9. The correlation coefficient was r = 0.986, and the regression equation was thus:

$$y = 0.057\,x - 0.20$$

A straight line was drawn according to the equation; the line crossed the x-axis at the point of 35.1 mm indicating that the fish length – oral radius ratio is not constant.

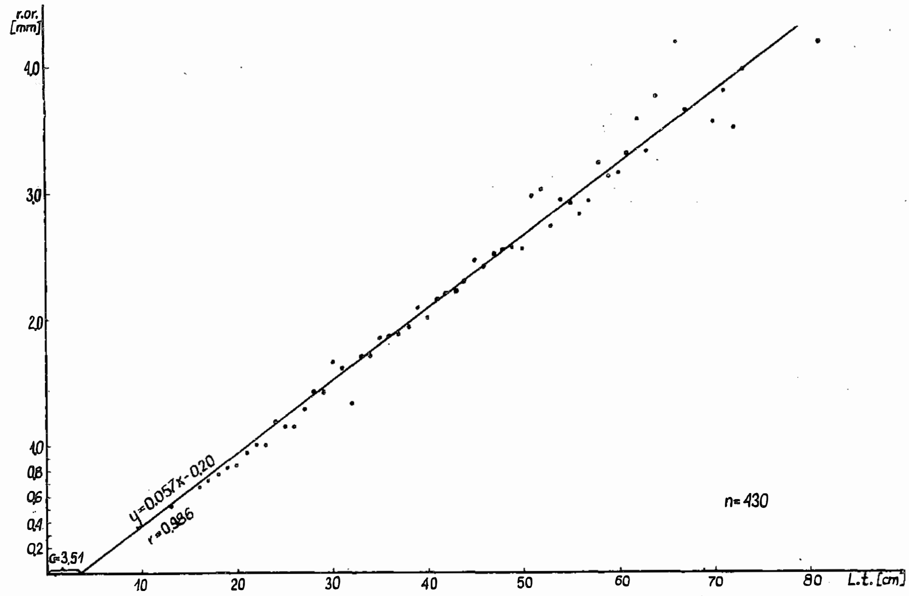

Fig. 9. Greenland halibut total length (l. t.) – caudal scale oral radius (r. or.) (spot 3) relationship

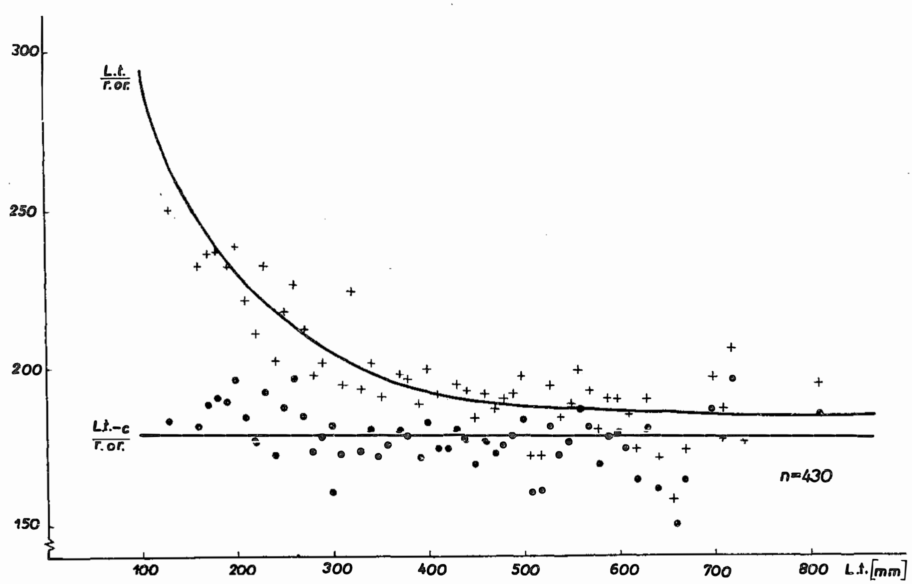

Fig. 10. Greenland halibut $\frac{\text{l. t.}}{\text{r. or.}}$ and $\frac{\text{l. t.}-\text{c}}{\text{r. or.}}$ – total length (l. t.) relationship

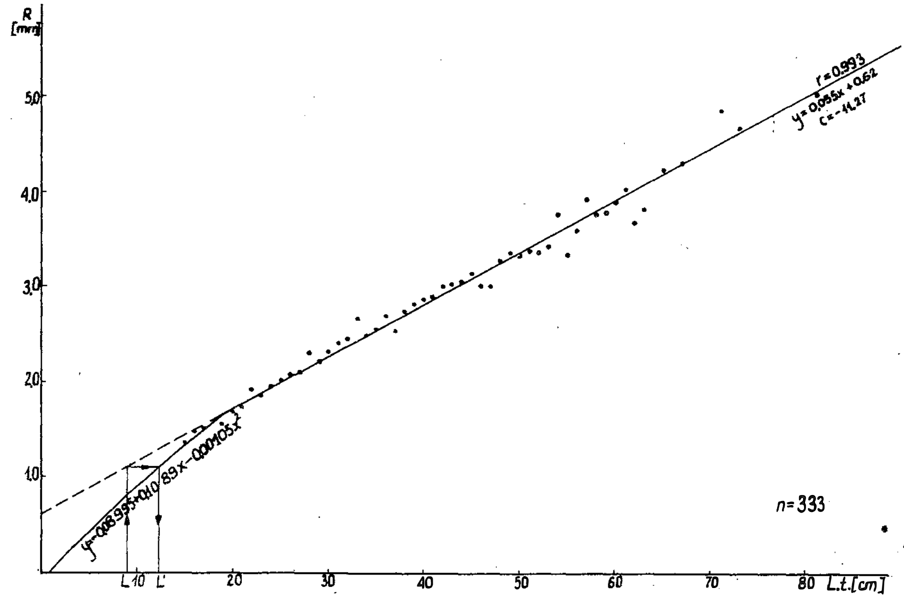

Fig. 11. Greenland halibut total length (l. t.) – left otolith radius relationship

Therefore the Dahl – Lea method applied without any correction can lead to erroneous results. The value of 35.1 mm indicates to a length at which a scale begins to grow at the spot 3 on a Greenland halibut's body.

Fig. 10 presents changes observed in the l.t./r.or. ratio with the fish length. As is seen, the larger the fish, the smaller the ratio. On the other hand, the $\frac{\text{l.t.}-\text{c}}{\text{r.or.}}$ ratio is almost constant and equals 178 when c = 35.1 mm. Therefore, when studying the Greenland halibut growth rate based on back calculations on scales, the Rosa Lee formula was used.

In order to check if the scales-based growth rate calculations were properly done, the relations between vertebrae sizes and otoliths on one hand and the fish total length on the other were also followed using the material obtained from the New Foundland fishing grounds.

Fig. 11 presents the relationship between the total length (l.t.) of Greenland halibut and a left otolith radius size, calculated from 333 specimens measured. The correlation coefficient here is high, r = 0.993, but the line drawn according to the regression equation

$$y = 0.055\,x - 0.62$$

crosses the y-axis relatively far from the origin. The line crossed the x-axis at c = –11.27 mm. The figure shows the empiric points for lengths less than 20 cm to lie beneath the line, which would point to a curvilinear relationship within the length range of 0–20 cm. Therefore the total length (l.t.) – left otolith radius relationship up to

20 cm was calculated and drawn according to the formula given by Sheriff (1922) who states the parabolic nature of the relationship studied. Back calculations on otoliths were performed as in the Rosa Lee formula and corrected (the results less than 20 cm only) by a graphic method (the method is schematically outlined in Fig. 11).

The relationship between the vertebra radius and the total fish length, calculated from 86 individuals measured, is presented in Fig. 12. This relationship has a linear form as well. The correlation coefficient was r = 0.964, and the line drawn according to the regression equation

$$y = 0.078\,x - 0.73$$

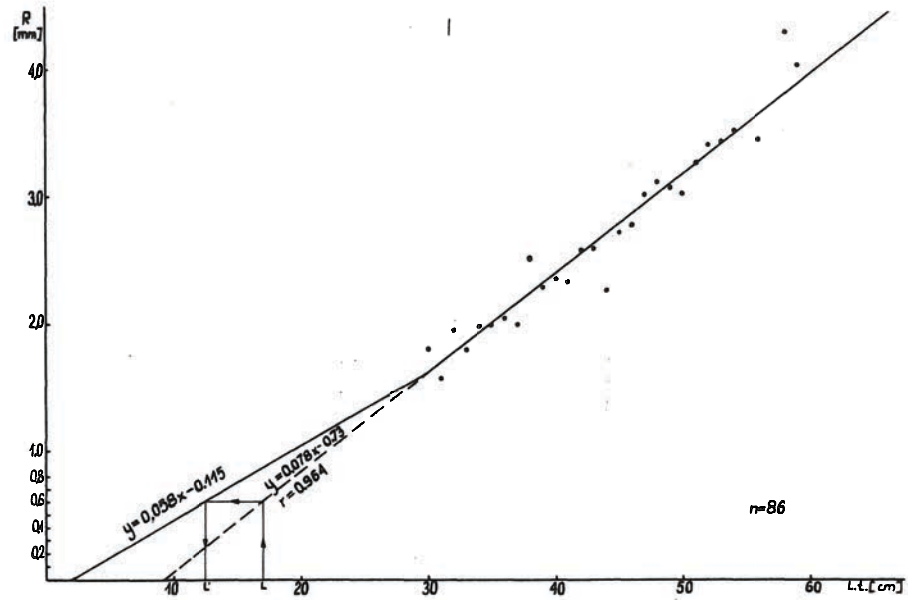

Fig. 12. Greenland halibut total length (l. t.) – vertebra radius relationship

crosses the x-axis relatively far from the origin. That happened because the material taken to follow the relationship was poorly representative and lacking individuals smaller than 30 cm. Therefore an additional line, based on two points, was drawn for the lengths less than 30 cm. The points were set as follows:

1. a point lying on the regression line, corresponding to the 30 cm length, i.e., at the smallest length found in fish studied;
2. a point corresponding to the 2 cm length, where a vertebra radius had been assumed to equal O (from data on halibut larvae length, Smidt, 1969).

The equation for the additional line is given in form of

$$y = 0.058\,x - 0.115$$

Using this line, lengths less than 30 cm, back-calculated from vertebrae, using the Rosa Lee formula were corrected. The scheme for corrections is presented in Fig. 12.

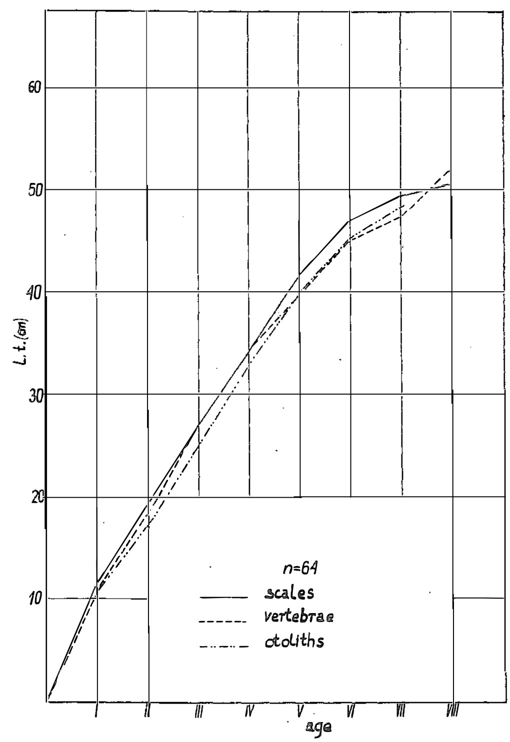

Fig. 13. Comparison of growth rates as back-calculated from scales, vertebrae, and otoliths in a sample caught on April 8, 1972

Fig. 13 presents a comparison of growth rates back-calculated from scales, vertebrae, and otoliths in a sample caught on April 8, 1972 at the New Foundland fishing grounds. Smaller differences were found between back calculations based on scales and vertebrae, while the back-calculated growth rate based on otoliths is underestimated in relation to the other two elements. The difference emerges from the presence of secondary zones mentioned earlier which cause the age calculated from otoliths to be overestimated when compared to that obtained from scales and vertebrae. The maximum difference between the lengths calculated from the three elements is, however, small and equals 2 cm. The curves drawn on the figure show fairly close results to have been obtained from the three elements, which confirms the appropriateness of the method applied.

CONCLUSIONS

1. Basing on the analysis of relevance of five anatomical elements to the age determinations, fin rays and opercular bones were found to be unsuitable for the

purpose. Alizarin-stained vertebrae can be used, but owing to difficulties inherent in the preliminary preparations, they are of no use when a numerous material is to be dealt with. Calcinated otoliths show a satisfactory readability only in a low number of fish. Scales proved the most suitable material for the age and growth rate determinations.

2. Scales to be used in the age and growth rate determinations should be taken from the caudal part of the fish body, where they are largest in size and show the clearest pattern of annuli (Figs. 2, 3, 4, 5).
3. The relationship between the total length (l.t.) and oral radius of a scale taken from above the lateral line from the caudal part of the eye side of the body is linear and has the highest correlation coefficient. The line expressing the relationship crosses the x-axis at 35.1 mm. This value can be assumed as a length of a fish on which body the first scales emerge. Growth rates were back-calculated using the Rosa Lee formula.

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PORÓWNAWCZA ANALIZA PRZYDATNOŚCI RÓŻNYCH ELEMENTÓWANATOMICZNYCH DO OZNACZANIA WIEKU I TEMPA WZROSTU HALIBUTA NIEBIESKIEGO *REINHARDTIUS HIPPOGLOSSOIDES* (WALBAUM)

Streszczenie

W celu znalezienia właściwej metody określania wieku i tempa wzrostu przeprowadzono analizę porównawczą przydatności pięciu elementów anatomicznych: promieni płetw, kości operkularnych, kręgów, otolitów i łusek. Stwierdzono, że promienie płetw i kości operkularne, ze względu na ich delikatną strukturę oraz bardzo słabą czytelność nie nadają się do tego celu. Kręgi, po zabarwieniu

alizaryną, mogą służyć do określania wieku, jednak ze względu na trudności związane z preparowaniem, nie znajdują zastosowania przy badaniu licznego materiału. Otolity po wyprażeniu przewyższają wyrazistością nieprażone, lecz wykazują zadowalającą czytelność tylko u niewielkiej liczby ryb. Najodpowiedniejszym materiałem do określania wieku i tempa wzrostu halibuta niebieskiego okazały się łuski.

Stwierdzono, że wielkość łusek w kierunku głowy zmniejsza się. Do oznaczania wieku i szybkości wzrostu należy pobierać je z ogonowej części ciała, gdzie mają największe rozmiary i najwyraźniejszą strukturę pierścieni rocznych.

Zależność pomiędzy długością całkowitą (l.t.) a wielkością promienia oralnego łuski (r.or.) pobranej z części ogonowej ma charakter prostolinijny. Ponieważ prosta będąca wyrazem tej zależności nie przechodzi przez początek układu współrzędnych, wsteczne odczyty tempa wzrostu przeprowadzono przy zastosowaniu wzoru Rosy Lee.

СРАВНИТЕЛЬНЫЙ АНАЛИЗ ПРИГОДНОСТИ РАЗЛИЧНЫХ АНАТОМИЧЕСКИХ ЭЛЕМЕНТОВ ДЛЯ ОПРЕДЕЛЕНИЯ ВОЗРАСТА И ТЕМПА РОСТА ЧЁРНОГО ПАЛТУСА REINHARDTIUS HIPPOGLOSSOIDES (WALBAUM)

Резюме

В поисках соответствующего метода определения возраста и темпа роста исследуемой рыбы был проведен сравнительный анализ пригодности пяти анатомических элементов: лучей плавников, оперкулярных костей, позвонков, отолитов и чешуй. При этом установлено, что лучи плавников и оперкулярные кости в силу их хрупкости и нечёткости для этой цели не годятся. Позвонки после окраски их ализарином могут быть пригодны для определения возраста, однако использование их в широком масштабе, при исследовании большого материала, невозможно, т.к. препарирование их является довольно трудным. Отолиты, подвергнутые кальцинации, имеют с этой точки зрения свои преимущества перед непрепарированными, однако обладают удовлетворительными качествами только у небольшого количества рыб. Наиболее пригодным материалом для определения возраста и темпа роста чёрного палтуса оказалась чешуя.

Установлено, что размер чешуй по направлению к голове уменьшается. Для определения возраста и скорости роста следует брать чешую с хвостовой части тела, где она имеет наибольший размер и наиболее отчётливую структуру годовых колец.

Зависимость между общей длиной (l.t.) и величиной радиуса оральной чешуи (r.or.) взятой с хвостовой части, имеет прямолинейный характер. Поскольку прямая, являющаяся выражением этой зависимости, не проходит через начало системы координат, обратное вычисление роста было проведено по методу Rosy Lee.

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