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AN ATTEMPT TO DETERMINE APPLICABILITY OF VARIOUS ANATOMICAL ELEMENTS OF ARCTIC CHARR, *SALVELINUS ALPINUS* (L., 1758) IN AGE AND GROWTH RATE STUDIES

PRÓBA OKREŚLENIA PRZYDATNOŚCI RÓŻNYCH ELEMENTÓW ANATOMICZNYCH DO OZNACZANIA WIEKU I SZYBKOŚCI WZROSTU GOLCA *SALVELINUS ALPINUS* (L., 1758)

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Various anatomical elements of the Arctic charr are discussed in terms of their applicability to age and growth rate studies. The following elements, obtained from 20 charr individuals caught in 1986 in Lake Svartvatnet, are considered: scales, otoliths, vertebrae, cleithrum, and some skull bones (operculum, interoperculum, suboperculum, ectopterygoid, and metapterygoid). Length growth rate was determined from scales, otoliths, and vertebrae.

INTRODUCTION

Fish age can be determined by examining various anatomical elements. Scales collected at a certain spot of the body have most often been used for the purpose. Annual rings, however, occur also on some flat bones, otoliths, vertebrae, and fin rays and are sometimes more conspicuous and easier to identify on those elements than on scales. Hence the need to use those elements to cross-check age determinations made on scales and, possibly, to find a better element to back read age from, as scales can be poorly legible or may be totally unsuitable for age studies.

The workers who have so far studied fish age and growth rate, used either scales (Gullestad, 1974) or otoliths (Tiller, 1986). However, results obtained with the two methods often diverged as reported, among the others, by Gullestad (1974) and Dutil and Power (1977). Thus a need arises to analyze applicability of various anatomical elements in age and growth rate calculations and to choose the most suitable material for the purpose.

MATERIALS AND METHODS

Materials used in the present work were collected within 1985–1986; 24 individuals were caught in 1985 from River Revelva and 38 individuals were caught in 1986 from Lake Svatvatnet.

Scales were collected from all the 62 individuals. Otoliths, vertebrae, and some skull bones and cleithra were obtained from 20 individuals caught in Lake Svartvatnet.

Comparative analysis of age and growth rate, back-calculated from scales, otoliths, and vertebrae was made based on data obtained from the Lake Svartvatnet sample consisting of 20 fish individuals.

The following anatomical elements were tested with respect to their applicability to age and growth rate studies in the Arctic charr: scales, otoliths, vertebrae, cleithrum, and some skull bones (operculum, interoperculum, suboperculum, ectopterygoid, and metapterygoid bones). As recommended by Jones (1959), scales to be used in age readings were collected from above the lateral line behind the dorsal fin.

Attempts were made to enhance legibility of the elements studied. Whole otoliths as well as their cross-sections (across the nucleus) were examined; some otoliths were calcinated. Both intact and sectioned otoliths were placed on heat-resistant slides and heated over a burner. The otoliths, calcinated in this way, were placed in small vessel against a dark background and examined in incident light under a Zeiss measuring microscope. Scales were examined and annual rings were measured under the same microscope in transmitted light.

The vertebrae, cleithrum, and skull bones were alizarin stained before examination.

Regression equations were derived and correlation coefficients calculated using formulae provided by Parker (1978).

RESULTS

Age determination

Attempts to enhance annual rings on otoliths by cross sectioning and calcination were futile. Intact, non-calcinated otoliths proved most suitable for age readings.

Alizarin staining of the vertebrae, cleithrum, and skull bones did not improve the legibility, either; conversely, the procedure even decreased the legibility.

The skull bones used (operculum, suboperculum, ectopterygoid, and metapterygoid), due to their delicate structure and poor legibility, particularly that of initial annuli, proved unsuitable for age determinations of the Arctic charr. Besides, it is very difficult to locate a centre on each of the bones mentioned.

Of all the anatomical elements tested, scales, otoliths, and vertebrae turned out to yield the most legible growth zones; however, otoliths, difficult to dissect out, would be difficult to use on a larger sample. Figs 1–3 show a scale, vertebra, and an otolith obtained from the same individual.

When determining age from scales, the number of annuli was determined, the annuli being not always visible as zones of densely packed circuli. More frequently,

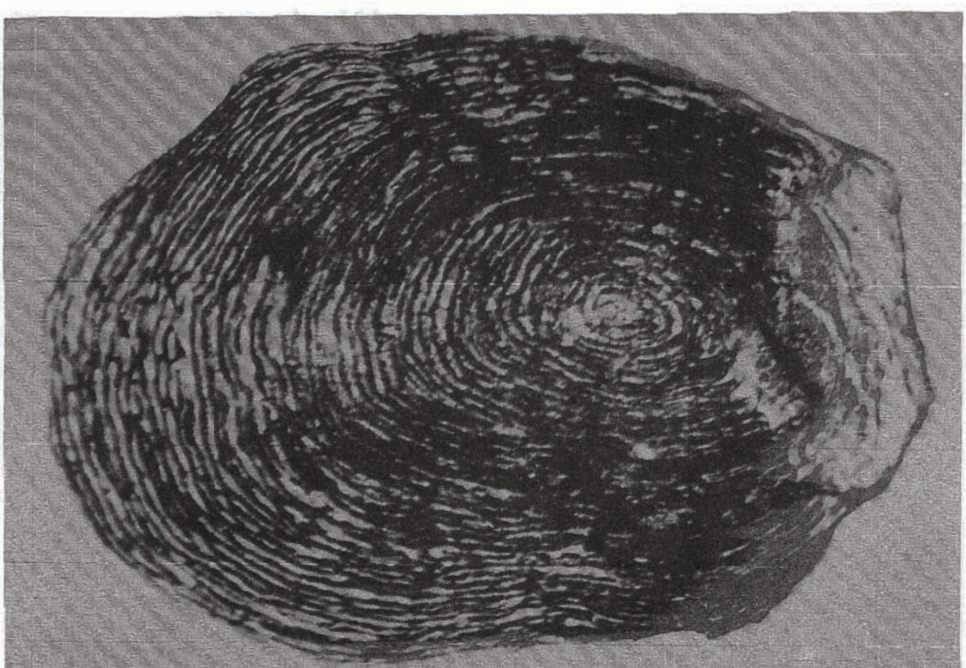

Fig. 1. A scale of 9+ Arctic charr individual (l.t. = 53.3 cm) (60X)

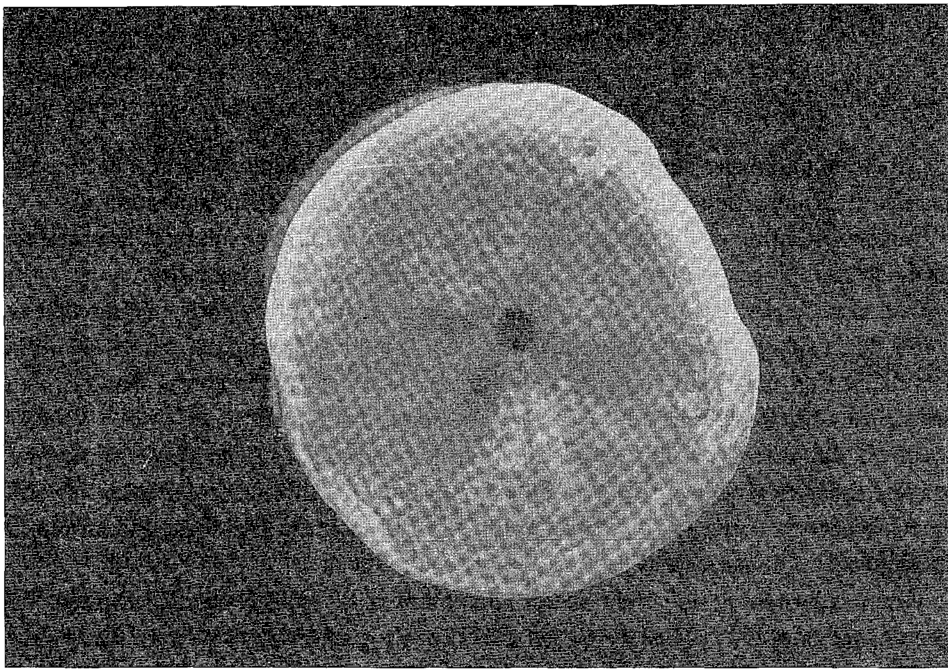

Fig. 2. A vertebra of 11+ Arctic charr individual (l.t. = 53.3 cm) (10X)

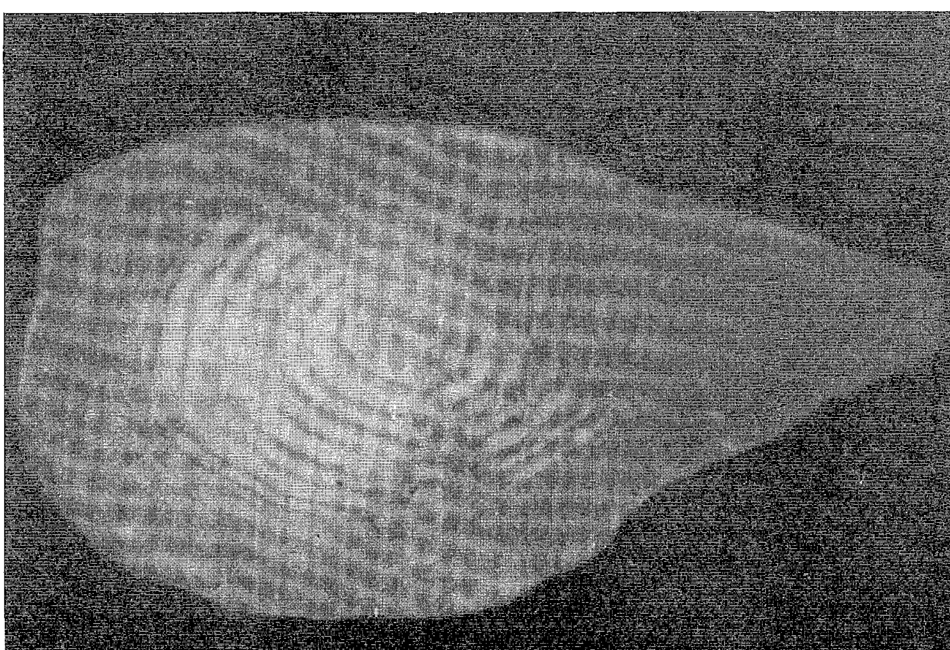

Fig. 3. An otolith of 12+ Arctic charr individual (l.t. = 53.3 cm) (25X)

an annulus on an Arctic charr scale looked like a narrow bright stripe separating two neighbouring annual increments. Basically, no false annuli were found; quite sporadically, the so-called double ring and partial ring would be found, the first located directly next to another ring and the second visible in some part of the scale only. The names of those additional rings are adopted following Čugunova (1959).

In spite of their small size, otoliths of the Arctic charr were the most suitable elements for age and growth rate calculations. Readability of the seasonal zones varied. The endpoint of annual increment was localized between the outer margin of the hyaline zone, dark when viewed in incident light (winter increment zone), and the inner margin of the opaque zone, white (summer increment zone) (Figs 4–6). Age readings and growth zone radius measurements (to 0.01 mm) were made on the convex side of an otolith, in incident light of the Zeiss stereomicroscope. Measurements were made along the lateral otolith radius. The otolith centre was determined as the geometric centre of the nucleolus, usually well visible.

The first few vertebrae were used for age determinations. Similarly to otoliths, readability of seasonal zones varied. Each vertebra was placed against a dark background, covered with water, and examined in incident light, the annulus being located on the outer margin of the winter increment zone (dark in incident light).

Basically, no additional rings were found on otoliths and vertebrae; the few which did occur were similar to those on scales.

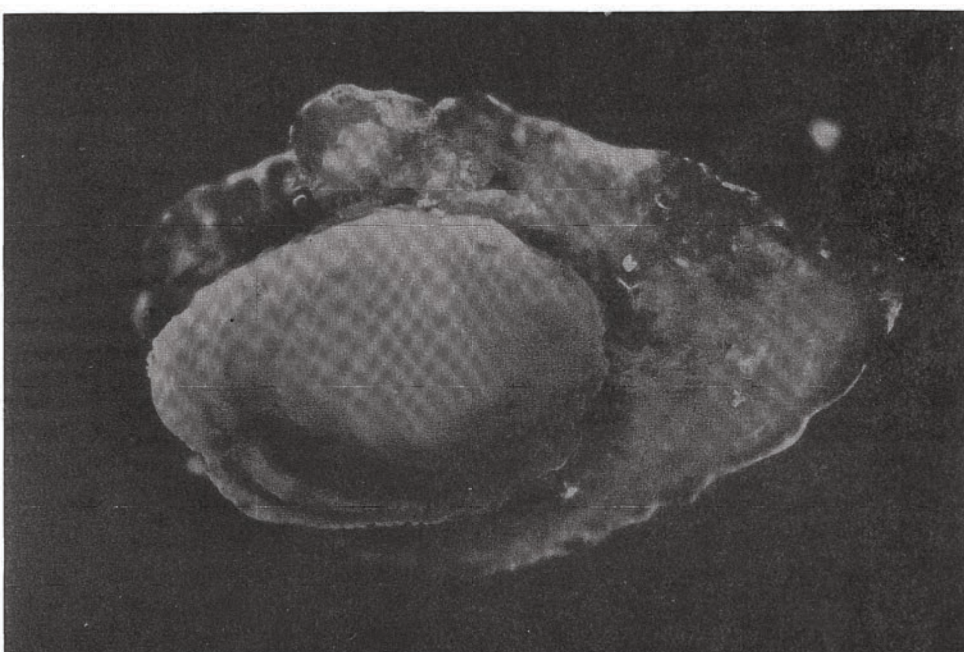

Fig. 4. An otolith of 6+ Arctic charr individual (l.t. = 15.5 cm) (45X)

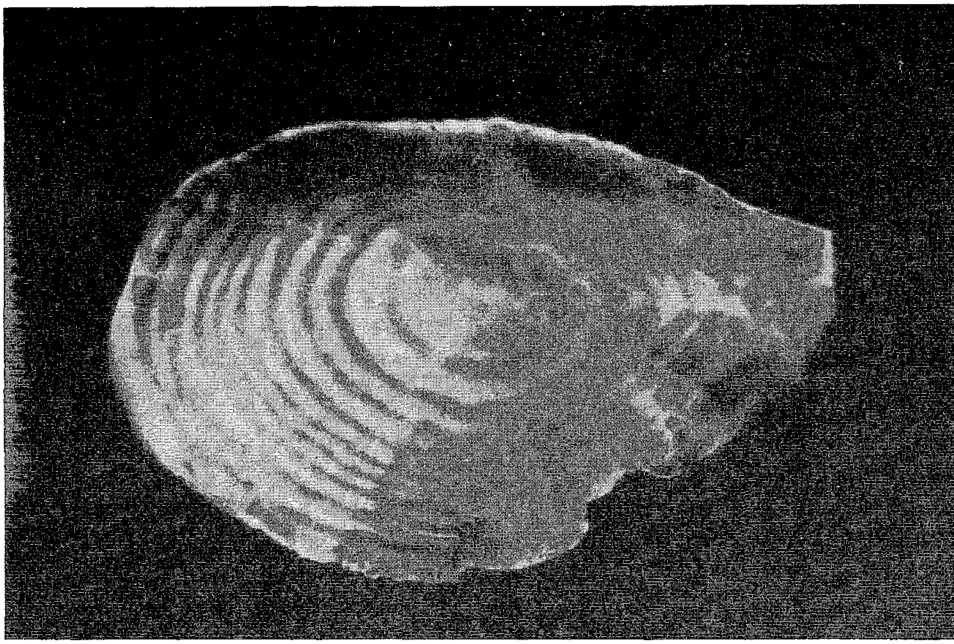

Fig. 5. An otolith of 9+ Arctic charr individual (l.t. = 17.5 cm) (45X)

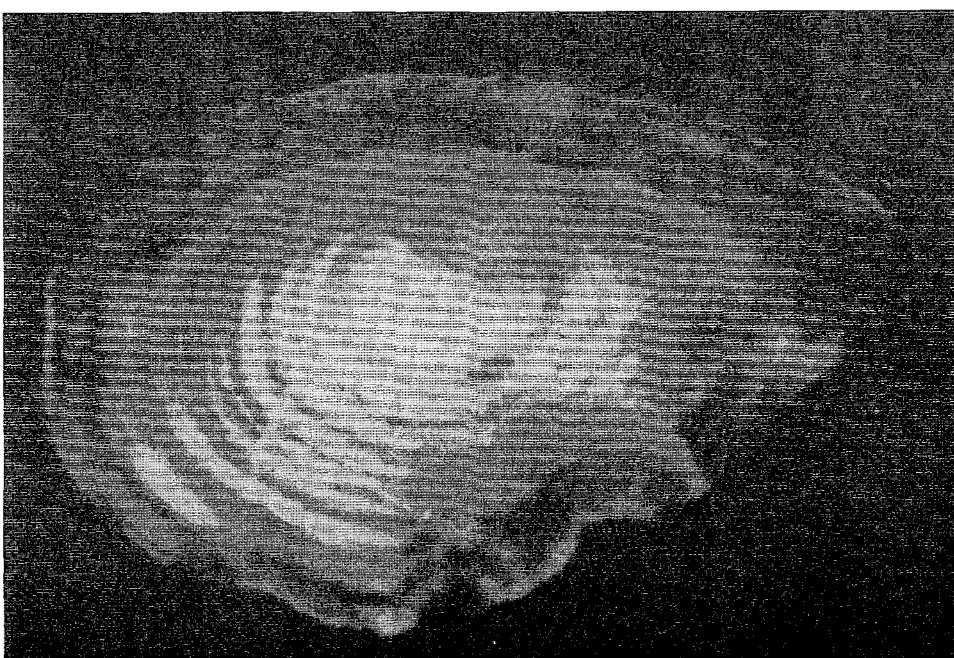

Fig. 6. An otolith of 9+ Arctic charr individual (l.t. = 21.4 cm) (45X)

Table 1

Comparison of number of annuli (age) visible on scales, vertebrae, and otoliths of Arctic charr caught in 1986 in Lake Svartvatnet

No.	L.t. (cm)	l. caud. (cm)	l.c. (cm)	Sex	No. of annuli (age)			Difference between 6 and 7	Difference between 6 and 8	Difference between 7 and 8
					scale	vertebra	otolith			
1	2	3	4	5	6	7	8	9	10	11
1	42.5	41.3	37.3	♂	6+	7+	10+	1	4	3
2	43.8	42.1	38.8	♂	8+	8+	8+	0	0	0
3	44.3	41.9	38.8	♀	7+	8+	8+	1	1	0
4	46.5	44.1	41.2	♀	8+	8+	8+	0	0	0
5	46.6	45.3	41.5	♂	8+	8+	9+	0	1	1
6	49.1	46.8	43.2	♂	9+	9+	9+	0	0	0
7	49.3	47.2	43.6	♂	7+	9+	9+	2	2	0
8	49.7	48.2	44.8	♀	7+	8+	8+	1	1	0
9	49.8	47.7	43.2	♂	8+	9+	9+	1	1	0
10	50.6	49.3	44.5	♂	9+	9+	9+	0	0	0
11	51.3	49.1	44.6	♀	9+	9+	10+	0	1	1
12	52.3	50.5	45.8	♀	8+	10+	10+	2	2	0
13	53.3	51.3	46.2	♂	9+	11+	12+	2	3	1
14	53.5	51.1	47.0	♀	9+	10+	10+	1	1	0
15	54.1	52.4	48.0	♀	10+	10+	10+	0	0	0
16	55.0	52.7	48.6	♂	9+	11+	12+	2	3	1
17	55.0	53.2	48.5	♀	8+	9+	10+	1	2	1
18	55.5	53.5	48.1	♀	7+	11+	11+	4	4	0
19	56.0	54.3	49.5	♂	10+	12+	12+	2	2	0
20	57.8	55.2	49.5	♂	9+	12+	11+	3	2	1
				Mean age:	8.25	9.75	9.40			
				Sum of absolute differences:				23	30	9

To cross-check the age readings, a comparative analysis was made on data obtained from scales, otoliths, and vertebrae of 20 individuals caught in 1986 in Lake Svartvatnet. The analysis is illustrated by Table 1. As seen in the table, scales yield age data lower by one year, two, three and even four years with respect to data obtained from otoliths and scales. The so-called average age calculated for the sample from the three elements compared was lowest on scale data and highest on otolith data, the latter being very close to that obtained from vertebrae data (the lowest sum of absolute differences).

Length growth rate

The growth rate of Arctic charr length was determined from scales, otoliths, and vertebrae obtained from the same 20 individuals used in age determinations.

Fig. 7 shows the relationship between the total length (l.t.) of a fish and the oral radius (R.or.) of its scale. The relationship was calculated from data yielded by all 62 individuals examined, the fish length ranging within 5.6–65.0 cm. The correlation coefficient was high ($r = 0.918$), the regression equation being as follows:

$$L = 1.8783 + 40.4118\,R$$

As shown in the figure, fish length to oral radius ratio is not constant. For this reason, the Rosa Lee formula was used in calculations of the Svartvatnet Arctic charr growth rate from scale back-readings.

Fig. 8 shows a relationship between the total length (l.t.) and otolith lateral radius (R), obtained on a sample consisting of 20 individuals. The correlation coefficient is significant ($r = 0.587$), but the regression line, plotted from the equation:

$$L = 12.9494 + 31.0000\,R$$

intercepts the „y" axis relatively far away from the origin. This shows that the sample was not wholly representative of the population, lacking individuals smaller than 42 cm. For this reason, an additional line was plotted for those individuals, using two points:

1. a point corresponding to the length of 0.8 cm for which the otolith radius was assumed to be 0 (an assumption based on length data on larval Arctic charr, Balon 1980);
2. a point on the regression line, corresponding to the length of 43.9 cm, i.e., almost the smallest fish length.

The equation obtained was as follows:

$$L = 0.8 + 43.1\,R$$

The regression served to calculate lengths for R up to 1.0 mm; for higher R's, the Rosa Lee formula was used.

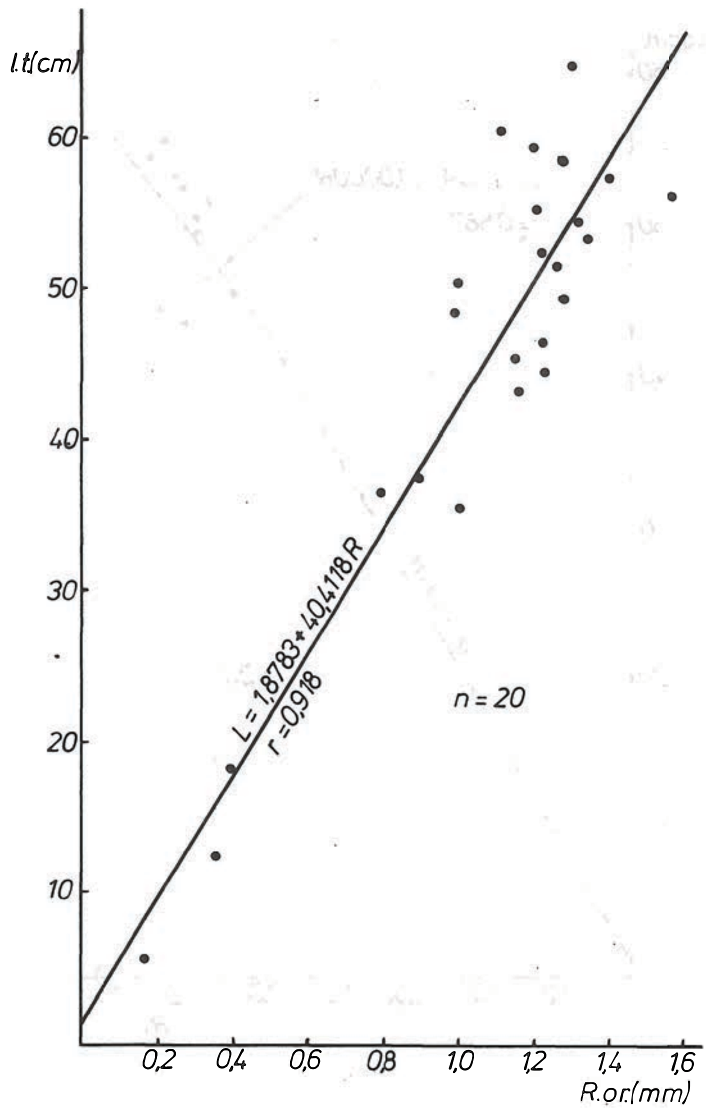

Fig. 7. Total length (l.t.) — scale radius (R.or.) relationship in the Arctic charr

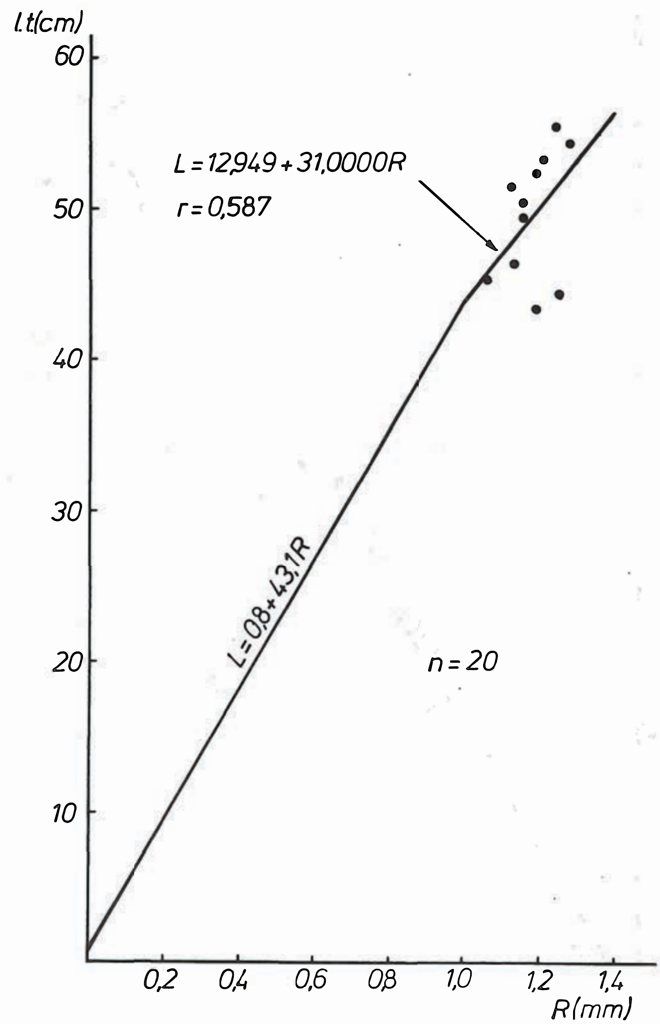

Fig. 8. Total length (l.t.) — otolith lateral radius (R) relationship in the Arctic charr

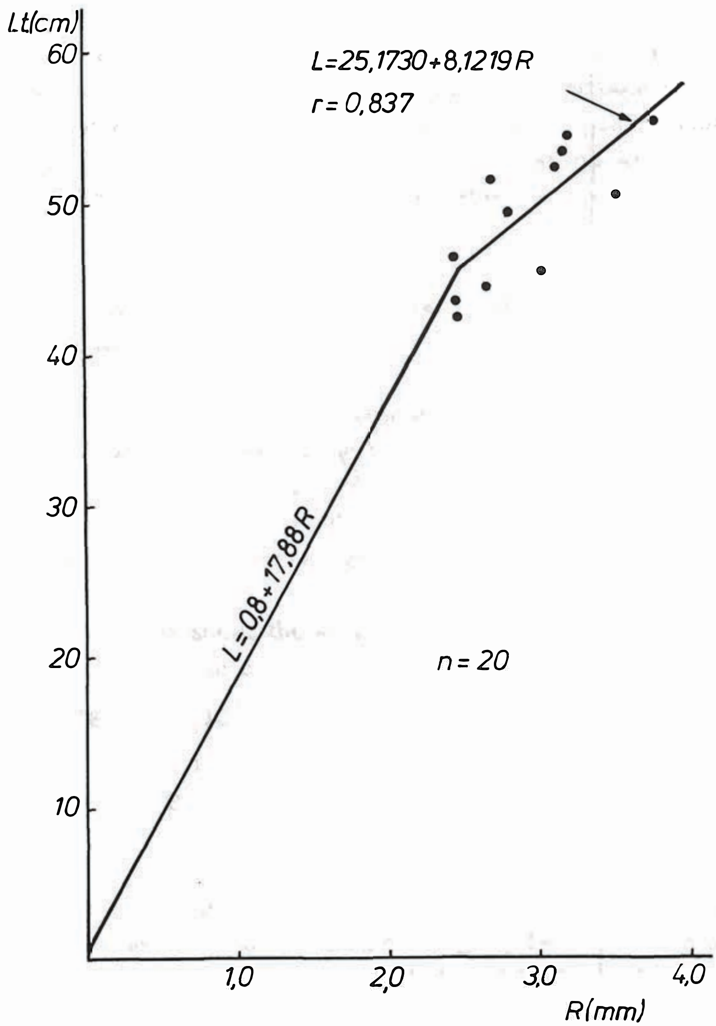

Fig. 9. Total length (l.t.) — vertebra radius (R) relationship in the Arctic charr

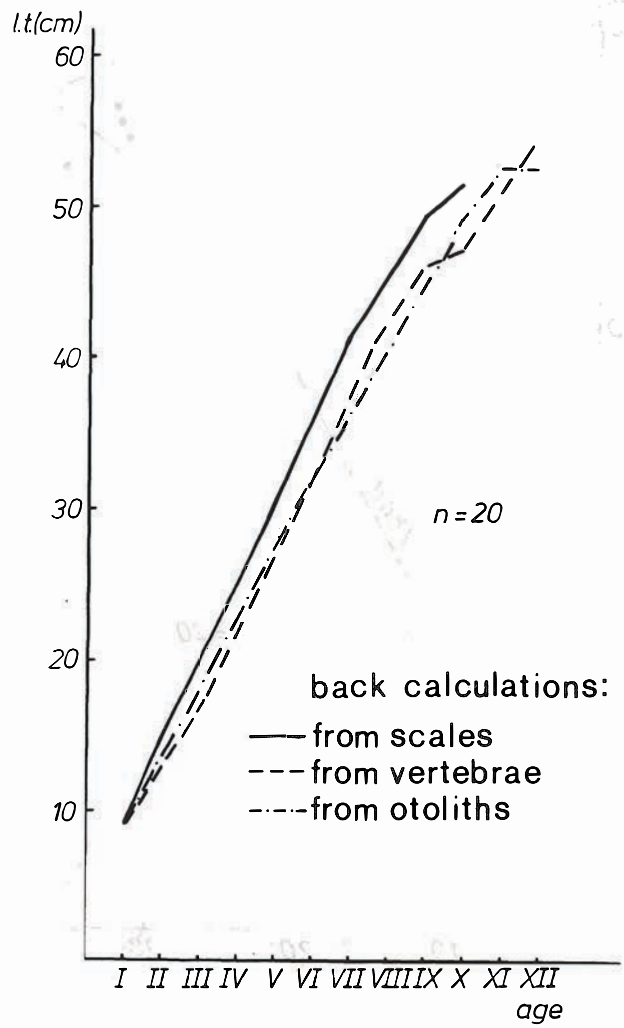

Fig. 10. Comparison between Arctic charr growth rates calculated from scale, vertebra, and otolith back readings

Fig. 9 shows a relationship between the vertebra radius and total length (l.t.) of the Arctic charr, plotted from data obtained from 20 fish individuals. The relationship is linear, too. The correlation coefficient is $r = 0.837$ and the line fitting the equation:

$$L = 25.1730 + 8.1219\,R$$

intercepts the „y" axis at a relatively large distance from the origin. Here, too, the sample was not entirely representative and missing individuals smaller than 42 cm, for which reason an additional line was plotted using the two points similar to those described for otoliths. Coordinates of the two points were as follows: $x = 0$; $y = 0.8$ and $x = 2.5$; $y = 45.5$. The additional regression equation was:

$$L = 0.8 + 17.88\,R$$

The regression served to calculate lengths for radii smaller than 2.5 mm; for larger radii, the Rosa Lee formula was used.

Fig. 10 shows a comparison of length growth rates as back calculated from scales, otoliths, and vertebrae for the Lake Svartvatnet sample (20 individuals caught in 1986). The comparison shows lower differences between back readings made on otoliths and vertebrae. On the other hand, readings from scales overestimate the growth rate relative to results yielded by otoliths and vertebrae. As shown by the curves, otoliths and vertebrae produced similar results, which may indicate that the method used was appropriate.

Additionally, the fiqure shows the Arctic charr growth in Lake Svartvatnet to be almost uniform. Obviously, this conclusion ought to be verified on a more representative material.

DISCUSSION

Of the osteological elements used, scales, otoliths, and vertebrae proved most useful in terms of annual ring legibility. As shown by the comparative analysis of age data obtained, scales, as a rule, underestimate the age by 1–4 years. This finding is in agreement with data reported by Gullestad (1974) and Dutil and Power (1977) who found the scale-read age of the Arctic charr to be underestimated to an extent similar to that in the present work, mostly by 2 years. Wayne et al. (1987), too, found the scale-read age of a kin species, *Salmo clarkii* Richardson, 1836 to be underestimated by almost 3 years relative to the otolith-read age.

Annual rings on the Arctic charr scales were very seldom visible as zones of densely packed circuli. Most often, an annulus resembled a narrow bright stripe forming a boundary between the neighbouring annual increments. Similar are the annuli of the roach in Węgorzewo lakes (Karpińska-Waluś, 1961). This type of annual rings requires a considerable expertise in reading. Moreover, as found also by Backiel (1964)

Table 2

Length growth rate of the Lake Svartvatnet Arctic charr as calculated from scale back-readings (data in cm)

Age group	Year of life										No. of individuals
	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	
VI	7.8	12.5	19.5	26.4	32.6	41.0					1
VII	8.9	15.8	21.1	26.1	33.4	39.0	46.6				4
VIII	9.7	14.9	20.1	25.3	30.0	35.6	41.9	47.1			6
IX	8.8	14.0	18.7	24.1	29.4	34.4	39.2	44.7	49.9		7
X	10.4	14.7	18.7	23.0	27.9	33.0	37.2	42.4	46.9	51.3	2
Weighed mean	9.2	14.6	19.6	24.9	30.4	35.9	41.4	45.4	49.2	51.3	20
Standard deviation	0.64	0.83	0.97	1.04	1.80	2.27	3.15	1.66	1.32	–	–
Coefficient of variation	6.96	5.68	4.95	4.18	5.92	6.32	7.61	3.66	2.68	–	–

Table 3

Length growth rate of the Lake Svartvatnet Arctic charr as calculated from otolith back-readings (data in cm)

Age group	Year of life												No. of indivi-duals
	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	l_{11}	l_{12}	
VII	9.5	14.4	18.7	23.6	27.6	32.1	38.1	42.8					4
IX	9.1	13.7	18.4	23.5	28.3	33.5	38.3	42.1	46.4				5
X	8.8	13.0	16.9	21.2	25.8	29.6	34.5	39.4	44.6	48.8			6
XI	10.2	16.9	21.5	25.3	27.9	31.2	35.3	39.6	44.7	51.8	55.8		2
XII	9.9	14.3	18.9	23.4	27.2	30.7	33.8	37.1	40.9	47.5	49.9	52.2	3
Weighed mean	9.3	14.0	18.4	23.0	27.2	31.4	36.1	40.4	44.5	49.0	52.3	52.2	20
Standard deviation	0.49	1.13	1.33	1.32	1.01	1.54	1.96	2.02	1.95	1.51	3.23	–	–
Coefficient of variation	5.27	8.07	7.23	5.74	3.71	4.90	5.43	5.00	4.48	3.08	6.18	–	–

Table 4

Length growth rate of the Lake Svartvatnet Arctic charr
as calculated from vertebrae back-readings (data in cm)

Age group	Year of life												No. of individuals
	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	l_{11}	l_{12}	
VII	8.0	13.0	17.1	22.4	28.7	34.4	39.2						1
VIII	8.3	12.0	15.7	20.1	24.5	29.8	36.9	43.1					5
IX	10.0	14.7	19.9	25.7	30.4	34.7	39.4	43.4	48.4				6
X	7.9	11.9	16.8	20.9	24.5	30.2	38.3	46.0	49.5	51.8			3
XI	7.4	12.4	17.3	22.8	27.2	31.6	36.2	40.7	44.0	46.7	52.4		3
XII	6.8	11.0	15.8	20.3	24.9	29.4	32.8	35.2	37.3	41.2	47.7	54.2	2
Weighed mean	8.4	12.8	17.4	22.4	26.9	31.8	37.5	42.4	46.1	47.2	50.5	54.2	20
Standard deviation	1.18	1.34	1.75	2.38	2.63	2.25	2.02	2.98	4.25	4.41	2.57	–	–
Coefficient of variation	14.05	10.47	10.06	10.62	9.78	7.08	5.39	7.03	9.22	9.34	5.09	–	–

who dealt with salmonid growth under natural conditions, numerous Arctic charr scales were malformed and thus unsuitable for age determination. Scale malformation, according to Müller (after Backiel, 1964) is related to environmental conditions as the fish living under more severe conditions exhibit a higher proportion of malformed scales. Thus caution should be exercised when analysing growth data obtained from the Arctic charr scales.

As shown by Tables 2–4 containing mean lengths for different age classes calculated from scales, otoliths, and vertebrae, the variability in data (reflected in standard deviation values) was at its highest in the sixth and seventh years of life as shown by the scale data (Table 2) and between the eight and tenth year as shown by vertebrae (Table 4). The relatively smallest range of variation was found in the otolith data (Table 3). The coefficient of variation values evidence a fairly extensive variability in different years of life. The observations coincide with results reported by Johnson (after Balon, 1980) for the Arctic charr from Lake Nauyuk who found a tremendous variability of length data in different age classes.

Growth rate of the Arctic charr differs widely between water bodies, as reported by Balon (1980). The growth rate data presented here for the Lake Svartvatnet fish are similar to growth rates of the species living in some Kamtchatka rivers (Tiller, 1986).

CONCLUSIONS

1. The analysis of utility of different anatomical elements in age determination showed the skull bones and the cleithrum to be unsuitable for the purpose. Alizarin staining of those elements failed to enhance their legibility.
2. Vertebrae (unstained) can be used in age determination, but due to difficulties with their preparation they do not seem to be useful in routine analyses made on ample material.
3. In spite of their fairly good readability, scales should be used as an auxiliary tool only, as back readings from them tend to underestimate the Arctic charr age.
4. Whole otoliths turned out to be the most suitable element on which to determine age and growth rate of the Arctic charr. Attempts to increase otolith legibility (calcination, crosssectioning) failed.
5. Growth of the Lake Svartvatnet Arctic charr is almost uniform.

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PRÓBA OKREŚLENIA PRZYDATNOŚCI RÓŻNYCH ELEMENTÓW ANATOMICZNYCH DO OZNACZANIA WIEKU I SZYBKOŚCI WZROSTU GOLCA *SALVELINUS ALPINUS* (L., 1758)

STRESZCZENIE

Praca zawiera charakterystykę przydatności różnych elementów anatomicznych do określania wieku i tempa wzrostu golca, *Salvelinus alpinus* (L., 1758). Na podstawie przeprowadzonej analizy stwierdzono, że kości czaszki: pokrywowa, międzypokrywowa, podpokrywowa, skrzydłowa zewnętrzna i skrzydłowa tylna nie nadają się do tego celu. Łuski (rys. 1), pomimo ich względnie dobrej czytelności, powinny być stosowane z reguły jako materiał porównawczy do określania wieku golca, ze względu na zaniżenie wieku (nawet do 4-ech lat) oraz liczne występowanie łusek zregenerowanych. Kręgi (rys. 2) mogą służyć do określania wieku, jednak ze względu na trudności związane z preparowaniem, nie wydaje się, by znalazły zastosowanie przy badaniu licznego materiału. Najodpowiedniejszym materiałem do określania wieku okazały się całe otolity (rys. 3, 4, 5, 6). Poczynione próby zwiększenia czytelności otolitów poprzez dokonywanie przełomów oraz prażenie, nie dały zadawalających rezultatów.

Przeprowadzona analiza porównawcza odczytanego wieku z łusek, otolitów oraz kręgów w odniesieniu do 20 ryb złowionych w roku 1986 w jeziorze Svartvatnet (tab.1) wykazała, że wiek oznaczony na podstawie otolitów i kręgów jest bardzo zbieżny, o czym świadczy najmniejsza suma bezwzględnych wartości różnic.

Przedstawione zależności pomiędzy długością całkowitą golca (l.t.) a promieniem oralnym łuski (rys. 7), promieniem lateralnym otolitu (rys. 8) oraz promieniem kręgu (rys. 9) mają charakter prostoliniowy, a współczynniki korelacji pomiędzy tymi wielkościami, charakteryzują się istotnymi wartościami. Ponieważ proste będące wyrazem tych zależności nie przechodzą przez początek układu współrzędnych, wsteczne odczyty tempa wzrostu przeprowadzono przy zastosowaniu wzoru Rosy Lee.

Z przedstawionego porównania tempa wzrostu długości obliczonego wstecznie z łusek, otolitów i kręgów (tab. 2, 3, 4 oraz rys. 10) wynika, że bardzo zbieżne wyniki otrzymano przy użyciu otolitów i kręgów, zaś odczyty wsteczne z łusek są zawyżone w stosunku do wyżej wymienionych elementów.

Wzrost golca z jeziora Svartvatnet (rys. 10) ma charakter prawie równomierny.

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