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VARIATIONS IN AGE AND LENGTH GROWTH RATES OF VENDACE, *COREGONUS ALBULA* (L.), FROM SELECTED LAKES IN WESTERN POMERANIA

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ABSTRACT. The aim of the study was to investigate the age and length growth rate of vendace, *Coregonus albula* (L.) from several of the most important commercially exploited lakes in Western Pomerania. Age and length growth rates were determined from scales using back-calculations of the Rosa Lee variant as well as mathematical growth models: Ford-Walford, von Bertalanffy, second degree polynomials, and the modified power function. Fish condition was determined based on the Fulton and Clark factors. The analysis of fish age in the individual lakes indicated that vendace from age class 2+ dominated; this was impacted by the deployment of selective gear (gill-nets with 24 mm mesh size). The most advantageous condition measured with the Fulton and Clark factors was noted in the fish from lakes Drawsko and Komorze. The growth of vendace from lakes Drawsko, Siecino, Komorze, and Pile was average, while that of the fish from Lake Kamienny Jaz was slow. Of the four mathematical models of growth rate, the best fit was obtained with the von Bertalanffy variant.

Key words: VENDACE, GROWTH, MATHEMATIC MODELS OF GROWTH, CONDITION

INTRODUCTION

Thanks to its fast growth rate, shoaling life strategy, and high quality meat, vendace, *Coregonus albula* (L.), is one of the most valuable fish species caught in the lakes of northern Poland. It exhibits significant phenotype variation which is an indirect reflection of the particular environmental conditions in which it occurs. Gąsowska (1973) reported that each lake had a different variety of vendace that is specific to that basin. The high plasticity of the species is most apparent in its body shape and biological characters that are impacted by, among other factors, maximum depth, surface area, water transparency, and the content of oxygen and nutrients (Thienemann 1933, Kozikowska 1961, Radziej 1973). Of the 1,575 lakes (Filipiak and

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Raczyński 2000) in Western Pomerania, vendace occur in 44, while commercial catches of this species are conducted in just 23 of them (Czerniejewski and Filipiak 2001). Unfortunately, the disadvantageous oxygen conditions render the natural spawning of this species difficult or even impossible, thus necessitating the stocking of lakes with allochthonous material. Since little is known about the most important biological characters of many vendace populations, the stocking material (hatchlings or, less commonly, fry) has substantially lower biological parameters than desired, which impacts the profitability of fisheries. Bearing in mind the rational exploitation of vendace resources in various lakes, it is essential to perform detailed biological studies, especially of growth rate, on the various exploited fish populations. This prompted undertaking the current study, whose aim was to evaluate vendace age and growth rate among fish caught in economically important and morphologically and environmentally varied lakes of Western Pomerania.

MATERIALS AND METHODS

The vendace used in the study were obtained during nighttime catches conducted with gill-nets (24 mm mesh size) in 2000-2002 in lakes Pile, Kamienny Jaz, Siecino, Drawsko, and Komorze, which all differ environmentally and morphometrically (Table 1).

TABLE 1

Limnological and environmental characteristics of the studied lakes

	Lake				
Parameter	Drawsko	Kamienny Jaz	Komorze	Pile	Siecino
Surface area (ha)	1781.5	27.1	416.7	980.1	729.7
Maximum depth (m)	79.7	11.6	34.7	43.9	44.3
Mean depth (m)	18.6	5.1	11.8	11.7	14.3
Volume (thousand m^3)	331443.4	1382.1	49372.0	115171.4	1044441.7
SDI*	4.97	2.0	1.57	2.80	2.54
EI*	95.8	5.3	3.1	83.8	51.0
Purity class	n.d.	II	II	u.w.	II
Class of susceptibility to degradation	n.d.	II	I	I	I

SDI – shoreline development index, EI – exposure index, u.w. – unclassified water, n.d. – no data

A total of 503 individuals were evaluated for age, length growth rates, and weight (Table 2).

TABLE 2

Vendace age structure in the studied lakes

Lake	N	Age group				
		1+	2+	3+	4+	5+
Drawsko	110	23	56	27	4	-
Kamienny Jaz	80	1	72	7	-	-
Komorze	97	13	62	22	-	-
Pile	100	10	63	25	1	1
Siecino	116	18	72	26	-	-
Numerical share (%)	100	12.92	64.61	21.27	0.99	0.20

The fish caught underwent preliminary biological examination: measurements were taken of individual weight (W) (on an electric Axis scale to the nearest 0.1 g) and total length (Lt), with an electronic slide caliper coupled with a microcomputer to the nearest 0.1 mm. With the aid of the power function, this data permitted determining the dependence between total length and the weight of individual fish (Szypuła et al. 2001).

$$W = k\,L^{n}$$

where:

W – total fish weight - W_1 (g);

L – total length - Lt (mm);

k, n – constant parameters, calculated based on empirical data.

Additionally, the weight and length data was used to determine the condition of the vendace using the Fulton and Clark factors (Bolger and Connolly 1989, Ritterbusch-Nauwerck 1995).

Vendace length and weight growth rates were determined from scale readings. The scales were collected with method developed by Bernatowicz (1952). Traces of mucous were cleaned from the scales with ammoniated water and then they were prepared. Age readings and measurements of scale radii (to the nearest 0.001 mm) were done on the oral sections with a computer running MultiScan (Computer Scanning Systems II, Poland), a picture analysis program. In addition to the measurement function, this software allowed enlarging scale pictures, adjusting focus, and improving picture quality. Due to the R-L linear dependence, back-calculations were done with the Rosa Lee variant at the standard length of 30 mm (at which vendace form scales (Grudniewski

1970)). The empirical data obtained with this method were used to present the theoretical vendace length growth determined with the following: von Bertalanffy, Ford–Walford, second degree polynomial, and modified power function (Szypuła et al. 2001).

The statistical analysis of the results was performed with the Statistica (StatSoft Inc., USA). Prior to comparing the body length and condition of the vendace from different lakes, the distribution of the analyzed characteristics was tested with the Shapiro-Wilks test, while the equality of variance was tested with Levene's test (Stanisz 2000). Then ANOVA was performed to verify the hypothesis of the equality of means, and the ad hoc Duncan's test was used.

RESULTS

Most of the vendace caught belonged to age groups 2+ (64.6%) and 3+ (21.3%), while the least were of age groups 4+ and 5+ (Table 2). Although fish from age class 2+ clearly dominated, significant differences were noted in the mean total lengths and median lengths of the studied populations (ANOVA, $P < 0.05$, Table 3).

TABLE 3

Length and condition characteristics of vendace from the studied lakes

	Length characteristics		Condition factors	
Lake	Total length (cm)	Range	Fulton	Clark
Drawsko	22.78 ± 1.72^{a}	19.72-28.49	0.84^{a}	0.75^{a}
Kamienny Jaz	18.81 ± 1.45^{c}	16.71-24.36	0.82^{b}	0.60^{c}
Komorze	20.49 ± 1.06^{b}	17.87-23.80	0.85^{a}	0.76^{a}
Pile	20.57 ± 1.05^{b}	17.90-24.02	0.81^{b}	0.72^{b}
Siecino	19.60 ± 0.77^{b}	18.05-21.06	0.81^{b}	0.69^{b}

Values with the same letter superscript in the same column do not differ significantly statistically ($P > 0.05$)

The highest values of these parameters were noted in the fish from Lake Drawsko (22.78 and 22.37 cm, respectively), while the lowest were for the fish from Lake Kamienny Jaz (18.81 and 18.42 cm, respectively). Vendace achieve the greatest growth during the first year of life, after which the growth rate slowed (Table 4). The fastest growth in the first year was observed in fish from Lake Drawsko (130.9 mm), and the slowest in those from Lake Kamienny Jaz (115.8 mm).

TABLE 4

Growth rate of vendace from the studied lakes by age group determined with the back-calculation method

Age group (individuals)	L_1	L_2	L_3	L_4	L_5
Pile					
I (10)	13.22				
II (63)	12.12	17.76			
III (25)	11.36	16.15	19.16		
IV (1)	10.33	15.37	19.67	21.88	
V (1)	10.39	14.95	17.72	20.09	22.05
Mean	12.01	17.25	19.12	20.98	22.05
Length growth	12.01	5.25	1.87	1.86	1.07
Kamienny Jaz					
I (1)	11.32				
II (72)	11.51	15.86			
III (7)	12.28	17.28	19.92		
Mean	11.58	15.98	19.92		
Length growth	11.58	4.41	3.94		
Siecino					
I (18)	13.60				
II (72)	13.13	17.34			
III (26)	12.51	17.22	19.54		
Mean	13.06	17.31	19.54		
Length growth	13.06	4.25	2.26		
Drawsko					
I (23)	15.22				
II (56)	12.83	18.64			
III (27)	12.17	17.80	21.45		
IV (4)	10.63	16.41	20.40	23.48	
Mean	13.09	18.28	21.32	23.48	
Length growth	13.09	5.19	3.04	2.16	
Komorze					
I (13)	14.19				
II (62)	12.45	17.56			
III (22)	11.68	16.44	19.31		
Mean	12.51	17.26	19.31		
Length growth	12.51	4.76	2.05		

Of the mathematical models of growth applied, the von Bertalanffy model best fit the back-calculated scale readings (Table 5). The comparison of fish growth determined with back-calculations and the von Bertalanffy model indicated that in lakes

TABLE 5

Comparison of vendace growth rates in different lakes determined with various methods

	Method								
Age (year)	Back-calculations (1)	Ford-Walford (2)	von Bertalanffy (3)	Second degree polynomials (4)	Modified power function (5)	[1-2]	[1-3]	[1-4]	[1-5]
Pile									
1	12.01	11.83	11.28	12.72	11.89	0.24	0.79	0.65	0.18
2	17.25	17.33	16.85	16.29	17.31	0.08	0.40	0.96	0.06
3	19.12	19.89	19.71	19.07	19.58	0.77	0.59	0.05	0.46
4	20.98	21.08	21.18	21.06	20.88	0.10	0.20	0.08	0.10
5	22.05	21.63	21.93	22.26	21.75	0.42	0.12	0.21	0.30
		Mean absolute difference				0.32	0.42	0.39	0.22
Kamienny Jaz									
1	11.58	11.30	11.58	11.68	11.64	0.28	0.00	0.10	0.06
2	15.98	16.87	15.98	15.86	16.16	0.89	0.00	0.12	0.18
3	19.92	19.62	19.92	19.95	20.07	0.30	0.00	0.03	0.15
		Mean absolute difference				0.49	0.00	0.08	0.13
Siecino									
1	13.06	12.96	13.06	13.24	13.00	0.10	0.00	0.18	0.06
2	17.31	17.66	17.31	17.07	17.51	0.35	0.00	0.24	0.20
3	19.54	19.37	19.54	19.62	19.40	0.17	0.00	0.08	0.14
		Mean absolute difference				0.21	0.00	0.17	0.13
Drawsko									
1	13.09	12.79	13.08	13.14	12.94	0.30	0.01	0.05	0.15
2	18.28	18.86	18.21	18.09	18.57	0.58	0.07	0.19	0.29
3	21.32	21.74	21.43	21.51	21.41	0.42	0.11	0.19	0.09
4	23.48	23.11	23.45	23.42	23.25	0.37	0.03	0.06	0.23
		Mean absolute difference				0.42	0.06	0.12	0.19
Komorze									
1	12.51	12.48	12.51	12.67	12.45	0.03	0.00	0.16	0.06
2	17.26	17.36	17.26	17.04	17.51	0.10	0.00	0.22	0.25
3	19.31	19.27	19.31	19.38	19.12	0.04	0.00	0.07	0.19
		Mean absolute difference				0.06	0.00	0.15	0.17

Kamienny Jaz, Siecino, and Komorze the mean average absolute difference was 0.00 cm, while in Lake Pile it was 0.42 cm, and in Lake Drawsko it was barely 0.06 cm. All of the other models fit the back-calculated data quite well; the Ford-Walford model exhibited the worst fit, although the mean absolute values ranged from 0.06 to 0.49 cm (Table 5). The values of the parameters calculated for the other models are in Table 6.

TABLE 6

Values of the parameters of the various mathematical models of growth

Model	Parameter	Lake				
		Drawsko	Kamienny Jaz	Komorze	Pile	Siecino
Ford-Walford	l_1	12.7898	11.2973	12.4793	11.8315	12.9637
	k	0.4747	0.4930	0.3911	0.4650	0.3628
Von Bertalanffy	l_∞	26.8455	53.6670	20.8665	22.7266	22.0018
	K	0.4662	0.1104	0.8403	0.6668	0.6449
	t_0	-0.4324	-1.2020	-0.0890	-0.0282	-0.3962
Second degree polynomial	a	6.6800	7.4027	6.2816	8.3750	8.1041
	b	7.2240	4.3269	7.3970	4.7421	5.7802
	c	-0.7600	-0.0485	-1.0098	-0.3929	-0.6476
Modified power function	A	-33.1754	6.8892	-9.6408	-15.9488	-13.4077
	B	-0.2683	0.7277	-1.0724	-0.5983	-0.5906
	C	46.1170	4.7497	22.0910	27.8413	26.4096

The vendace in lakes Drawsko and Komorze had statistically significantly higher Fulton and Clark condition factors values in comparison to those of the fish from the other lakes (Table 3). This is also confirmed by the L-W dependence determined, where distinctly faster weight growth was noted in the fish from Lake Drawsko (Fig. 1).

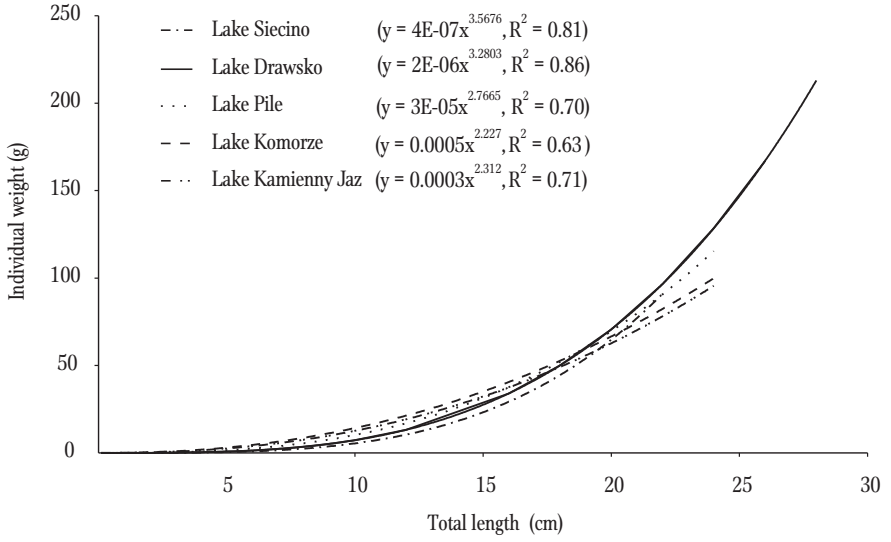

Fig. 1. Dependence between total length and individual weight of vendace from the studied lakes.

It should be emphasized that among the five vendace populations analyzed, only in lakes Siecino and Drawsko did parameter "n" of the power function reach a level above 3.0. However, the highest parameter "k" value was noted in the fish from lakes Komorze and Kamienny Jaz (0.0005 and 0.0003, respectively). In the other lakes the value of "k" was less than 0.00001. Among the studied vendace populations, growth in the first years of life can be considered to be average, and in the case of individuals from Lake Kamienny Jaz as slow (Fig. 2).

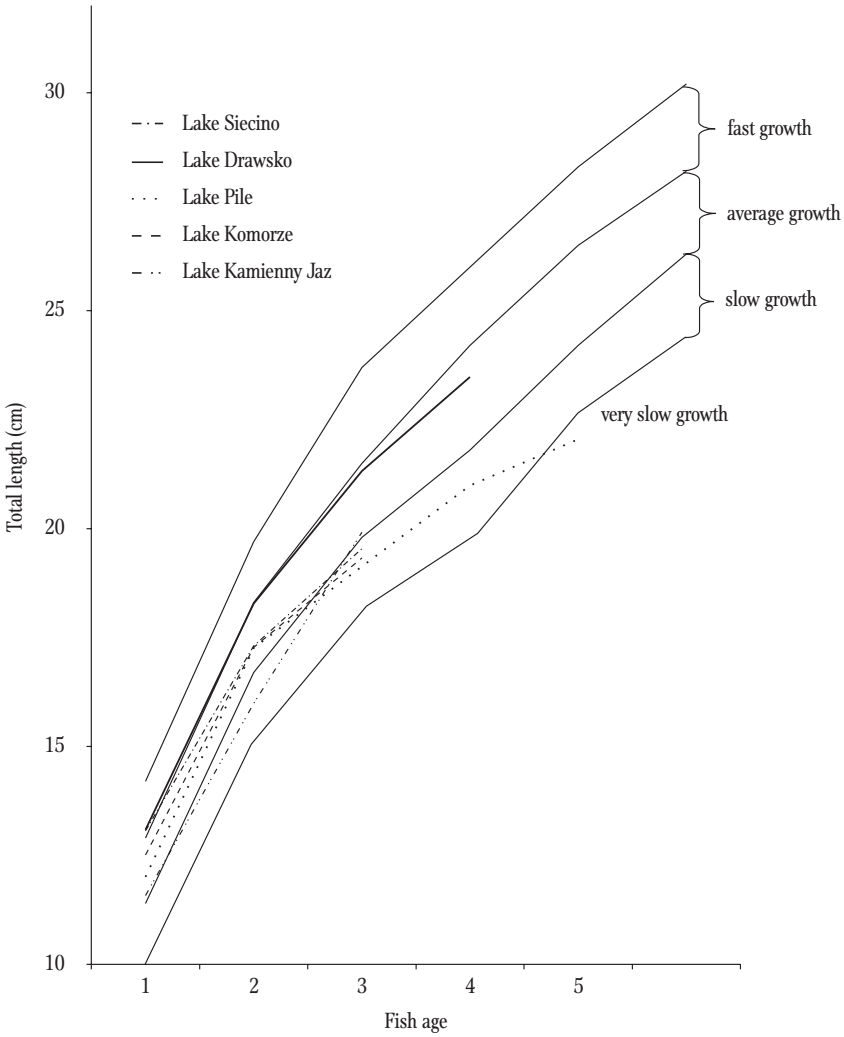

Fig. 2. Evaluation of growth rate of the studied vendace populations (according to the Szczerbowski scale (1978)).

DISCUSSION

Vendace catches in the lakes of Western Pomerania are most frequently performed with gill-nets with a mesh bar length of 24 mm, and less frequently with hauled gear (Czerniejewski and Wawrzyniak 2006). The deployment of these selective gears permits catching fish measuring from 17.8 to 24.2 cm, and the length of fish caught at maximum effectiveness is 21.0 cm (Ciepielewski 1974). This explains the relatively high continuity of total length and individual weight of the fish obtained from the analyzed populations.

Generally, vendace are pelagic fish with a relatively short life cycle, and commercial catches are comprised in 80-90% of age classes 1+ to 3+ (Viljanen 1988, Christianus 1995, Czerniejewski and Filipiak 2002). However, as suggested by Leopold (1970), in light of the short life of the vendace, maximum fishing pressure should be directed at individuals from age class 2+. In accordance with this, catches of this species in lakes Drawsko, Kamienny Jaz, Komorze, Pile, and Siecino were performed with gill-nets with a mesh bar length of 24 mm, which permitted catching fish from this age group in respective quantities of 11.13, 14.31, 12.33, 12.52, and 14.31% of all the vendace caught. The high percentage of year class 2+ in the catches stems from the fact that vendace growth intensity is the highest in the first three years of life (Bernatowicz et al. 1975). While planning catches, however, it must be remembered that if there are changes in fish growth rates, conducting catches with the same fishing gear or halting fisheries exploitation in a given basin can lead to the aging of the exploited segment of the population (Ciepielewski 1974, Winfield et al. 1996).

The growth rate of vendace varies significantly among lakes. Viljanen (1988) maintains that as latitude increases the length of vendace caught in subsequent years of life clearly diminishes, which is probably the result of lower production in these lakes. Bauch (1961) also suggests that specific environmental conditions play a decisive role in vendace growth, and the highest growth and maximum age are noted in lakes that are rich in crustaceous zooplankton. This is confirmed by the results of studies by Radziej (1973), who stocked Lake Wierzbiczany (maximum depth – 21.6 m, good oxygen and food conditions) with vendace that originated from a slow-growing population from the Mazurian Lake Narie. The first generation of vendace from the stocked basin exhibited faster growth than the population from Lake Narie. In addition to the abundance of zooplankton, growth was also influenced by the size of the lake (Marciak

1970), its depth, water transparency and oxygenation during the summer stagnation period (Bernatowicz et al. 1975), and population abundance. Generalizing, Christianus (1995) maintains that the highest growth rate is usually confirmed in vendace that occur in small basins (28-120 ha) with depths of 21.0 to 42.5 m and good water transparency. In order to evaluate precisely the growth rate of the analyzed populations in Western Pomerania lakes, the criteria proposed by Szczerbowski (1978) were used. Among the five vendace populations studied, individuals from Lake Kamienny Jaz had the slowest growth rate, while that of the other populations was average. The short lengths achieved by the vendace from Lake Kamienny Jaz in subsequent years of life probably resulted from the unstable and disadvantageous hydrochemical conditions prevailing in the summer period when the highest vendace growth is noted. To date, the most commonly applied method for calculating vendace length growth rate has been the von Bertalanffy method (Sandlund 1992, Czerniejewski and Czerniawski 2004). Taking into consideration the calculations made with several mathematical models of growth for the current study, it was confirmed that the von Bertalanffy method was indeed optimal since in three cases the results obtained fully conferred with the data obtained from scale readings and back-calculations (Table 5).

An important element of the study of various fish populations is estimating the condition of individuals. Bolgier and Connolly (1989) reported that the analysis of the degree to which fish feed can be done with the dependency function between length and body weight (Winfield et al. 1996) and the Fulton, Clark, and Le Cren mathematical formulas (Ritterbusch-Nauwerck 1995). The dependency between fish length and weight is usually of a power function character. The value of the exponent of this function depends, among other factors, on fish body shape; in “slimmer” fish it is below 3, while in “stouter” fish it is higher (Wootton 1996). In vendace the value of this parameter is about 3 (Sandlund 1992, Christianus 1995, Czerniejewski and Filipiak 2002), which indicates growth in this species is isometric. In some lakes that are rich in crustaceous zooplankton, this parameter reaches a value of almost 3.5 (Winfield et al. 1996); however, in lakes that have disadvantageous environmental conditions for vendace, the value of this power exponent falls to below 2.5 (Czerniejewski and Flipiak 2002) The mean value of parameter “n” of the dependence of length-weight of the studied vendace from lakes Drawsko, Siecino, and Kamienny Jaz had similar values to the data reported by the authors cited previously. However, in the fish from lakes Komorze and Kamienny Jaz, the value of this was fairly low (2.23 and 2.31,

respectively), which indicates that in these two basins the environmental conditions were less advantageous than those in the other lakes.

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STRESZCZENIE

ZRÓŻNICOWANIE WIEKU, TEMPA WZROSTU DŁUGOŚCI I MASY CIAŁA SIELAWY, *COREGONUS ALBULA* (L.) Z WYBRANYCH JEZIOR POMORZA ZACHODNIEGO

Celem pracy była analiza wieku, kondycji i tempa wzrostu długości sielawy, *Coregonus albula* (L.) z jezior różniących się warunkami środowiskowymi (tab. 1). Wykonano pomiary długości całkowitej, masy jednostkowej, określono płeć oraz przeprowadzono analizę wieku i wzrostu sielawy metodą odczytów wstecznych oraz matematycznych modeli wzrostu: Forda-Walforda, von Bertalanfy'ego, wielomianu II stopnia i zmodyfikowanej funkcji potęgowej. Dodatkowo oceniono kondycję ryb na podstawie współczynników Fultona i Clarka oraz wykreślono zależność między długością a masą ryb.

W poszczególnych jeziorach zanotowano podobną strukturę wieku ryb, z wyraźną dominacją sielaw w wieku 2+ (tab. 2). Fakt ten wynika z dużej selektywności wontonów o średnicy oczka 24 mm, którymi złowiono ryby. Populacje sielawy z jezior: Drawsko, Komorze, Siecino i Pile charakteryzowały się przeciętnym tempem wzrostu, natomiast w jeziorze Kamienny Jaz wzrostem wolnym (tab. 4, rys. 1). Najbardziej dopasowanym modelem wzrostu w stosunku do odczytów wstecznych okazał się model von Bertalanfy'ego, natomiast najmniej dopasowany był model Forda-Walforda (tab. 5). Najwyższą kondycją charakteryzowały się ryby z jeziora Drawsko i Komorze. Średnia wartość współczynnika kondycji Fultona i Clarka dla sielaw z pierwszego jeziora wyniosłya odpowiednio 0,84 oraz 0,75, natomiast dla jeziora Komorze 0,85 oraz 0,76.