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RESEARCH ARTICLE

Age and growth of vendace, *Coregonus albula* (L.), from Lake Wigry (northeast Poland)

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Abstract. The aim of the study was to determine the age and length growth rates of vendace, *Coregonus albula* (L.), from Lake Wigry (northeastern Poland). Fish were captured from 2001 to 2005 in the months of August and September. The most frequent age group in the catches was 2+, which comprised 53% of all fish caught. Growth was determined using Dahl-Lee and Rosa Lee back-calculation methods. These were the basis for calculating mathematical growth rate models. The growth that best corresponded with the empirical data was that calculated with a second-degree polynomial model based on Rosa Lee back-calculations. Fish aged 3+ were characterized by average length growth and attained a mean body length (SL) of 17.2 cm.

Keywords: vendace, fish age, population dynamics, growth models

Introduction

Knowledge about the age and growth of fish is an essential element of studies of fish biology, and it also has many practical applications in fisheries management. Determining the growth of fish species in a given water body is useful as it reflects the prevailing environmental conditions. Growth rates can help to draw conclusions regarding relationships among fish species and to track changes occurring in ecosystems. Studies of growth are also essential for determining protected and commercial sizes of fish. It is assumed that growth rates should be adjusted to different populations of fish since they vary. Simultaneously, the protected and commercial sizes of fish should be set so the fish can spawn at least once. Knowledge of fish growth permits optimizing the exploitation of individual fish species. Catches should target fish that are in the most vigorous phases of growth (Szczerbowski 1981, Opuszyński 1983).

Vendace, *Coregonus albula* (L.), is a pelagic, shoal-forming fish that feeds on zooplankton. Lakes that this fish inhabits are deep and well oxygenated. Water oxygen saturation should not be less than 2 mg dm^{-3} (Dembiński 1971, Winfield et al. 2004). Vendace have a short life cycle. They reach an age of 9+ sporadically, by which they attain a length exceeding 30 cm and a weight of approximately 500 g. Vendace spawning occurs in the homothermic fall period (Łuczyński 1986), which is usually from mid October to early December in Poland. The length and intensity of spawning are linked to atmospheric conditions and water temperature. The incubation time at the spawning grounds is from four to five months, depending on the temperature (Grudniewski 1970). During this period, the spawn is subjected to a variety of disadvantageous conditions such as sedimentation, oxygen deficits, and predation by both vertebrate and invertebrate fauna. These disadvantages mean that spawn survival under the conditions prevailing at natural

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spawning grounds is marginal. The occurrence of vendace in Poland is presently dependent on stocking; however, in the past fifteen years declines in both catches and stocking of this species have been noted (Wołos 1994, 1998).

Reliable information regarding the vendace from Lake Wigry date to the late nineteenth and early twentieth centuries when approximately 7 tons of this fish were caught annually. Drastic decreases in catches were noted beginning in 1907 (Eglit 1912). Thanks to intense stocking from the early 1930s, vendace was successfully reintroduced (Białokoz et al. 1999). Since this time, the lake has been stocked systematically. Current annual catches of vendace are from 10 to 20 tons. The vendace population of Lake Wigry is probably the most abundant in Poland. The biomass of this species is estimated to be 222 kg ha^{-1} (Świerzowski 1999). Therefore, this population might be the vendace nursery of Poland.

The aim of the study was to determine the age structure of the vendace inhabiting Lake Wigry and to determine the growth rate of this species. Simultaneously, the authors also attempted to determine which is the optimal method for estimating growth rates in the Lake Wigry vendace population.

Materials and Methods

Study area

Lake Wigry is situated in the middle reaches of the Czarna Hańcza River course in the Niemen River drainage basin on the Augustów Plain. The lake has a surface area of 2186.7 ha and a maximum depth of 73 m, which makes it both one of the largest and deepest lakes in Poland (Czeczuga and Gołębiewski 1976). Mean depth is 15.3 m. The trophic classification of the lake borders between mesotrophic and eutrophic (Dunalska et al. 2003). Lake Wigry is unique with its varied, natural post-glacial landscape, and it has long been treasured for its natural beauty. It is also the largest lake in Wigry National Park. The ichthyofauna of Lake Wigry comprises 28 fish species; in addition to vendace, the most valuable fish species include the European whitefish, *Coregonus lavaretus* (L.), the lake trout, *Salmo trutta m. lacustris* L., the brown trout, *Salmo trutta m. fario* L., and the protected species spine loach, *Cobitis taenia* L., bitterling, *Rhodeus sericeus* (Bloch), and Eurasian weather loach, *Misgurnus fossilis* (L.) (Białokoz et. al. 1999).

Sample collection

The study material was collected from 2001 to 2005 in the months of August and September using anchored gill-nets (50 m length, 8 m height, twine thickness 0.18 mm) with mesh bar lengths of 18, 20, 22, 24, 26, and 28 mm. The catches were conducted in Słupiańska Bay in the southern part of the lake. Fish measurements (± 1 mm) included standard length (SL) and total length (TL). A total of 441 vendace specimens were examined ranging in standard length from 14.8 to 29.8 cm and weighing from 37.9 to 376.5 g (Table 1).

Table 1
Summary characteristics for five year catches of vendace from Lake Wigry, Poland

		Standard length (mm)		Body weight (g)	
Catches data	N	mean	range	mean	range
17-20 September 2001	29	172.6	152-194	67.9	42.8-83.6
4-8 August 2002	94	178.8	148-232	73.3	37.9-145.9
19-23 August 2003	161	180.5	151-164	86.7	40.8-256.8
24-26 August 2004	79	195.2	159-258	95.2	48.2-272.1
5-8 September 2005	78	180.8	155-298	91.8	45.8-376.5

Sample analysis

The age of the fish was determined based on the number of annuli on scales viewed under a light microscope. Ten scales were examined from each fish, and the most legible (i.e., the one with the most distinct annual marks) was used for measurements. The width of the radii from the focus to the first annulus was recorded with a measuring microscope. The data obtained were verified by reading cross-sections of the hard rays of the dorsal fin. The samples were cleaned of the marginal zone, and then cut with a low speed saw (Isomet Low Speed Saw, BUEHLER) into sections 0.5 mm thick. These were fixed in resin and then viewed under a light microscope. The vendace scales examined were legible, and the annuli were distinct, especially in younger fish at age 2+. The scales of older fish were less legible, and age estimated from these was verified with readings of the marginal zone. The age read from scales conferred with that from the marginal zone. After determining fish age, based on the year in which the sample was collected, the scales were sorted by generation; for example, scales collected from fish in 2003 with one annulus were classified as the 2002 year class, while fish aged 2+ were classified as year class 2001. All of the scale material was sorted using these criteria. The dependence between the oral radii of the scales and total length (TL) of the fish was determined by measuring the mean length of the scale radius on three scales from each fish (total –1323 scales). These measurements are presented in graphic form with the mean scale radius length positioned on the y axis, while the mean total length of the fish is on the x axis. The location where the x axis is intercepted corresponds to the length of the fish when the scale covering was laid down (c). Recalculating these values (TL) into the standard length (SL) of the fish when the scale covering was formed was done by multiplying the value of TL by 0.8585, which corresponds to the ratio of SL to TL (Kozłowski, unpublished data).

Fish age was determined based on the Dahl-Lea and Rosa Lee back-calculation methods. The results obtained from the back-calculations were the basis for developing a vendace growth model equation. The following mathematical functions were used: von Bertalanffy; Gompertz; Ford-Walford; second degree polynomial; modified power function. Each mathematical growth model depended on determining length as a function of time using constant parameter values that were calculated with the least squares method based on the mean length of vendace in subsequent years of life (Szypuła et al. 2001). The results obtained were compared with single factor analysis of variance (ANOVA) using the Statistica package (Statsoft Inc., USA).

Results

The most frequent year class in the experimental catches was 2+, which comprised 53% of all the fish caught. Year classes 1+, 3+, and 4+, occurred less frequently at 14.8, 17.3, and 10.2%, respectively. Few fish aged 5+ and 6+ occurred in the vendace catches at 3.6 and 1.1%, respectively, and there was just one specimen from year class 7+. The dependence between the length of the scale oral radii and fish length was linear with the following formula: $y = 0.1055x - 0.3612$, with a correlation coefficient of $r = 0.998$. The straight line intercepted the x axis at the value of 3.4 cm (Fig. 1). This size can be viewed as total length (TL) of vendace when the scale covering is laid down. However, SL at which the scale covering is laid down was 3.4 cm × 0.8585 = 2.9 cm.

Increases in SL were determined with the Dahl-Lea back-calculation method, and these

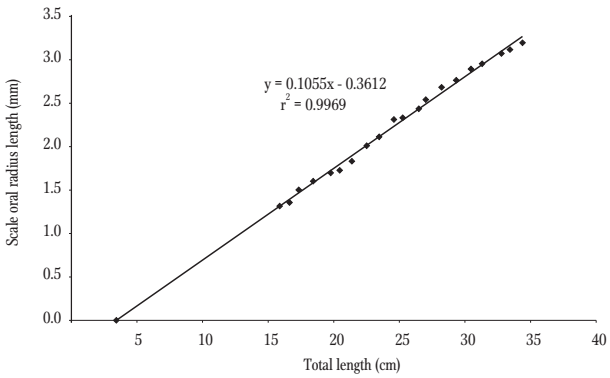

Figure 1. Relationship between vendace total length and the size of the oral radius of scales.

Table 2
Growth rates of vendace body length (mm) in individual generations based on back-calculations with the Rosa Lee method

	Age group					
Fish generation	1	2	3	4	5	6
1999	101	144	179	20.9	245	272
2000	106	147	182	206	239	
2001	104	145	186	221		
2002	107	145	194			
2003	100	146				

Table 3
Mean total length at age (L_1-L_6, in mm) of the vendace from Lake Wigry based on Dahl-Lea back-calculated method determined with mathematical growth rate models

Age group	Back calculations	von Bertalanffy	Gompertz	Ford-Walford	Second degree polynomial	Modified power function
L1	88	81	144	79	89	83
L2	136	140	158	139	136	141
L3	178	185	169	185	178	182
L4	213	219	179	220	214	214
L5	239	246	186	246	243	241
L6	270	266	196	266	266	265

Table 4
Mean total length at age (L_1-L_6, in mm) of the vendace from Lake Wigry based on Rosa Lee back-calculated method determined with mathematical growth rate models

Age group	Back calculations	von Bertalanffy	Gompertz	Ford-Walford	Second degree polynomial	Modified power function
L1	104	114	143	90	102	97
L2	146	172	164	153	137	151
L3	186	212	179	197	172	184
L4	212	239	192	226	206	218
L5	242	258	201	249	239	243
L6	272	271	208	264	273	264

differed from those determined with the Rosa-Lee method. The greatest difference was observed in the first year of fish life (1.6 cm), and the least in the fourth (0.1 cm). Vendace growth calculated with Rosa-Lee back-calculations was similar in all the generations (Table 2). No statistically significant differences between vendace length in the first ($P = 0.152$) and second ($P = 0.414$) years of life were detected among the generations.

The standard lengths (SL) of vendace calculated with different models was divergent. In the first year of life, these ranged from 7.9 cm (Ford-Walford, Dahl-Lea) to 14.4 cm (Gompertz, Dahl-Lea) (Table 3). In the subsequent year, they ranged from 13.6 cm (second degree polynomial, Rosa Lee) to 17.2 cm (von Bertalanffy, Rosa Lee) (Table 4). In the fourth and fifth years of life the calculated lengths ranged from 17.9-18.6 cm (Gompertz, Dahl-Lea) to 23.9-25.8 cm (von Bertalanffy, Rosa Lee).

Discussion

Vendace has a short life cycle, and only achieves ages of 9-10 years sporadically (Bernatowicz et al. 1975, Ciepielewski and Hornatkiewicz-Żbik 2006). It is widely believed that the lives of vendace are shorter in lakes in which their growth rate is slow (Kozikowska 1961). In Lake Wigry the oldest specimen caught was aged 7+. The most numerous age class of vendace was 2+, which comprised approximately 53% of the entire sample.

Vovk (1956) concluded that the correlation between fish length and the length of the scale radius is characteristic of species, while Briuzgin (1969) contended that this is characteristic of populations. Chugunova (1961), in turn, reported that this dependency could vary within a population, and that this could be caused by environmental conditions. Heese (1992) concluded that the period in which samples were collected, their number, and the size variation in the material could influence this dependence. In a study of roach, *Rutilus rutilus* (L.), from a dam reservoir, Pierzchały concluded that the dependence between fish length and the oral radius of scales is linear in specimens not exceeding 30 cm SL (Heese 1992), but in larger specimens the shape of this dependency is parabolic. Disproportional, linear dependencies between fish length and scale radius length were also described in tench, *Tinca tinca* (L.), and rudd, *Scardinius erythrophthalmus* (L.) (Zawisza and Antosiak 1961, Kosior 1967, Koblickaja 1981), among other species, while in pikeperch, *Sander lucioperca* (L.), whitefish, and bream, *Abramis brama* (L.), it was confirmed to be curvilinear (Nagięć 1961, Krawczyk 1965, Shentyakova 1966, Heese and Mastyński 1990).

The dependency between TL and the length of the oral radius of scales in the vendace from Lake Wigry is not simply proportional. The straight line depicting this dependency does not appear at the beginning of the set of coordinates, but intercepts the y axis at the value of 3.4 cm. This value can be interpreted as total vendace length when the scale covering is laid down. Szypuła (1970) confirmed that in vendace from Lake Legińskie, the scale covering is laid down at a total length of 3 cm. Identical results were obtained under controlled conditions (Grudniewski 1970).

The body lengths of vendace from Lake Wigry calculated using the Dahl-Lea and Rosa Lee methods differed by 1.4 cm SL in the first year of life, which is confirmed by the disproportional dependency between the lengths of the fish body and the oral scale radius (Szypuła 1970, Heese 1992). In their determinations of vendace growth in lakes Pluszne and Łańskie, Ciepielewski and Hornatkiewicz-Żbik (2006) also confirmed differences in growth rates depending on the method employed; in Lake Pluszne vendace growth in the first year of life was calculated as 10.8 cm using the Dahl-Lea method, while that determined with the Rosa Lee method was 12.1 cm.

The models usually applied to describe fish growth are asymptotic, which means they present growth limited to length (von Bertalanffy, Gompertz, and Ford-Walford models) or age and length (second degree polynomial). An alternative to these is the modified power function in which the course of growth can be both limited or unlimited (Szypuła 1991). Since fish growth can vary within a single species, there are no ideal models that can describe the growth of individual species. Based on an analysis of fifty populations, Szypuła (1991) reported that growth patterns in vendace are poorly determined; in thirty instances, growth was asymptotic, while in twenty it was unlimited.

The analysis of the growth equation parameters ($A, B > 0; C < 0$) of vendace from Lake Wigry indicated that this population exhibits unlimited growth. The greatest discrepancy between the empirical and model data were noted with the Gompertz model, while the best fit was achieved with the second degree polynomial method. Because of this, further discussions of vendace growth in the current paper and comparisons of it with data from other authors are restricted to the results obtained with the second degree polynomial. This model was also the closest to the empirical data with regard to vendace from Lake Hańcza (Kozłowski et al. 2008).

Table 5
Back-calculated length (mm) of vendace in successive years of life in different lakes as estimated with the Rosa-Lea method

	Age group						
Lake	1	2	3	4	5	6	Reference
Mean in Polish lakes	120	174	202	223	249	267	Marciak (1970)
Lake Narie	106	132	173				Marciak (1970)
Lake Żerdno	149	213	247	267			Marciak (1970)
Lake Plusze	121	165	197	223			Ciepielewski and Hornatkiewicz-Żbik (2006)
Lake Łańskie	121	190	231	265	285	301	Ciepielewski and Hornatkiewicz-Żbik (2006)
Lake Wigry	118	159	200	239	278	318	present study

The reference point for describing vendace length growth was the length they had attained in the third year of life. This was dictated by practical considerations; in most instances fish aged 3+ comprise the bulk of commercial catches. Bernatowicz (1952) proposed a three-degree growth rate scale based on length achieved in the third year of life: good growth < 20 cm; weak growth < 18 cm; mediocre growth range 18-20 cm. According to this classification, the growth rate of Lake Wigry vendace, which attained a length of 20.0 cm in the third year of life, is good. According to Szczerbowski (1981), who employed a five-scale growth rate scale based on six years of life, the vendace from Lake Wigry exhibited mean growth in the first and third years of life, while in the second it was at the upper border of poor growth. In the fourth and fifth years of life the Lake Wigry vendace exhibited fast growth and in the sixth year very fast length growth.

In an analysis of vendace growth rates in 186 Polish lakes, Marciak (1970) identified two groups of lakes with extreme conditions for fish growth. According to these data, vendace growth in Lake Wigry was faster than that in the group of lakes with the slowest growth and slower than that in the group of lakes with the highest growth rate (Table 5). The length attained by vendace in Lake Wigry in the third year of life was similar to that of the mean length of the fish from 168 lakes. In comparison to the length of fish from Lake Narie, it was longer by 2.7 cm, while it was shorter by 4.7 cm than that of vendace from Lake Żerdno and 3.1 cm than that the fish from Lake Łańskie.

In conclusion, the results of the current study indicate that a second degree polynomial model best describes the body length growth of vendace from Lake Wigry. In comparison to other vendace populations, that from Lake Wigry is in good condition with growth rates that are relatively fast, especially in older fish past their third year of life.

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Streszczenie

Wiek i wzrost długości sielawy, *Coregonus albula* (L.) z jeziora Wigry (północno-wschodnia Polska)

Celem badań było określenie wieku oraz tempa wzrostu sielawy z jeziora Wigry. Próby zebrano zestawem wontonów w latach 2001-2005. Wiek ryb ustalono na podstawie pobranych łusek, jednocześnie przeprowadzono jego weryfikację na przekrojach poprzecznych promieni twardych płetw grzbietowych. W połowach najliczniejsze były ryby w wieku 2+, stanowiły one 53% wszystkich ryb. Wzrost ryb oszacowano metodami odczytów wstecznych Dahl-Lea i Rosa Lee. Wielkość ryb w momencie zakładania się pokrywy łuskowej określono metodą graficzną na podstawie pomiarów 1232 łusek. Największe różnice we wzroście długości obliczonymi tymi metodami stwierdzono u ryb w pierwszym roku życia. Na podstawie odczytów wstecznych obliczono matematyczne modele tempa wzrostu (metodami: von Bertalanffy'ego, Gompertza, Forda-Walforda, wielomianu II stopnia oraz zmodyfikowanej funkcji potęgowej). Najbardziej dopasowane wyniki do danych empirycznych, uzyskano w przypadku wielomianu II stopnia określonego z odczytów wstecznych Rosa Lee. Tempo wzrostu sielawy z jeziora Wigry do trzeciego roku życia było przeciętne. Ryby cztero- i pięcioletnie charakteryzowały się szybkim tempem wzrostu.