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RESEARCH ARTICLE

Growth rate and condition of a population of migratory common whitefish, *Coregonus lavaretus* (L.), from Oder estuary waters

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Abstract. The aim of the study was to describe the biological and population characteristics of common whitefish, *Coregonus lavaretus* (L.), from Oder River estuary waters and to evaluate theoretical growth models for this species. Of the 100 fish analyzed, there was a greater share of males (56%), and individuals aged 2+ dominated (63%). The mean individual weight and total length was 957.6 g (range 401.0-2738.0 g) and 446.9 mm (range 358.0-605.0 mm), respectively, and the values of these parameters for the females were statistically significantly higher ($P < 0.05$). The analyzed fish exhibited substantially faster growth in the first years of life and slower annual growth in subsequent years. In comparison with data from the literature, whitefish length growth was significantly higher than in the 1950s, but similar to the results of studies from the 1980s.

Keywords: age structure, length and weight growth models, migratory whitefish

Introduction

The migratory whitefish, *Coregonus lavaretus* (L.), has a circumpolar distribution and inhabits the waters of northern Europe, Asia, and America (Szczerbowski 2000). A post-glacial relict, this species is highly valued by consumers for its organoleptic qualities. It is also of great interest to many ichthyologists and the fisheries industry because of its strict thermal, oxygen, and environmental requirements (Marciak 1967, Lehtonen 1981, Raitaniemi et al. 1999). In Europe, catches of whitefish are made in inland basins (Szczerbowski 1969, Salojarvi 1988, Heikinheimo-Schmid 1992) and in the coastal waters of the Baltic Sea (Svardson 1979, Lehtonen 1981, Heese 1985). This is one of the most heavily fished freshwater fish species caught in the estuarine waters of the Baltic (Lehtonen 1981). Studies of the ecological forms (Svardson 1979) and biological characters (Valtonen 1972, Lehtonen 1981, Heese 1985) of whitefish inhabiting the coastal Baltic waters have been ongoing for many years. The results of these studies indicate that several sub-species exist with different numbers of gill rakers, and varied growth rates, spawning seasons, and behavior patterns (Valtonen 1976, Lehtonen 1981). In Poland, the largest population of migratory whitefish inhabits the Oder River estuary, where two forms of this species have been confirmed, *typica* and *gibbosa* (humpback), which differ with regard to meristic characters and linear body parameters (Heese 1985). Catches of this fish in this basin in the past one hundred years have fluctuated substantially, and marked decreases were noted in the 1980s (Pęczalska 1962, Heese 1985). The cessation of stocking in the 1970s and disadvantageous

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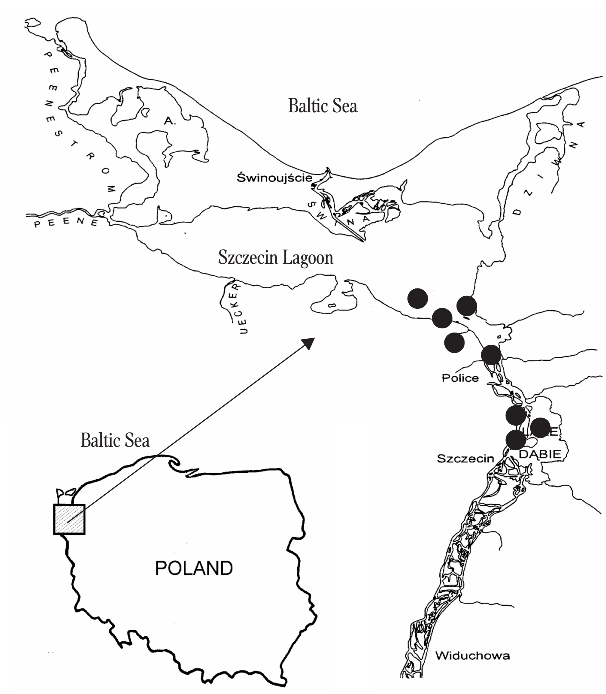

Figure 1. Location of migratory whitefish (*Coregonus lavaretus*) catches in the Oder estuary.

environmental changes that resulted in higher spawn mortality both contributed to decreased catches of this species (Heese 1985). In the past decade, increased catches of migratory whitefish have been noted in this basin, and current catches are approximately 10-12 tons, which is 0.45% of total fish catches (Czerniejewski et al. 2006). The continued growth of this fish population depends on taking appropriate management measures based on knowledge of the biological characters of this species. Thus, the aim of the current study was to determine basic biological (length of caught fish, conditions, and growth rate) and population (size and age structure) characteristics and to evaluate theoretical growth models for the migratory whitefish of the Oder estuary waters.

Materials and Methods

The whitefish used in the study came from nighttime catches made from October 29 to December 12, 2007. Deep-water gill nets were used to catch 100 individuals in the southern part of the Szczecin Lagoon and the northern part of Lake Dąbie (Fig. 1). The total length of the fish was measured with an electronic caliper (± 0.1 mm), and they were weighed on an electronic scale (± 0.1 g; Axis, Poland). The condition of the fish was described with Fulton's (F) and Le Cren's (K) condition factors (Bolgier and Connolly 1989) and by analyzing the parameters "n" and "k" on the total length (L) and weight (W) relationship among the whitefish. Fish age and growth rates in length and weight were determined using scales collected using the method described by Heese (1992). Age readings and measurements of the scale circuli on the oral sections were performed with a computer and an image analysis program (MultiScan, Computer Scanning Systems Ltd, Poland) that permitted taking precise measurements (± 0.001 mm). Because of the curvilinear dependence of R-L, back calculations were performed with the modified Vovka method (Heese 1992). The empirical data obtained with this method were used to present the theoretical increase in whitefish length and to calculate length using the von Bertalanffy, Ford-Walford, second order polynomial, and modified power function mathematical growth models. Increases in whitefish weight were also determined using a modified von Bertalanffy equation (Szypuła et al. 2001). When comparing the groups of fish, the hypothesis of the equality of means was tested with the non-parametric Mann-Whitney U-test. The dependencies among variable were tested with regression analysis. The degree to which the function fits the empirical data was determined by calculating the correlation (r) or determination (r^2) coefficients. The significance of the correlation coefficients were tested with the t-test (Sokal and Rohlf 1995).

Results

Body length and weight

The fish caught comprised 44% females and 56% males. The mean total length of the whitefish was 446.9 mm (range 358-605 mm), but females were

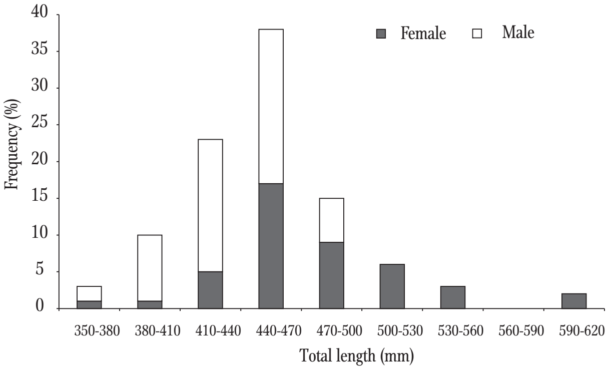

Figure 2. Size-distribution of males and females in 30 mm total length classes in whitefish (*Coregonus lavaretus*) from Oder estuary waters.

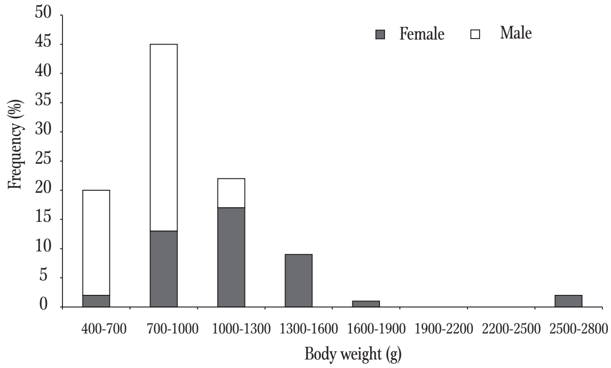

Figure 3. Size-distribution of males and females in 300 g body weight classes in whitefish (*Coregonus lavaretus*) from Oder estuary waters.

statistically significantly longer (mean 473.7 mm, range 358-605 mm) in comparison to males (mean 434.2 mm, range 374-484 mm). After dividing the fish in to 30 cm length classes, the most fish were noted in the 440.1 to 470.0 mm class (Fig. 2).

The mean weight of the whitefish was 957.6 g (range 401-2738 g). The whitefish caught were sorted in to six weight classes. Individuals weighing from 700.1 to 1000.0 g were dominant comprising 45.0% of the fish caught. Females were characterized by a statistically higher mean weight (mean 1160.9 g, range 401-2738 g) in comparison to males (mean 765.3 g, range 455-1206 g). Females occurred most numerously in the 700.1 to 1000.0 g and 1000.0 to 1300.0 g weight classes, while males did so in the 700.1 to 1000.0 g class (Fig. 3).

Whitefish condition and length-weight relationship

The length-weight relationship of whitefish from Oder estuary waters was expressed by the equation $y = 0.000006x^{3.1176}$ ($r^2 = 0.8742$, $P < 0.05$; Fig. 4). The mean values of Fulton's and Le Cren's condition coefficients were 1.00 and 1.87, respectively. The values of both Fulton's and Le Cren's condition factors were statistically significantly higher for females than for males ($P < 0.05$, Table 1). Fulton's and Le Cren's condition factors increased with the total length of the whitefish; however, linear regression

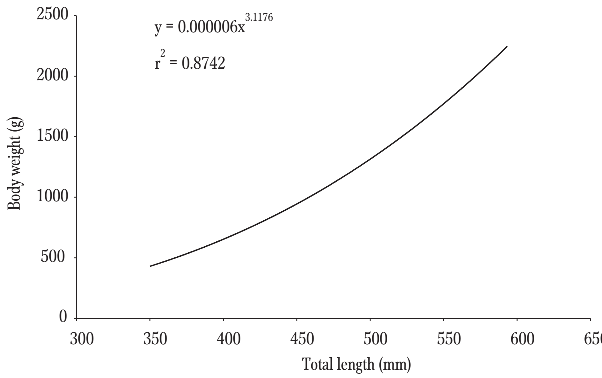

Figure 4. Length-weight data for whitefish (*Coregonus lavaretus*) from Oder estuary waters.

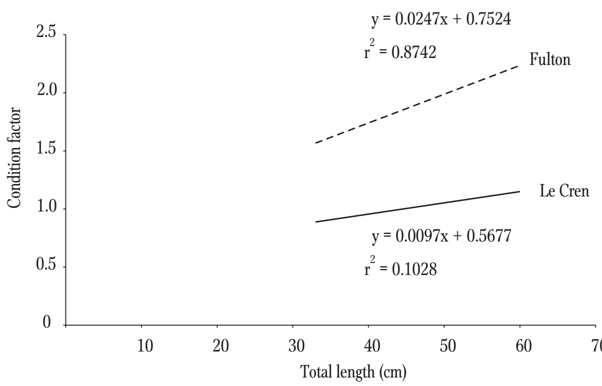

Figure 5. Fulton and Le Cren condition factors plotted as a total length of migratory whitefish (*Coregonus lavaretus*) collected from Oder estuary waters.

parameters indicated there was a greater increase in the Fulton condition factor parameter with respect to total length (Fig. 5). The statistical analysis of the correlation factors indicated significant values of

Table 1
Means (± SD) and ranges of condition factors for migratory whitefish (*Coregonus lavaretus*) from the Oder estuary. Data in columns with different letter indexes differ significantly statistically

	Fulton condition factor		Le Cren condition factor	
Sex	mean ± SD	min-max	mean ± SD	min-max
Male	$0.94^a \pm 0.10$	0.74-1.23	$1.74^a \pm 0.18$	1.38-2.27
Female	$1.08^b \pm 0.12$	0.85-1.35	$1.99^b \pm 0.25$	1.42-2.49
Total	1.00±0.13	0.74-1.35	1.87±0.25	1.38-2.49

coefficient r for the L-F dependency at $P < 0.05$, and for the L-K dependency at $P < 0.1$.

Whitefish age structure

Five age classes were identified among the fish obtained, with age class 2+ as the distinct dominant (63%). The share of age class 3+ was over two times lower, while the other age classes comprised less than 10% of the number of fish (Fig. 6).

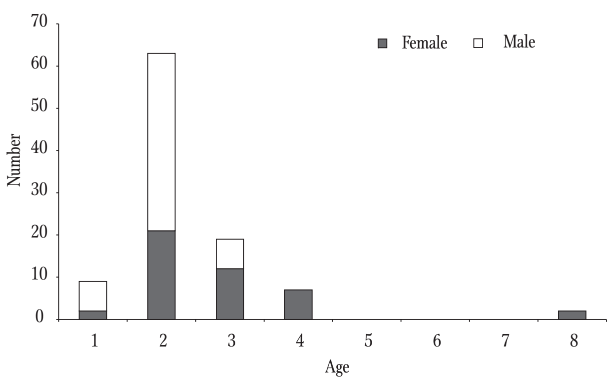

Figure 6. Share of males and females by age class in whitefish (*Coregonus lavaretus*) from Oder estuary waters.

Length and weight growth rates

Whitefish weight growth rates are presented in Fig. 7. A modified von Bertalanffy equation was used to calculate the following formula: $Wt = 4975.08 (1-e^{-0.318 (1-0.295)})^{3.1176}$. The whitefish from the Oder estuary achieved the greatest annual growth in the first year of life (mean 224.4 mm), while in the second and third years growth is nearly two times lower in comparison with the values of these parameters from the previous year (99.5 and 88.2 mm, respectively). In subsequent years of life, there is a gradual decrease in length growth to as little as 38.7 mm in the eighth year of life (Table 2). Among the mathematical models used for whitefish length growth, the greatest differences were noted in the first year of life. For example, the difference between the results obtained for the second order polynomial and the modified power function for fish in the first year of life was 2.8 cm. This difference decreased as the fish grew older. It must be underscored that the smallest absolute difference among results from back-calculations with mathematical growth models were obtained with the modified power function (the mean absolute difference was 7.4 mm).

DISCUSSION

Whitefish are caught as by-catch in catches of other fish species made with trap gear in the autumn in the Oder estuary (Pęczalska 1962, Heese 1985, Czerniejewski et al. 2006). The deployment of these gear, especially ensnaring and entangling varieties, is more advantageous for the whitefish population than other

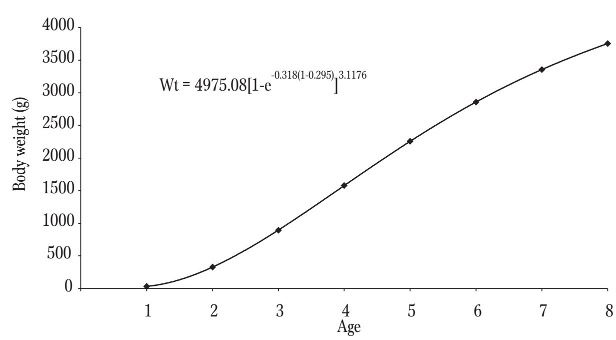

Figure 7. Growth rate of whitefish (*Coregonus lavaretus*) calculated with the modified von Bertalanffy equation.

Table 2
Comparison of migratory whitefish (*Coregonus lavaretus*) growth rates determined with different methods. 1. Back calculations; 2. Ford-Walford model; 3. von Bertalanffy equation; 4. Second degree polynomial; 5. Modified power function

Age	Method								
	Back calculations (1)	Ford-Walford (2)	von Bertalanffy (3)	Second degree polynomial (4)	Modified power function (5)	1-2	1-3	1-4	1-5
1	22.44	19.1	14.8	18.1	20.9	3.34	7.64	4.34	1.54
2	32.39	33.2	30.8	30.4	33.6	0.81	1.59	1.99	1.21
3	41.21	43.7	42.5	40.9	42.3	2.49	1.29	0.31	1.09
4	48.55	51.5	51.3	49.6	49.2	2.95	2.75	1.05	0.65
5	55.04	57.2	57.2	56.6	54.9	2.16	2.16	1.56	0.14
6	60.59	61.5	61.7	61.8	59.9	0.91	1.11	1.21	0.69
7	64.68	64.6	65.0	65.2	64.3	0.08	0.32	0.52	0.38
8	68.55	67.0	67.3	66.8	68.3	1.57	1.25	1.75	0.25
Average absolute difference						1.79	2.26	1.59	0.74

types of gears since undersized fish or fish caught during closed seasons can be released live back into the water (Sendłak 2007). However, Lehtonen (1981) reported that in the gulfs of Bothnia and Finland the greatest numbers of whitefish are caught with gill nets that have a mesh bar length of 37 to 45 mm.

Trap gear catch fish with greater length, weight, and age distributions, and such catches permit determining precisely the biological characteristics of the targeted segment of the population. The distribution of the total length of the whitefish caught in the Oder estuary was 35.8 cm to 60.5 cm (mean 44.69 cm), while the individual weight distribution was 401.0 to 2738.0 g (mean 957.6 g). Pęczalska (1962) and Heese (1985) reported wider ranges of whitefish caught in the Oder estuary, but these results were obtained using a variety of gears (pair trawls, eel trawls, trammels, seines, fry trawls). For example, Heese (1985) reported that fry nets allowed catching fish 10.4 cm in length, while the fish caught with gear used in the fisheries permitted catching fish measuring from 34.8 to 64.5 cm total length. However, the fish caught in the gulfs of Bothnia and Finland are smaller with a length distribution of 29.0 to 50.0 cm (Lehtonen 1981).

Establishing the sex ratio, age, and growth rates of whitefish is essential for sustainable fisheries management of this resource. Pęczalska (1962) analyzed the sex ratio of whitefish from the Oder estuary in the 1950s and noted that there was a slightly higher share of males, which comprised 52.11% of the fish caught. However, Heese (1985) reported that in the early 1980s the proportions were reversed: among the whitefish *typica* form there was 1 male per 1.48 female, and among the *gibbosa* form - 1 male per 1.65 female. In comparison to that of previous years, the share of males in the current whitefish sex ratio has increased substantially to 56.0% of the population. As Lehtonen (1981) reported, the analysis of vendace, a species related to the whitefish, indicated that the share of males in the autumn can appear to be higher because individuals of this sex remain in the spawning grounds for a longer period which might mean that they are caught in greater numbers.

The age distribution of fish has a significant influence on reproduction and mortality, and, consequently, on the reproductive potential and future of populations (Szczerbowski 1995). The maximum age of the whitefish in the Oder estuary in the 1950s was 7+ (Pęczalska 1962), but in the early 1980s it was 10+ (Heese 1985), and the estimated age of the oldest individual from the current study was 8+. The maximum age ranges of populations of migratory whitefish from the gulfs of Finland and Bothnia is higher at 10-19 years depending on where the catches were made (Valtonen 1976, Lehtonen 1981).

The age structure of the fish also changed during the period under consideration. In the 1956-1958 period, fish aged 1+ dominated at 41.10% of the population. In the 1980s, age groups 2+ and 3+ together comprised over 55.0% of the population, and currently, fish aged 2+ are the dominants at 63.0% of the population. The only fishing gear used in whitefish catches during this period was trap gear, which presumably indicates that the whitefish population is currently in a growth phase. In such populations, the share of young individuals is higher than it is in stable populations (Szczerbowski 1995). It should be emphasized that catches made with trap gear in the southern parts of the Gulf of Bothnia were also dominated by fish aged 2+, while in the northern parts of this basin, where morphometric and salinity parameters differ, a greater share of fish aged 1+ were noted (Lehtonen 1981).

Whitefish from different lakes are characterized by substantially varied growth rates; however, the greatest growth is recorded in all populations during the first year of life. Growth in the second year is nearly twofold lower, and subsequent annual increases in length are substantially lesser (Szczerbowski 1969, Heese 1985). Migratory whitefish from the Oder estuary exhibit higher growth rates in comparison to those from other Polish lakes in the Mazurian, Pomeranian, and Greater Poland regions (Table 3). Further, in comparison to populations of migratory whitefish inhabiting the gulfs of Finland and Bothnia, the Oder population growth rate is nearly twofold higher (Lehtonen 1981, Valtonen 1976).

Whitefish growth rates are dependent on many environmental factors (Marciak 1967, Raitaniemi et al. 1999) including population density (Salojarvi 1988). Based on studies of American whitefish, *Coregonus clupeaformis* (Mitchill), Healy (1980) concluded that when stocking increases by from 10 to 30%, then the growth rate of this species decelerates. Additionally, Langeland and Nost (1994) reported that there is a distinct dependency between whitefish growth and the ichthyofanua species structure, especially with regard to the quantities of cyprinids. Bergstrand (1990) also confirmed a similar deceleration in whitefish growth rate and catches when there was a simultaneous increase in the biomass of cyprinids. These factors, as well as the water thermal regime and the resulting higher primary production of the southern Baltic, probably contribute to the substantially higher body length growth in whitefish from the Oder estuary.

Changes in the growth dynamics among catch years are characteristic of migratory whitefish (Lehtonen 1981). Such changes are also evident among the whitefish catches in the Oder estuary over the span of the past fifty years when the data from the current study are compared with those from the studies by Pęczalska (1962) and Heese (1985). The length growth rates of the whitefish studied in the 1980s increased distinctly from those studied in the 1950s, but the current length growth rate of this species has stabilized and is now similar to that reported by Heese (1985). These changes in whitefish growth rates might be a reflection of changes in the environmental conditions of the Oder estuary, in which the progression of eutrophication was pronounced in the 1970s and 1980s (Łysiak-Pastuszak et al. 2004). Recent research conducted by the Regional Environmental Protection Inspectorate (Wojewódzki Inspektorat Ochrony Środowiska; Landsberg-Uczciwek et al. 2006, 2007) indicates that the trophic conditions in the Oder estuary are stable, and some of the hydrochemical parameter values obtained indicate there has been a slight improvement in the environmental conditions of this basin.

Conclusions

The migratory whitefish from the Oder estuary have a high growth rate in comparison to populations inhabiting the inland waters of Poland and the northern parts of the Baltic Sea (gulfs of Finland and

Table 3
The length growth rates of migratory whitefish (*Coregonus lavaretus*) in various Polish sites (in cm). *Data marked refer to the growth of the dense gill raker form (above) and the sparse gill raker form (below)

	Total length (cm) at age (years)										
Lake	1	2	3	4	5	6	7	8	9	10	Source
Gołdopiwo	13.7	27.5	35.5	39.6	42.6	-	-	-	-	-	Gąsowska (1953)
Wielewskie*	12.1	18.8	25.1	31.1	35.6	39.5	42.6	-	-	-	Szczerbowski (1969)
	15.7	26.6	32.9	39.4	43.0	44.6	45.2	-	-	-	
Zagananie*	11.2	18.5	24.2	28.7	31.6	34.6	36.6	35.9	-	-	Szczerbowski (1969)
	12.2	24.9	35.6	40.7	45.6	-	-	-	-	-	
Brzeźno*	13.1	20.2	30.0	35.6	38.5	-	-	-	-	-	Szczerbowski (1969)
	12.8	20.7	31.0	36.6	38.7	37.4	-	-	-	-	
Dgał Wielki	14.9	27.0	35.0	40.8	-	-	-	-	-	-	Szczerbowski (1969)
Gorzyń	10.9	19.1	27.1	35.5	39.6	42.6	-	-	-	-	Kaj (1955)
Tuczno	14.8	23.5	31.0	35.0	39.0	43.0	-	-	-	-	Kaj (1955)
Wdzydze*	11.9	20.8	26.6	31.6	34.3	37.7	39.2	40.9	-	-	Szczerbowski (1969)
	11.9	23.1	30.9	39.3	42.6	47.2	48.1	-	-	-	
Pomeranian Bay	18.0	29.8	38.2	44.5	48.5	-	-	-	-	-	Pęczalska (1962)
Pomeranian Bay	21.8	37.0	43.9	48.3	51.5	53.8	56.3	57.9	59.6	61.2	Heese (1985)
Oder estuary	22.4	32.4	41.2	48.6	55.0	60.6	64.7	68.6	-	-	current study

Bothnia). The age structure was dominated by individuals from the 2+ age group, while length and weight growth rates were comparable to those reported by Heese (1985). Increased numbers of whitefish have been confirmed in the last decade as environmental conditions have improved; these encouraging signs hopefully indicate that sustainable migratory whitefish fisheries in this basin are possible. It is likely that this species will soon become one of the more important aspects of fisheries exploitation in these waters as well as one of the more important bioindicators used in evaluating the state of the aquatic natural environment. It follows that continued and broadened studies of whitefish populations from the Oder estuary are necessary to determine in which direction the exploitation of this species is headed, and also to estimate resources of it.

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Streszczenie

Wiek, tempo wzrostu i kondycja populacji siei wędrownej, *Coregonus lavaretus lavaretus* (L.) z wód estuarium Odry

Materiały będące podstawą do opracowania niniejszej syntezy obejmowały 100 osobników siei, złowionych w jeziorze Dąbie i Zalewie Szczecińskim w okresie od 29 października do 12 grudnia 2007 roku. W związku z tym, iż zależność pomiędzy długością ryby a promieniem łuski był krzywoliniowa, wzrost długości określano metodą odczytów wstecznych w zmodyfikowanym wariancie Vovka. Posługując się wynikami z odczytów wstecznych obliczono tempo wzrostu długości ryb posługując się 4 matematycznymi modelami wzrostu: von Bertalanffy'ego, Forda-Walforda, wielomianu II stopnia i zmodyfikowanej funkcji potęgowej. Przy wyznaczaniu zależności L/W stosowano funkcję potęgową, zaś kondycję oznaczano przy użyciu współczynników Fultona i Le Crena. Wzrost masy przedstawiono stosując zmodyfikowane równanie von Bertalanffy'ego. Sieje złowione w estuarium Odry osiągały największe przyrosty roczne w 1 roku życia. Najmniejszą przeciętną bezwzględną różnicę pomiędzy wynikami uzyskanymi metodą odczytów wstecznych a matematycznymi modelami wzrostu uzyskano dla zmodyfikowanej funkcji potęgowej. Wartość współczynników kondycji średnio przyjęła wartość 1,0, przy czym samice charakteryzowały się istotnie statystycznie wyższymi wartościami obu współczynników kondycji. Przy zakresie masy od 401 do 2738 g, średnia masa jednostkowa siei wyniosła 957,6 g. W porównaniu do samców, samice charakteryzowały się istotnie statystycznie wyższą średnią masą jednostkową (średnia 1160,9 g, zakres 401-2738 g).