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Biological and Morphological Characteristics of Vendace (Coregonus albula (L.)) from the Latvian Deepest Lake Drīdzis

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***Abstract*— The vendace (*Coregonus albula* (L.)) is a representative of the genus Coregonus, found in many lakes in Latvia. Although its share in the fishery is small, catches are insignificant and unstable. This species is included in the list of specially protected species with limited use in Latvia. Vendace is common in both large and relatively small lakes with favourable oxygen conditions. It requires high oxygen content in water and is very sensitive to eutrophication and water pollution. Therefore, in this study, the main biological characteristics of the vendace population from the deepest lake in Latvia were assessed. Lake Drīdzis has the most favourable ecological conditions for the existence of this species. The lack of precise scientific data on local vendace populations and their biology hinders the rational exploitation of this fish and does not allow for its reproduction in Latvian lakes. Biological properties were determined for 234 vendace specimens from Lake Drīdzis, caught in autumn during four years. In this study, statistical analysis of biological and morphological characteristics was performed. Von Bertalanffy equations describing theoretical growth of the studied fish in length and weight were calculated. The average condition value was quite high. According to generally accepted criteria for the growth rate of vendace, individuals from Lake Drīdzis showed quite good growth, exceeding that recorded in some other populations inhabiting other whitefish lakes in Latvia, which indicates the presence of suitable food resources for vendace in Lake Drīdzis.**

Keywords*— *Coregonus albula (L.), morphometric and meristic characteristics, adaptation, environmental conditions.

I. INTRODUCTION

European vendace *Coregonus albula* (L.) is a widespread species in northern Europe. It appeared in North–eastern Europe after the last glacial period and is often regarded as an example of a glacial relict [1], [2] and together with other whitefish and salmonids, it is considered an economically valuable fish.

Due to its economic importance, European vendace has been artificially propagated in Latvia since 1900. The vendace (*Coregonus albula* L.) was introduced into more than 30 lakes of Latvia from Peipus (Estonia) and (Russia) lakes. In the 1930s commercial catch of vendace reached 13 tons per lake. However, in the 1990s the vendace was observed only in five Latvian lakes [3]. Presently it can be found in no more than 15 Latvian lakes. Furthermore, its share in the Latvian fishery is small, with rather insignificant and unstable catches [4], [5], [6].

Vendace, *Coregonus albula* (L.), is a species that exhibits considerable phenotypic variation, which is an intermediate reflection of particular environmental conditions that it inhabits. Vendace is common in large and relatively small lakes with favourable oxygen conditions. It requires high oxygen content in water and is very sensitive to eutrophication and water pollution.

Vendace is a polymorphic species of circumpolar distribution composed of several intraspecific forms.

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Coregoninae subfamily group is known as phylogenetically young; therefore, variations in the growth rate and morphological characters of individuals are common within populations. It is said that morphological variations depend more on the hydrological and hydrobiological parameters of the lake where vendace live than on the genetic heredity. Thus when parameters in the lake are changing, there is a possibility that morphologic parameters of vendace are changing too. So Lake Drīdzis has the most favourable ecological conditions for the existence of this species. The lack of precise scientific data on local vendace populations and their biology hinders the rational exploitation of this fish and does not allow for opportunities of its reproduction in Latvian lakes.

The aim of present study is to evaluate the main biological characteristics and its changes in time in the vendace population from the deepest lake in Latvia.

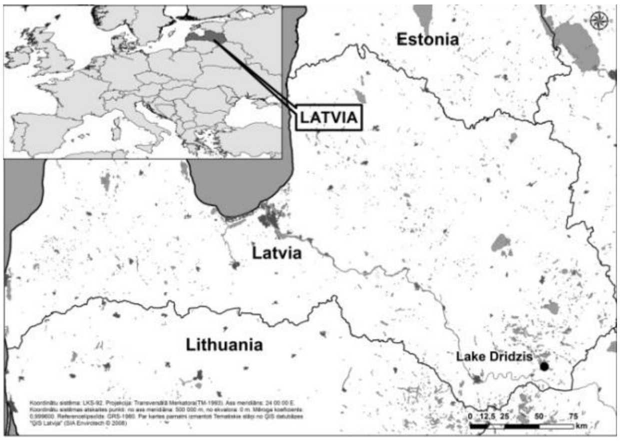

Fig. 1. Location of the Lake Drīdzis in Latvia where vendace were sampled.

II. Material and methods

A. Study sites and sample collection

Vendace samples, in total 234 individuals, were collected in the autumn of 2015, 2017-2019 from Latvian Lake Drīdzis. Lake Drīdzis is located in Skaista and Kombuļi rural municipalities of Krāslava District in Latvia. Lake Drīdzis is part of Baltic Lakeland (see location of the lake in Fig. 1). Area of Lake Drīdzis is 753.2 ha; the maximal depth is 66.2 m (12.8 m on average). Lake is located in a post-glacial recess and is the deepest in Latvia.

Freshly caught vendace individuals were measured by the whitefish measurement methods described by [7], which is commonly used today [8], [9], [10]. The measured morphological features are presented in Table 1; the lateral view of vendace, indicating points used for morphometric measurements, is shown in Fig. 2. Plastic (morphometric) properties are presented as measurement indices expressed in percent of the head and body length.

TABLE 1 MEASURED MORPHOLOGICAL FEATURES OF VENDACE

Abbreviation	Description of morphological features
	Morphometric features
HL	Head length: from the snout end to the farthest gill cover edge
ED	Horizontal diameter of the eye: from the anterior to the posterior edge of the eye
PO	Postorbital length: from the posterior edge of the orbit to the farthest gill cover edge
StL	Snout length: from the snout end to the anterior edge of the eye
	Meristic features
LL	Number of the perforated scales on the lateral line
Sp.br.	Number of gill rakers on the first left gill arch
RA	Number of ray in anal fin

B. Statistical analysis

Head measurement indices (snout length, eye diameter, and postorbital length in relation to the head length and head length in relation to fish length) of the vendace individuals in Lake Drīdzis during four years were compared. Mean values of indices of the above mentioned parameters were considered for each sampling year separately.

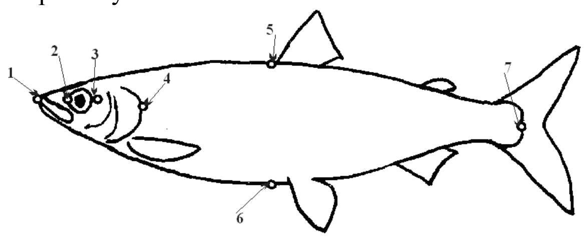

Fig. 2. Lateral view of vendace indicating landmarks used for morphometric measurements.

1 – 2, snout length (StL); 2 – 3, horizontal diameter of the eye (ED); 3 – 4, postorbital length (PO); 1 – 4, head length (HL); 5 – 6, body depth (H); 1 – 7, fish length (SL); 4 – 7, body length (OD).

Since body measurement indices depend on age, Coregonus spp. sexually mature individuals aged 3+ and 4+ were used for the analysis of plastic properties. Scales were taken to determine age of the fish. Age was determined according to Prawdin [7]. Sexual dimorphism in the Coregonus spp. appears only during spawning. Thus, in order to test for significant differences, distinctions in the morphological parameters of males and females aged 3+ and 4+ using Single Factor analysis (ANOVA) were determined. No dependence of morphological properties on gender was discovered. Therefore meristic parameter indices were calculated and pooled in samples from each year.

In order to evaluate variations in vendace meristic properties (number of rays in the anal fin (RA), number of scales in the lateral line (LL) and number of gill rakers on the gill arch (sp. br.)) of individuals in Lake Drīdzis from different years were compared. It is known that the meristic properties development influence fish egg incubation temperature. Two-Factor analysis Without Replication (ANOVA) ($P < 0.05$) was carried out. No dependence of meristic properties on age and gender was discovered. Proceeding from this, meristic parameter indices were calculated and pooled in samples from each year.

The von Bertalanffy equation that describes theoretical growth of the fish examined in length was calculated for sample from 2015 and 2018 (1) [11].

$$L_t = L_\infty[1 - e^{-k(t-t^0)}] \quad (1),$$

where L_t is fish body length at age t, L_∞ is a theoretical maximum estimated fish length, k is a coefficient of growth rate, t^0 is hypothetical age at which fish length equals 0 cm.

When populations with a short life cycle are studied, a correlation is observed between L∞ and k. In one case, a high L∞ value is combined with a low k value, and in another, a low L∞ value is combined with a high k value, and both cases show the same result. Therefore, the $\emptyset^`$ value was calculated for the analyzed samples using the formula (2) [12].

$$\emptyset^` = Logk + 2LogL\infty \quad (2)$$

Thus, the resulting single parameter allows comparison of the growth of the same fish species in different lakes and in deferent year [13].

On the basis of morphometric data, fish condition was examined for each individual separately, and an average condition for each sample was worked out. The fish condition was determined using the Fulton condition factor (K) (3) [14].

$$K = \frac{w*100}{L^3} \quad (3),$$

where w is the fish weight in grams, and L the fish length from the snout end to the end of scales layer at the caudal fin base.

The growth rate of the vendace individuals was assessed according to the power function equation (4).

$$W = K * L^n \quad (4),$$

in which W is body weight of the individuals (BH) (g), L is standard body length of the vendace individuals (SL) (mm), K and n – the parameters of the power function [15], [16].

III. RESULTS AND DISCUSSION

The assessment of growth rate and morphometric parameters of individuals contributes to the study of fish resources and their successful management [17], since vendace is not only an economically valuable object, but also an important link in the food chain [18]. The assessment of the condition of fish individuals is an important component in the study of various fish populations. According to Bolgier and Connolly [19], the variability of fish condition is often assessed by the ratio of the standard length to body weight of a fish individual, as well as using the mathematical formulas developed by Fulton [19]. Usually, the standard body length and body weight of a fish are closely correlated. However, at different periods of life, the body weight of a fish individual may change without changing its standard length and vice versa. Therefore, the ratio of standard length to body weight is determined for all individuals of the sample (all age groups) together and interpreted as the growth rate of individuals [15].

A. Condition factor

Fulton's condition factor is influenced by several factors, including the age and sex of fish, gut filling, composition of the food consumed, and the fattening level of the fish [20]. In present studies, Fulton's condition factor for both females and males, and for different age groups in the same year's sample sets, did not differ significantly ($p>0.05$). Although Fulton's condition factor values for vendace individuals in samples from different years differed slightly, the differences were not significant ($p>0.05$) (Fig. 3).

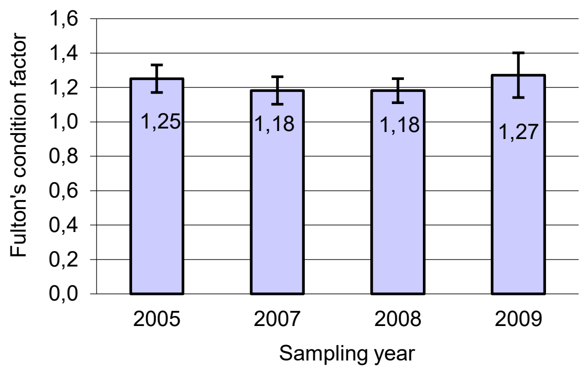

Fig. 3. Mean of Fulton`s condition factor of the vendace individuals from different years in Lake Drīdzis (error bar shows standard deviation).

Fulton condition factor is an indicator of the body condition of a fish. It is considered that individuals with a higher Fulton condition factor are more fattened than individuals with a lower Fulton condition factor [15]. It is also known that the condition of vendace individuals affects spawning. For example, in individuals with a fairly good fattening, the reproductive products mature faster, which in turn accelerates the onset of spawning.

In whitefish, the Fulton condition factor index values in different populations fluctuate within quite wide limits: 0.60-1.9; 0.87-2.08 [21]. For vendace, this indicator is usually around 1.0 [22], [23], [24]. For example, in lakes Drawsko, Kamienny Jaz, Komorze, Pile and Siecino in Poland, this indicator did not exceed 0.84 in the vendace populations [17], in Lake Chłop Fulton's index of fish condition ranged from 0.68 to 1.10 with a mean value of 0.82 [25], but in Lake Miedwie in Poland, the Fulton condition factor for vendace individuals was even lower: 0.69-0.80 [23]. In Latvian lakes the highest Fulton condition factor was detected for vendace in Lake Razna and lake Alūksnes (1.3 and 1.27 accordingly) [24].

In present studied sample sets of vendace individuals, Fulton`s condition factor was relatively high in all sample sets, this exceeded 1.0 (Fig. 3). Therefore, it can be concluded that in our studied sample sets, vendace individuals are in relatively good condition and condition do not changes significantly in time.

It is considered that the growth rate of vendace and the Fulton condition factor are strongly influenced by various lake factors in the summer period: for example, hydrochemical conditions and hydrobiological conditions. Earlier it was noted that the Fulton condition factor is more influenced by the food resources of the water body than other environmental factors [26].

B. The growth rate of vendace individuals

Judging from the ratio of the body weight and standard length of the vendace individuals and the parameters of the power function equation, it is possible to define the growth rate of the individuals.

It is estimated by the power function equation. A constant value of "n" significantly greater or less than 3.0 indicates allometric growth of fish individuals. The constant "n" of the power function equation also determines the body shape of the fish. For example, it does not exceed 3.0 for fish individuals with a slender body, but for fish individuals with a rounded body shape it is higher than 3.0. [15], [16]. Usually the "n" constant varies from 2.5 to 3.5 [22], [27]. For vendace, this parameter is usually around 3.0 [28]. Although in some lakes with insufficient food base this value does not exceed 2.5 [22], [23] and even 2.2 – 2.3 [17].

The ratio of the body weight and standard length of the vendace individuals in the studied vendace samples and its power function equations are shown in Fig. 4. The lowest value of the parameter "n" was in the vendace sample in 2018 (2.75), but the highest value was in the vendace sample in 2019 (3.53). In total, the parameter "n" was above 3.00 in tree from four samples (2015, 2017 and 2019).

It is considered that the growth of individuals is influenced by both abiotic and biotic factors, and fish growth has an adaptive nature, which ensures optimal interaction between the fish population and the environment. In studies of four populations of vendace in the Wielkopolska region in Poland, it was noted that the growth rate of vendace is higher in individuals in water bodies located in the south of the range. The authors noted that such regularity is associated with high productivity of water bodies in the south of the range and low productivity of water bodies in the north of the range [26]. It has also been shown that the rapid growth of vendace is facilitated not only by the productivity of the lake, but also by the low density of the vendace population. However, fast-growing vendace individuals can be overfished already in the first year of life, which can negatively affect the population size [29], [30]. Also it was shown that the growth rate of vendace living in Lithuanian lakes varies from lake to lake [8], [31]. The authors consider that this is the result of adaptation to certain environmental factors. Thus, it is considered that all vendace samples in present study had a quite good degree of fattening. In earlier studies of Latvian vendace populations, the fastest growing vendace individuals were also observed in Lake Drīdzis [24].

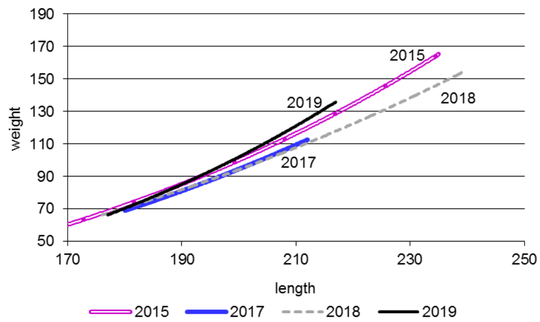

Fig. 4. The ratios of the standard length and body weight of the vendace individuals and their power function equations in the samples from Lake Drīdzis during four years

(Power function equations: 2015: $y = 7E-06x^{3.1166}$, $R^2 = 0.8787$; 2017: $y = 1E-05x^{3.0057}$, $R^2 = 0.6712$; 2018: $y = 4E-05x^{2.7546}$, $R^2 = 0.8723$; 2019: $y = 8E-07x^{3.5321}$, $R^2 = 0.7349$).

The L∞ values for samples from 2015 and 2018 were 251mm and 238 mm accordingly. These are medium length, because L∞ in Lithuanian lakes were the highest 57 cm and 48 cm and, the lowest only 16.4 and 15.5 cm [31]. According to the values of Ø` the vendace individuals from 2015 and 2018 years are diveded to fast groving form (4.25 and 4.31 accordingly). These are quite high value comparing with such in Lihuanian lakes (from 2.38 till 2.78) [31].

Same authors noted that the strength of vendace populations varies depending on the spawning conditions of certain year, so it may be that population growth rates should be variable. Populations in the same lake may be assigned to a different group in different years, depending on the nature of growth.

Therefore, it can be assumed that the growth rate of the studied vendace individuals in Lake Drīdzis are relatively high, which is probably influenced not only by the available food resources as noted in our earlier studies

[24]. Although detailed studies of the vendace population density in Lake Dridzis have not been conducted, given the protected status of vendace in Latvian water bodies due to its small numbers, it can be assumed that the growth rate can also be influenced by the vendace population density in this lake, which was noted for small vendace populations in similar studies [30].

C. Morhometric parameters

Various morphological differences in vendace populations are mainly determined by ecological reasons and have the character of adaptation to changing environmental conditions. Thus, in whitefish, body proportions can vary not only in different water bodies, but also in one rather large water body, individuals from different places also have different body proportions [32], [33], [34]. It is known that head parameters are most subject to variability [22]. Significant differences in head parameters were also found in vendace populations in Lithuanian lakes [8], [31]. In present studies, values of this parameter were found from 19.20 to 20.46% in different years (TABLE 2). Studies of the populations of vendace from two Polish lakes (Drawsko and Pelcz) showed similar values of relative head length measurements (19.94-21.33%) [22]. The authors note that when comparing the two lakes, the smallest head parameter was in the deepest lake (max. depth 79.7m), while vendace individuals with longer heads were observed in the medium-deep lake (max. depth 31.0m). A similar trend was observed in present studies, since Lake Drīdzis is a deep lake (max. depth 65.1m).

It is considered that a relatively large head and eyes are characteristic of slow-growing fish, but relatively small eyes are characteristic of fish populations that live in lakes with a good food base [35]. In turn, if the food base of the lake is quite good, then the condition and growth rate of the individuals are also quite high. Comparing the data obtained in present studies, it was found that the average values of relative measurements of head length and eye diameter are not related to the growth rate of vendace individuals. In Lake Drīdzis, the relative eye measurements of vendace vary from 24.47 to 26.32% in different years (TABLE 2).

Earlier, relatively large eyes in fish were found in populations that live in conditions of low light and low water transparency, which in turn are very relevant for plankton-feeding fish (pelede, ripus and vendace) [35], [36]. According to the size of eyes vendace forms that live in the deepest layers of the water body are distinguished from forms that live in the upper layers of the water body [37].

Individuals of vendace living in deeper water bodies have the largest relative eye diameter. According to our data, such regularity cannot be traced, because in the deepest Drīdzis Lake, the relative eye diameter of the individuals of vendace was approximately average compared to previous studies of vendace morphometric parameters in Latvian lakes [24]. Some authors consider that the eye diameter of vendace individuals is most influenced by the food base of the water body [22], because in studies of vendace populations in Drawsko and Pelcz lakes, larger values of eye diameter were found in the shallower Pelcz Lake. Significant differences were observed between the vendace populations of Pleshcheevo Lake and Rybinsk Reservoir (Russia) in terms of the eye diameter parameter, and its values were quite high (27%, 32%) (compared to our data). However, the authors did not try to explain its possible causes [38]. In studies of vendace populations in Lithuanian lakes, significant differentiation of vendace individuals in terms of the eye diameter parameter was observed and a significant correlation was found between this parameter and the area and width of the lakes [31], [39]. It is possible that the size of the eye diameter of vendace individuals in each lake develops as a result of the influence of various factors, and the combination of these factors may be different in each lake.

TABLE 2 HEAD PROPORTIONS OF VENDACE (COREGONUS ALBULA) IN LAKE DRĪDZIS DURING FOUR YEARS

(n – number of individuals; mean value ± standart error; *StL; ED; PO* in % of the *HL*; *HL* in % of *SL*; parameters see in TABLE 1)

3+				
PPMI (%)	***2015***	***2017***	***2018***	***2019***
n	20	43	31	26
HL/SL	19.20±0.14	19.56±0.11	20.46±0.12	20.39±0.16
PO/HL	47.38±0.63	49.92±0.25	51.01±0.35	50.51±0.24
StL/HL	26.29±0.46	24.27±0.2	24.12±0.17	24.37±0.17
ED/HL	26.32±0.31	25.91±0.19	24.51±0.16	25.12±0.16

4+			
PPMI (%)	***2015***	***2018***	***2019***
n	9	18	24
HL/SL	19.19±0.2	20.52±0.17	20.45±0.17
PO/HL	48.83±0.72	50.9±0.5	50.62±0.16
StL/HL	25.17±0.44	24.34±0.29	24.23±0.14
ED/HL	26.00±0.39	24.47±0.23	25.15±0.16

As is known, individuals of the vendace from water bodies with a good food base usually have a short and wide head, a small snout and small eyes [40], [41]. In present studies, the features of this complex (short and wide head, small snout and small eyes) were not found in the studied vendace sample groups. However, in Polish lakes, differences in the parameters of snout length and head width were found in vendace individuals in different water bodies [22]. A significant positive correlation was also observed in studies of Lithuanian vendace populations between the length of the pectoral fin and lake depth; between the postorbital head length and lake area;

between the head length, postorbital head length and lake width [8], [39]. The aforementioned studies also found that the populations of the vendace that live in lakes in southern Lithuania differ most from other populations, both in terms of morphometric and meristic parameters.

The basic statistical parameters of the meristic parameters of the studied vendace samples are presented in TABLE 3. In total, three meristic parameters were analysed.

TABLE 3 MERISTIC CHARACTERISTICS OF VENDACE IN LAKE DRĪDZIS DURING FOUR YEARS

(n – number of individuals; mean value ± standard error; parameters see in TABLE 1)

Meristic parameters	2015	2017	2018	2019
n	50	58	66	60
RA	13.06±0.11	13.67±0.1	14.14±0.1	13.94±0.05
LL	83.46±0.7	87.32±0.26	88.43±0.5	86.64±0.51
sp.br	37.26±0.73	40.56±0.32	39.93±0.38	41.62±0.37

The number of rays in the anal fin (RA) of the vendace individuals in the sample sets of different years varied. For example, the highest average values of this parameter (14.14±0.1) were found in the 2018 vendace individuals. In contrast, the lowest (13.06 ±0.11) values of the RA trait were found in the 2015 vendace individuals. The average values of the number of perforated scales in the lateral line (LL) also varied in the vendace individuals of different years. The highest number of perforated scales in the lateral line was found in the 2018 sample set (88.43±0.5). In contrast, the lowest (13.06 ±0.11) values of the LL trait were found in the 2015 vendace individuals (83.46±0.7). The highest average value of the number of gill rakers (sp.br) was observed in vendace individuals in the 2019 (41.62±0.37), while the lowest values of the sp.br. trait (37.26 ±0.73) were found in vendace individuals in the 2015.

Compared to plastic traits, meristic (countable) traits change less; they are even considered as constant parameters that are less exposed to the influence of environmental conditions [39]. However, meristic traits have a different degree of variability, which depends on the time when a final number of countable elements is formed in ontogenesis: the earlier the trait is starting to development, the lower its degree of variability [35].

The number of rays in even and odd fins of whitefish has a relatively small variability. It was noted that the number of lateral line scales varies in different populations depending on living conditions. But the number of gill rakers is considered a particularly valuable feature, since it has no modifications and the functional significance of gill rakers is known. The next generation of whitefish always inherit a moda of the number of gill rakers [42].

Some researchers consider that vendace living in oligotrophic lakes have more gill rakers, while vendace living in eutrophic lakes have fewer gill rakers [22]. It is also considered that, along with the influence of temperature, the number of gill rakers is also affected by the quality of the food of the individuals. For example, Nikanorov [41] notes that in water bodies with weak food resources, vendace have more gill rakers. Comparing the data of vendace populations obtained in present studies with data in previous studies in Latvia, it was found that Lake Drīdzis has average meristic parameter values among six reported vendace populations [24].

It has been determined that the variability of fish is particularly strongly influenced by environmental temperature and lighting during the development of eggs and larvae, especially these factors affect the meristic parameters of fish [40]. This effect is appeared in changes in the number of odd fin rays, the number of vertebrae and the number of perforated scales in the lateral line. That is in lakes where the incubation temperature in the spawning areas is lower. In present studies, higher coefficients of the above parameters were observed. Perhaps this can explain the relatively large number of perforated scales in the Drīdzis Lake vendace individuals. However, a close relationship between the depths of the studied lakes and the variability of meristic parameters in different lakes was not found in present studies. It was also noted that the number of perforated scales in the lateral line is a rather variable parameter. For example, in the summary table of meristic parameters [22], according to the data of the vendace populations from Switzerland, Poland, Belarus and Russia, the maximum amount of this parameter was 91 (in Lake Lanskie in Poland). The maximum indicator of the number of perforated scales of the vendace individuals from Lake Drīdzis found in our studies (97, not shown) has not been noted in any study of vendace populations from the literature sources available to us. In previous studies of vendace populations in Latvia, specimens with the highest number of perforated scales were observed in Lakes Svente and Drīdzis (97, 98 respectively) [43]. According to Nikanorov's data [41], the highest number of perforated scales was found in vendace individuals from Lakes Svente and Drīdzis, but the author associates such differences more with the incubation temperature in the spawning grounds. So, in our studies, the data obtained confirm that the number of perforated scales in the lateral line is a fairly constant parameter in the vendace in Lake Drīdzis. The number of perforated scales in the vendace of Lake Drīdzis is also higher than in the vendace populations of Polish lakes [22].

Considering the obtained results, it is worth talking not about the effect of a certain ecological factor on the development and life of the vendace, but about the adaptation of the vendace populations to the environmental conditions of a particular lake. Thus, in each lake, a set of different ecological factors differently affects the organisms and the variability of their features. This confirms the variability of the morphometric parameters of the vendace and the formation of forms most suitable for local environmental conditions. In recent research morphological analysis showed that representatives of different genetic lines of *C. albula* within the same lake show minor morphological variations between these lines, which is due to different food preferences and locomotor abilities [9]. Otherwise it was shown that the external appearance of the whitefish is determined more by the environment than by itself. In each lake, the existence of the vendace is influenced by various environmental factors; the interaction of these factors varies in different lakes. As a result, each lake forms its own specific set of ecological factors, in the process of which a specific, characteristic set of morphological factors of vendace individuals is formed in each lake. This set of factors can change over time, also affecting the variability of vendace morphometric characteristics [31]. It has been shown that the increase in the growth rate and fertility of vendace at low population density is a compensatory mechanism for the survival of this species. However, such compensation has its limits, which in turn can increase the risk of local extinctions [44]. Only long-term studies of vendace populations' morphometric parameters and lake environmental factors will allow us to determine the possible regularities of this variability.

IV. Conclusions

In general, the morphological characteristics of the vendace samples of different years in Lake Drīdzis do not exceed the limits of variability of the morphological characteristics of the European vendace (*Coregonus albula* (L.) and changes just slightly during four years. Our present results could be useful in the design and monitoring of conservation programs of vendace populations in Latvian lakes.

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