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Intraspecific Scale Variation among Different Populations of Vendace (*Coregonus albula* L.) in Some Polish Lakes

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Abstract

The reported study has been undertaken to check if the shape of vendace scales can be a parameter permitting reliable differentiation between the populations of fish from three lakes. The measurements were made on 354 scales of 144 vendace individuals (*Coregonus albula*) from lakes Drawsko, Pełcz and Morzyckoin West Pomerania area, NW Poland. The scales were subjected to 12 morphometric procedures defined in the program called Digishape for automatic morphometry. Step discriminant analysis confirmed statistically significant (P<0.001) differences in the shape of scales between three fish populations, with the mean accuracy of classification matrix at a level of 73.45%. According to the results; it is possible to distinguish the fish from the three populations studied, from three lakes in West Pomerania, on the basis of the shape of scales. This finding can be an interest for fish farming and protection of biodiversity.

Keywords: Shape of scales**,** DigiShape, populations, vendace.

Introduction

The scales are important objects of study as they permit not only classification of fish to appropriate taxon, but also provide information on the age, migration period and the influence of environmental conditions in a given reservoir on the fish (Johal and Sawhney, 1997; Esmaeili *et al.*, 2007). The latter factors determine the size of fish and specific shape of body characteristic of each population of a given fish species. One of the species showing high phenotypic variation is vendace, commonly found in lakes of low trophic status (Czerniejewski and Keszka, 2007). Although the protection status of vendace in the areas of its occurrence is low concern (LC), the high variation in a number of morphometrics traits between populations has made us consider a possibility of the presence of a few species, the more so that rarely the populations of *C. albula*can be differentiated from *C. sardinella* and *C. vandesius* on the basis of morphological traits (Kottelat and Freyhoff, 2007). The problem is more complex because this species is used for stocking of lakes and other water basins in northern and central Germany and Poland, (Kottelat and Freyhoff, 2007).However, the analysis of scales in fish from other species by Poulet *et al.* (2005), Matondo *et al*., (2010) has shown that also the scale shape and structure may reflect the environmental conditions. The aim of this study was to answer the questions:

Does the specific environmental condition in the lakes influence the shape of the vendace scales?

Can morphometric analysis of vendace scales be used for differentiation or identification of local lake population of vendace?

Materials and Methods

The material studied were scales of vendace fish caught at night with a 24 mm-mesh-size gillnets in the years 1999-2000, in spring, summer and autumn, in the lakes Drawsko (124 scales from 50 individuals), Morynskie (124 scales from 49 individuals) and Pełcz (106 scales from 45 individuals) (Figure 1). The scales for further analysis were collected from all the vendace caught in fisheries research from each lakes (the fish were not selected for the study). We decided to focus our attention on three above lakes, because have been considered to be major economic importance for fisheries and the vendace – type lake management model is implemented there, in some years vendace constitutes over 50% of fish captured. Moreover, the hydrological and environmental condition of the lakes differ each other (Table 1,

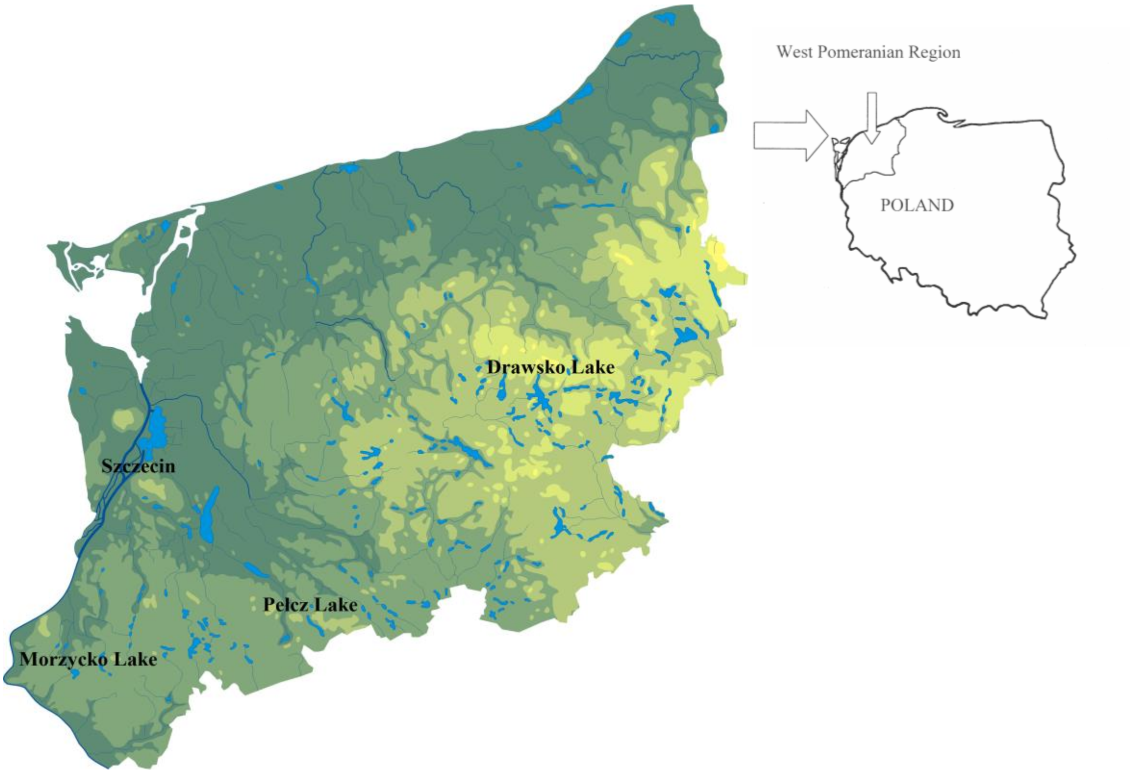

Figure 1. Location of lakes from which the vendace studied were collected.

Table 1. Morphometric characters of the lakes from which the fish studied were caught (after unpublished data, Institute of Inland Fisheries Olsztyn, Poland)

Morphometric data	Lake Drawsko	Lake Morynskie (Lake Morzycko)	Lake Pelcz
Surface area (ha)	18171.5	342.7	279.5
Maximal length (m)	12610	2900	7600
Maximal width (m)	3900	2400	660
Maximal depth (m)	79.7	60.0	31.0
Average depth (m)	18.6	14.5	12.2
Elongation factor	3.20	1.21	11.50
WL*	4.97	1.83	3.34

*Shoreline complexity index

Figure 2) and growth rate, condition of vendace population vary (Czerniejewski and Filipiak, 2002; Czerniejewski and Czerniawski, 2004).

The contribution of scales from males and females was at the 1:1 proportion to eliminate the influence of sex on the scale shapes. The total number of scales analysed was 354 collected from 144 vendace individuals. The scales from the fish caught from Lake Pełczhad the mean full length of 196.1 mm (range of variation 174.1-236.5 mm) and their mean weight was 70.7 g (30.5-110.6 g). The mean full length of the fish caught from Lake Morzycko was 200.6 mm (185.6-225.0 mm), the mean weight was 72.8 g (54.0-91.2 g), and the analogous parameters for the fish caught from Lake Drawsko were 221.6 mm (186.4-248.7 mm) and 93.1 g (69.1-112.1 g).

The morphometrics features of the lakes from which the fish were caught are given in Table 1.

The lakes from which the material for the study was collected belonged to different and separated catchment areas. Lake Morzycko belonging to the catchment area of the Słubia River and Lake Pełcz belonging to the Mala Ina river are the closest to each other as the rivers finally join the Odra river. Lake Drawsko belongs to the catchment area of the Drawa River and is much distant from the other two. The lakes were selected not only to represent different environmental conditions but also because the populations of vendace from them have never been mixed by stocking.

The scales for the study were collected by a pair of tweezers from above the lateral line and between the adipose fin and dorsal fin. The scales were then cleaned in a solution of water and a detergent to remove impurities. After drying, groups of 6 scales were placed between two glass slides, protected by tape to stabilise the preparation and subjected to analyses by DigiShape (CortexNova, 2005).

Program Digi Shape has been developed for automatic morphometric measurements of any objects presented in the form of silhouettes in graphic files, and was used in botany to evaluate the morphology of leaves and clumps of roseroot (Adamczak *et al*., 2014). Silhouette object is any separate black figure on a white background. Measurements are made for black and white images (monochromatic) but the program permits conversion of a coloured image into a black and white one.

To make automatic measurements, the digital images of the scales were fed to a computer by a scanner HP PSC 1500 Series. The images were then analysed by DigiShape program (Figure 3A). To prevent the problems with shape recognition that may have followed from high transparency of the oral part of the scale, the scale area was blackened (Figure 3B), while the background was whitened, similarly as the impurities in the background (Figure 3C). Each scale image was analysed individually. The images were subjected to automatic morphometric measurements. After the measurements by DigiShape the results were fed to Microsoft Excel and interpreted. List of measurements and morphometric procedures performed by DigiShape on vendace scales; abbreviations are given in parentheses.

1. Dissection Index MER (DIM)– describes the degree of the object division, defined for the length measurement according to MER. The higher the number of parts into which a given object is divided the higher the values of Dissection Index MER. For circular objects this index is 1.

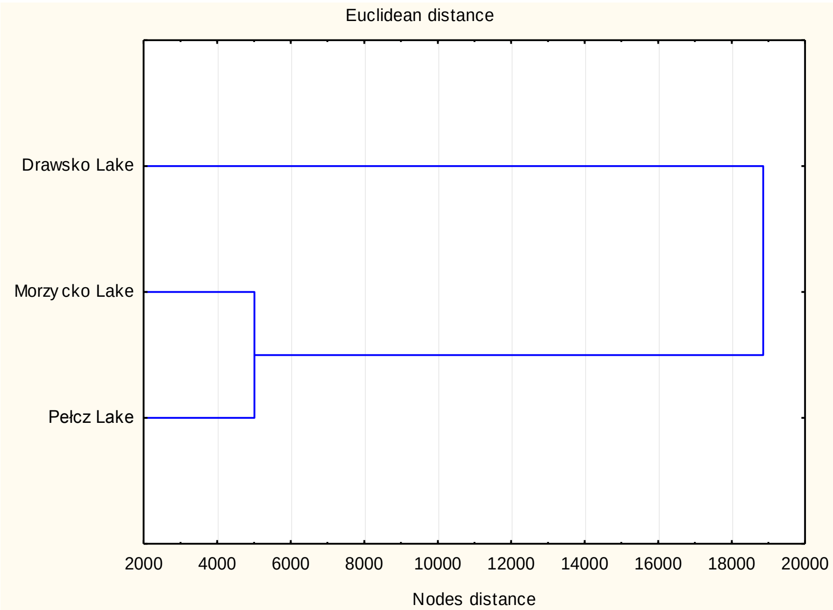

Figure 2. Cluster diagram of a single-linkage Euclidean distance based on 8 morphometric features of 3 lakes.

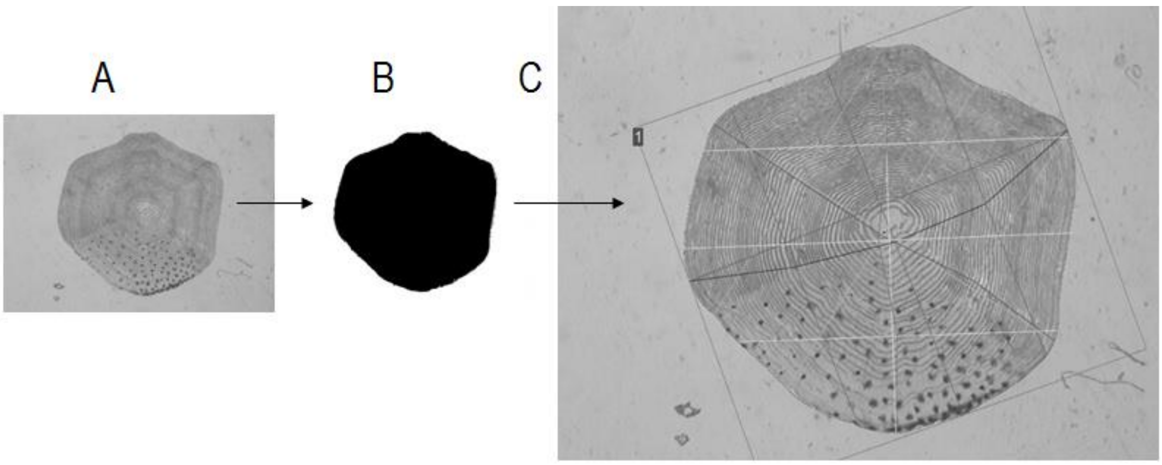

Figure 3. The steps of the scale image processing to permit measurements within Digishape program.

DissectionIndexMER = Perimeter / π × Length MER

where; Perimeter –is the circumference of the object found as that of the actual circumference of the object or after smoothing out by third rank polynomials

LengthMER (minimum enclosing rectangle) – the length of the object found as that ofthe smallest enclosing rectangle. The longer side of the rectangle is parallel to the main eigenvector, so the direction of maximum elongation of the object.

2. Rectangularity (RECT)- the ratio of the area of the object to the area of the smallest enclosing rectangle,

Rectangularity= Area / LengthMER × WidthMER

where; Area – is the object area.

WidthMER – the width of the object found as that of the smallest enclosing rectangle

3. Circularity (CIRC) – normalised circularity of the object, defined as

Circularity = Perimeter2 / 4π × Area

4. PerimToPerimMER (PTOPEM) – the ratio of the object circumference to that of the smallest enclosing rectangle

PerimToPerimMER = Perimeter / 2 × (LenghtMER + WidthMer)

5. MinorToMajorEigen (MITOMEI) – is the ratio of the length of the shorter to that of the longer eigenvector. The longer vector is that in which the object is most elongated and it is parallel to the longer side of the smallest enclosing rectangle. The shorter vector is perpendicular to the longer one and parallel to the shorted side of the smallest enclosing rectangle.

6. MajorEigenToPerim (MAEITM)– the ratio of the length of the longer eigenvector to the object circumference

7. CentroidMinToMean (CMTOME) – a parameter based on the concept of a centroid, which is defined as the point whose coordinates take the mean values of those of all points at the contour of the object, so that the centroid is equidistant from all points of the contour; CentroidMinToMeanis the ratio of the shortest distance from the centroid to a point on the object's contour to the mean distance from centroid to the contour.

8. CentroidMaxToMean(CMAXTOM)– the ratio of the longest distance from the centroid to a point on the object's contour to the mean distance from centroid to the contour.

9. CentroidMinToMax (CEMTMX) – the ratio of the shortest distance from the centroid to a point on the contour to the longest distance from the centroid to a point on the contour, .

10. MidToNarrowerDiam (MDTNDM) –is defined as

MidToNarrowerDiam=WidthDiam/WidthNarEndDiam

where; WidthDiam–is the width of the contour equal to the distance between the points on the object's contour being the points of intersection with a line perpendicular to the object's diameter and passing through the centre of the diameter.

WidthNarEndDiam – is the width of the object at ¼ of the length of its longer axis, from the side at which this distance is shorter

11. DissectionIndexDiam(DISINDI) –
DissectionIndexDiam = Perimeter / π × LenghtDiam

LenghtDiam – the length of diameter .

12. DissectionIndexCentr (DISINCE) –
DissectionIndexCentr = Perimeter / π × LengthCentr

where; LengthCentr – the length of the longest chord passing through the centroid.

The results provided by DigiShape were subjected at first to one-dimensional statistical procedures to calculate the arithmetic mean, standard deviation and range of variation of values describing particular features, using calculation sheet of Excell (Table 2).

To check if the shape of vendace scales can be used to discriminate particular lake populations, the discriminant analysis was made according to STATISTICA version 7.0 packet (StatsoftPoland). The results are presented in the form of matrices of classification together with the list of coefficients of canonical functions and scatter of these functions (Sokal and Rohlf, 1995).

Results

After measurements of the scanned scale images, 12 features describing the scale shape were selected for further analysis. For the values describing them the minima, maxima, arithmetic mean and standard deviation were found, see Table 2. With the help of the model of stepwise analysis of the discriminant function, 9 from the 12 features (variables) were accepted as showing the greatest discriminating power (Table 3).

The classification matrix for the discriminant function revealed that the highest accuracy in discrimination of vendace populations was found for the fish from Lake Pełcz (77.6%), then for those from Lake Morzycko (74.6%), and the lowest for the fish from Lake Drawsko (68.3%) (Table 4). The scatter of

Table 2. One-dimensional statistics of measureable featuresof the vendace scales from three lakes of West Pomerania region and comparison among lakes based on ANOVA Kruskall-Wallis Test (notation assumed : MIN.- minimum; MAX – maximum; Mean – arithmetic mean. SD –standard deviation, n.s. – not significant differences)

Lake and number of scales	Lake Drawsko		n=124	(1)	lake Morzycko		n=124	(2)	lake Pełcz		n=106	(3)	1-2	2-3	1-3
feature (abbreviation)	Min	Max	Mean	SD	v	MAX	MEAN	SD	Min	Max	Mean	SD	P	P	P
DissectionIndexMER (DIM)	1.03	1.86	1.21	0.15	0.93	1.61	1.13	0.11	0.95	2.01	1.21	0.20	<0,005	<0,005	n.s.
Rectangularity (RECT)	0.56	0.78	0.72	0.04	0.65	0.76	0.72	0.02	0.60	0.76	0.70	0.04	n.s.	n.s.	<0,005
Circularity (CIRC)	1.25	4.39	1.83	0.56	1.22	3.50	1.55	0.36	1.26	5.72	1.91	0.85	<0,005	<0,005	n.s.
PerimToPerimMER (PTOPEM)	0.80	1.45	0.95	0.11	0.73	1.26	0.88	0.09	0.74	1.57	0.95	0.15	<0,005	<0,005	n.s
MinorToMajorEigen (MITOMEI)	0.17	0.95	0.62	0.20	-0.17	0.95	0.59	0.25	-0.62	0.98	0.45	0.31	n.s.	<0,005	<0,005
MajorEigenToPerim (MAEITM)	0.36	1.13	0.78	0.16	0.42	1.08	0.75	0.14	0.32	1.28	0.63	0.22	n.s.	<0,005	<0,005
CentroidMinToMean (CMTOME)	0.52	0.91	0.79	0.09	0.68	0.90	0.83	0.05	0.43	0.91	0.76	0.11	<0,005	<0,005	n.s.
CentroidMaxToMean (CMAXTOM)	1.10	1.58	1.21	0.10	1.10	1.30	1.18	0.05	1.07	1.53	1.23	0.10	<0,05	<0,005	n.s.
CentroidMinToMax (CEMTMX)	0.33	0.81	0.66	0.11	0.57	0.82	0.71	0.06	0.28	0.83	0.63	0.12	<0,005	<0,005	n.s.
MidToNarrowerDiam (MDTNDM)	1.08	1.53	1.21	0.08	1.09	1.39	1.19	0.07	1.05	1.52	1.24	0.10	n.s.	<0,005	n.s
DissectionIndexDiam (DISINDI)	1.03	1.83	1.18	0.14	0.91	1.59	1.10	0.11	0.90	1.84	1.16	0.18	<0,005	<0,05	<0,05

Table 3. Standardized coefficients for canonical variables

Character	Canonical Factor 1	Canonical Factor 2
MAEITP	-0.18689	-0.24154
DISINCE	1.34513	0.017394
DIM	-141.394	0.17725
PTOPEM	141.4158	-1.69195
CIRC	-1.53017	1.186839
CEMTMX	0.467893	0.823933
CMAXTOM	0.513862	-0.03708
MDTNDM	-0.14006	-0.34423
RECT	-0.02895	-0.31869
Eigenvalue	0.999816	0.138607
Acc.prop	0.878246	1

Table 4. Classification matrix for vendace scales from three lakes in West Pomerania region

Lake	Percentage of Correct (%)	Lake: PEŁCZ P=0,32768 (n)	MORZYCKO P =0,3334 (n)	DRAWSKO P =0,33898 (n)
PEŁCZ	77.6	90	14	12
MORZYCKO	74.6	12	88	18
DRAWSKO	68.3	2	36	82
Average Total	73.5	104	138	112

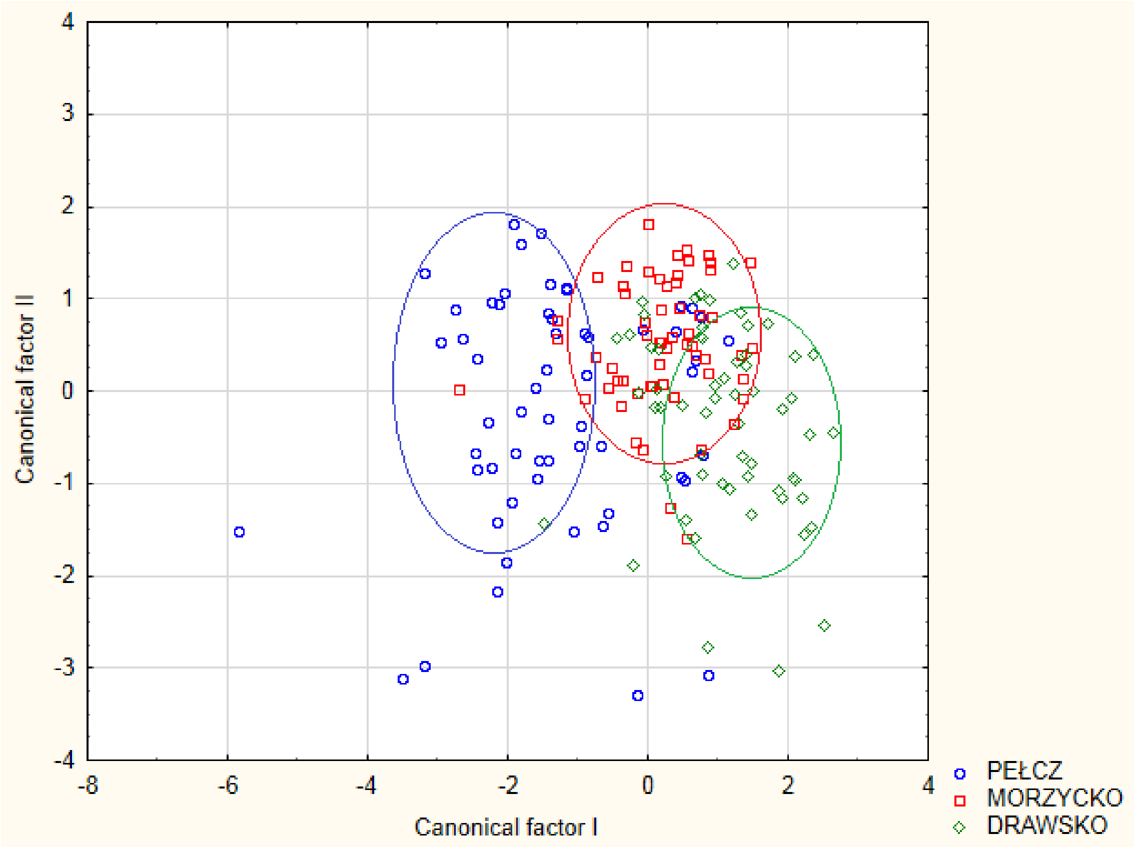

Figure 4. Scatterplot of first two significant canonical variables from the discriminant analysis for vendace scales for the fish from three lakes in West Pomerania.

canonical data illustrates that the first discriminant function best discriminates the fish from Lake Pełcz, left group marked in blue. The discrimination of the fish from the other lakes is not so accurate, as illustrated by the data marked in green and red (Figure 4).

As follows from the analysis of the standardized coefficients of canonical variables, the first classification function explained over 87,0% of variance (accumulated proportion), which means that this function has 87,0% of the total discrimination power. The first discrimination function is mostly determined by two features DIM and PTOPEM, while the contributions of the others is much smaller. The second function seems to be mostly determined by the variables PTOPEM and CIRC.

Discussion

Fish scales are the source of much information on the fish life and environmentand showhigh individual variation, intrapopulation and interpopulation variation.

Although the attempts at using scales for identification of populations have been made for many years, no results have been published for vendace. Methodologically similar papers have been published for pikeperch (*Sander lucioperca*), dace (*Leuciscus leuciscus. L. burdigalensis)*, yellow striped goatfish (*Upeneus vittatus)* (Poulet *et al.*, 2004, 2005; Matondo *et al.*, 2010).

This paper is the first one reporting results of measurements of 12 morphometric features of scales on three groups of vendace from three populations living in three major lakes in West Pomerania region (Poland). Analysis of the shape of scales from the representatives of the compared three populations has shown that the conditions in the lakes influence not only the morphometric and biological features of the species (Czerniejewski and Czerniawski, 2004; Czerniejewski and Filipiak, 2002; Czerniejewski and Rybczyk, 2008), but also the shape of scales. The specific environmental conditions of three selected lakes influence the shape of vendace scales and it can be used for differentiation or identification of local lake populations of vendace. However the classification matrix (73.5% of all scales were classified correctly) gave a bit lower result than that in the analogous study of Atlantic salmon scales. De Pontual and Prouzet (1988) reported the classification matrix accuracy higher than 99% for the shape of scales from two populations of the fish from Norway and France. Poulet*et al.* (2005) obtained the classification matrix accuracy of 75.6% for three river populations of *Leuciscus leuciscus burdigalensis* from the Viaurriver system, while Fraisse (1990) reported the accuracy of classification matrix as 85.0% for *Leuciscus leuciscus* from the two rivers of the same catchment area. As suggested by Poulet *et al.* (2005) such differences can be related to the use of different parameters describing the scale shape or to smaller geographic and environmental differences between the sites of fish collection. For lake fish, such as vendace, the important environmental factors can be lake morphology and abundance of nutrients, which affect the rate of fish growth. In our study, the first classification function brought the most accurate discrimination of vendace from Lake Pełcz (classification matrix accuracy of 77.6%), while the results for the fish from Lake Drawsko and Morzycko were in a different group in the scatter of results. According to literature on biology of vendace from the three lakes studied (Czerniejewski and Czerniawski, 2004; Czerniejewski and Rybczyk, 2008), the vendace from lakes Morzycko and Drawsko have similar growth rate, but the fish from lake Pełczare characterised by an exceptionally low rate of growth, their lengths in each age group are by about 10 mm shorter than the length of those from the other two lakes. Probably besides the feeding conditions influencing the rate of growth (Czerniawski and Czerniejewski, 2003), also the morphological features of the lakes (Table1) affect the shapes of scales. Lakes Drawsko and Morzycko have similar maximum depths, but lake Pełczis much shallower. As has been earlier established, vendace is a highly plastic species in lakes of West Pomerania, which is manifested by disproportions in body shape as well as biological and population features of this species (Czerniejewski and Filipiak, 2002; Czerniejewski and Keszka, 2007). On the other hand, the range of occurrence of this species also shows high inter population variation (Kottelat and Freyhoff, 2007).

The fundamental background of the studies on identification of local populations of fish is the thesis that geographical isolation can bring development of morphological features differentiating these populations as a result of the impact of environmental factors, selection, and genetic factors influencing individual development (Cadrin, 2000). Unfortunately, besides the factors that can be objectively evaluated there are anthropogenic factors whose effect can hardly be estimated such as the conditions of aquaculture (when growing stocking material) or stocking with material of unknown origin. As indicated by Babiak and Glogowski (1995), in Poland the scale of threats to biodiversity is much greater than in other countries. Devastation of the natural environment, overfishing of the spawning stock, genetically uncontrolled stockings lead to shrinking of the genetic pool and thus the adaptation abilities to changing environmental conditions decrease. In view of the above definition of a tool allowing identification of fish from specific populations like the shape of scales, seems relatively cheap and promising in the efforts to protect biodiversity.

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