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Length-Weight Relationships and Morphological Variability of Black-Striped Pipefish *Syngnathus abaster* Risso, 1827 in the Dnieper River Basin.

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Abstract

Length-weight relationships and morphological variability were assessed for black-striped pipefish *Syngnathus abaster* Risso, *1827* that has successfully spread in freshwater ecosystems of Ponto-Caspian basin. Ninety females and ninety males were analyzed. Their standard length was 10.65±0.9 cm, ranged 6.90–14.10 cm and the wet weight – 0.71±0.02 g (0.15 – 1.53 g) respectively. The length-weight relationships were significant (P≤ 0.05) for all samples. The R^2 values ranged from 0.869 to 0.949. In terms of growth, males in all observed areas were positively allometric (b > 3), while females showed isometry (b = 3). Poled samples (males + females) were positively allometric. In addition, measurements of thirteen morphometric characters allowed indicating several morphological differences of individuals from several samples. They manifested in body and head proportions, fins position and body heights with P≤0.05. Furthermore, principal components analysis allowed us to differentiatefish from lacustrine and stream habitats into two separate scatters by external morphology that proved the availability of some different ckreods (ontogenetic channels) of black-striped pipefish. One of them was implemented in lotic ecosystems of the lacustrine parts and another in lentic stream parts of Dnieper reservoirs.

Keywords: Black-striped pipefish, syngnathidae, length-weight relationships, morphological variability, ontogenetic channels.

Introduction

In aquatic environments, expanding and introduced species represent an important component of water ecosystems (Lavoie *et al.*, 1999). Swiftspreading of numerous aquatic organisms beyond the borders of their historical natural habitats was caused by global climatic changes, active human hydro-constructing activities, large-scale resettlement and introduction of animals into new water ecosystems (Copp *et al.*, 2005; Den Hartog *et al.*, 1992; Davis and Shaw, 2001; Paavola *et al.*, 2005; Havel *et al.*, 2005). Furthermore, qualitative and quantitative destabilization of structure in populations of major native fish species created the free ecological niche of zooplanktivors in Dnieper river basin that also promoted the process of penetration and successful naturalization of Ponto-Caspian marine fishfauna (Slynko *et al.*, 2011, Novitskiy, 2013).

One the most successful examples of such naturalization is the black-striped pipefish *Syngnathus abaster* Risso, *1827*. It is widely-spread in inland waters of Ukraine (Khrystenko *et al.*, 2012) and one of the most potential future invaders in Eastern Europe river basins (Semenchenko *et al.*, 2011). It is known, that *S. abaster* is a euryhaline fish species inhabiting a wide range of marine, freshwater and brackish habitats (Movchan, 1988; Kuiter, 2001; Kottelat and Freyhof, 2007). Its original distribution area includes coastal habitats and the lower reaches of rivers of the Caspian, Azov, Black and Mediterranean Sea basins, as well as the Atlantic coast from Gibraltar to the southern Bay of Biscay (Berg, 1949, Kuiter, 2001, Kottelat and Freyhof, 2007). During the 20th century, this fish species expanded its range upstream in the rivers Danube, Dniester, Dnieper, Don and Volga (Movchan, 1988; Reshetnikov*et al.*, 1997; Kottelat and Freyhof, 2007, Gürkan and Çulha, 2008, Ondračková *et al.*, 2012).

The first capture of 1 exemplar of *S. abaster* in studied region was marked in the Ros River– the tribute of the Dnieper River, which falls in Kremenchug reservoir in 1921 (Beling, 1923). Unfortunately, it was not proved and in later annual monitoring studies of Dnieper River basin provided by the Institute of Fisheries NAAS (Volkov, 1973;

Khrystenko *et al*., 2012) and Institute of Hydrobiology NAS (Movchan, 1988) black-striped pipefish was found much later and downstream. Consequently, we tend to think that it was absent in Upper and Middle Dnieper. The first proved finding of black-striped pipefish in the Lower Dneiper was sampled in Ingulets River (the tribute of future Kakhovskoe Reservoir) (Zhuravel, 1937). Nevertheless, only since 1951black-striped pipefish has been continuously registered in Kakhovskoereservoir (Melnikov, 1955). Naturally, that in Dneprodzerzhinsk Reservoir and Kremenchug Reservoir, which are located upstream of the Dnieper River, black-striped pipefish was founded only in 1990-s (in 1996 and 1991 respectively). Thus, this species is alien for investigated ecosystems.

Despite the fact that *S. abaster* does not make active migrations (Kuiter, 2001), the most probable way of its expansion in new areas is usually caused by unpremeditated invasion during various human economic activity like anthropogenic modifications of habitat and fish stocking (Slynko *et al*., 2011), transport in ballast waters (Lavoie *et al.*, 1999) and other. Thereby, the chronology of its findings in different water bodies of Ukraine, especially in Dnieper reservoirs, characterized by some unpredictability and incoherence. Additionally, its biological features caused successful settlement in new biotopes: unusual body form is promoted for weak elimination of black-striped pipefish by freshwater predators (Movchan, 1988; Savino and Stein, 1989), the nurture compensates a low fertility (Vinogradov and Tkacheva, 1949; Savchuk, 1981) etc. That has significantly influenced the native fish populations (Novitskiy, 2013).

Obviously, the question of *S. abaster* investigation in Ukrainian water bodies is still of current interest due to possibilities of this invader in occupying new territories. Surprisingly, but length-weight relationships for investigated region are absent in previous scientific papers. In comparison, there were detailed morphological studies of *S. abaster* from Lower Dnieper, the Azow and the Black seas (Movchan, 1988) and from the Dunabe (Cakic, *et al.*, 2002). It should be mentioned that one modern paper (Kiryukhina, 2013) had studied the variability of different black-striped pipefish populations in the Volga and the Dnieper basins. Unfortunately, this work was made with low number of morphometric characters and without taking into account sexual dimorphism, described in various papers and monographs (Berg, 1949; Movchan,1988; Kuiter, 2001; Silva *et al.*, 2006). Needless to say, that these aspects did not allow the author to find some differences. Therefore, themorphological variability of black-striped pipefish in studied region has been also poorly investigated so far.

Overall, the aim of the study was to analyze the features of *S. abaster* length-weight relationships and morpho type changes in fresh waters with diverse hydrological conditions, revealing the tendencies for realization of different development programs by certain groups of biological and morphological features.

Materials and Methods

Study Area

The Kremenchug Reservoir is the biggest reservoir in the cascade of six Dnieper reservoir sand covers an area of 2252 km^2. It has a length of 149 km, maximum width of 28 km, average depth of 6.0 m, and maximum depth of 28 m. Dam and a bridge near the Cherkassy town divides this water body into two sections with different hydrological regimes: the stream (channel-like) and the lacustrine (lake-like) parts (Denisova *et al.* 1989).

The Dniprodzerzhynsk Reservoir is situated below the Kremenchug Reservoir. It covers an area of 567 km^{2}and is the second smallest reservoir after the Dneprovskoe Reservoir in the cascade of six Dnieper reservoirs. It has a length of 114 km, maximum width of 8 km, average depth of 4.3 m, and maximum depth of 16 m. This stream water body has the same hydrological regime (Denisova *et al.*,1989).

Data Collection and Analysis

Sampling in the Kremenchug Reservoir and the Dniprodzerzhynsk Reservoir were conducted in late August 2013 and late August 2014 within the framework of annual cyprinid and perch juvenile fish surveys in littoral zones of the Dnieper reservoirs, where adult and sub-adult specimen of *S. abaster* were sampled simultaneously. (Figure 1) Etic permission for investigations was proved by scientific fishing licenses of Cherkasy, Sula and Poltava state fishery inspections because this fish species is protected with Appendix III of Bern Convention.

The samplings from the stream and the lacustrine parts of Kremenchug reservoir were taken separately from stream and lacustrine areas. In the stream part data was sampled near village Sokirno and in the lacustrine part – on traverse from Adamovka port to promontory Zhovnino. On the channel-like Dneprodzerzhinsk reservoir data was sampled near village Keleberda.Sites were sampled twice in both 2013 and 2014. Geographical coordinates of each sampling site were registered using a GPS receiver Garmin Dakota 10.

Fish were collected using a push-net (10 m ×1 m ×1 mm mesh size). The area of seine hauls depended on the water depth and bank steepness and ranged from approximately 10 to 100 m^2, which was measured visually using the seine length as a reference, according to standard methodology (Metodykazboru, 1998). Considering the sexual dimorphism males and females were studied and compared separately. Standard length and wet weight

Figure 1. Schematic sampling locations of the black-striped pipefish in Ukraine.
Notes: 1 – Kremenchug reservoir, stream part; 2 – Kremenchug reservoir, lacustrine part; 3 – Dneprodzerzhinsk reservoir;4 – Berezansky estuary; 5 – Tendrovsky Bay; 6 – Berdyansk Spit. Note: The sampling points 4–6 – by (Movchan. 1988).

data were recorded in the field to the nearest 0.1 cm and 0.01 g from the specimens collected. After that, specimens were kept in 70 % ethanol prior to examination of morphometric signs in laboratory.

The estimation of length-weight relationships parameters ($W = a \times SL^b$) were made using linear regression analysis after the logarithmic transformation of the data ($\log W = \log a + b \times \log SL$), where *W* is the wet weight and *SL* is the standard length, *a* is the intercept and *b* is the regression coefficient. The coefficient was calculated by sex. A Student's t-test (Sprinthall, 2011) was used to check if the estimated *b*-values differed significantly from the isometric value (H_0: b = 3) (P< 0.05), and to define the growth type of the species (positive allometric – *b* >3, negative allometric *b*< 3, isometric: *b* = 3).The degree of association between the weight and length was given by the coefficient of determination, R^2. (Morey *et al.* 2003).

Morphometric signs were measured by caliper to the nearest 1.0 mm. Morphological variability of *S. abaster* was analyzed by thirteen morphometric characters: head length (*HL*); maximum (*H*) and minimum (*h*) body height; maximum body depth (*iH*); distances: antedorsal (*aD*) – from snout end to dorsal fin insertion, postdorsal (*pD*) – from dorsal fin end to scaled cover end, anteanal (*aA*) – from snout end to anal fin insertion; height of dorsal fin (*hD*); occipital (*hc*) and ocular (*hc1*) height of head; snout length (*lr*), head width (*ic*) and interorbital distance (*io*) (Pravdin, 1966). Eight morphometric characters were expressed as % *SL* and five as % *HL* (Table 1). Measurements according to standard methods of I.F. Pravdin, (Pravdin, 1966) allowed to compare our standardized data with literary materials about *S. abaster* populations from the Azov sea area near Berdyansk Spit, the Black sea area near Tendrovsky Bay and Berezansky estuary (Movchan. 1988), measured in the same order.

Sudden environmental changes or mastering new habitats induct direct adaptive phenotype changes, which determine intra-population differentiation that mainly express on the level of plasticity (morphometric) body features. Meristic signs are much more conservative and they need longer period of time to change (Mayr, 1963; Fear and Price, 1998). In addition, the settlement of species into new territories and their naturalization make possible the channeling of development by certain phenotypic groups of traits (West-Eberhard, 1986; Williams *et al.*, 1995).

Comparisons of sample values were performed by t-test. Principal component analysis was used for index value distribution in different samples. Statistical calculations were performed in program *Statistica 8.0* for Windows.

Results and Discussion

A total of 180 fish (90 males and 90 females) were used to determine the length-weight relationships of *Syngnathus abaster* Risso, *1827* in studied water bodies. Due to gender variation (Berg, 1949; Movchan, 1988; Silva *et al.*, 2006), estimated parameters and the coefficient of determination (R^2) were given for poled samples and separately for males and females in Table 2. The fish standard length size (*SL*, cm) was 10.65±0.9 cm, ranged from 6.90 cm to 14.10 cm. The wet weight (*W*, g) was 0.71±0.02 g ranged from 0.15 g to 1.53 g. Linear regressions fitted

Table 1. Length-weight relationships of collected black-striped pipefish (*S. abaster*)

Location	*n*	*SL*, mm Mean ± SE	*SL*, mm Min–Max	Weight, g Mean ± SE	Weight, g Min–Max	*a*	*b*	R^2	Growth type
Kremenchug Reservoir, stream part, ♀+♂	60	10.72±0.16	6.90–13.20	0.67±0.03	0.18–1.20	0.0004	3.131	0.865	A+
Kremenchug Reservoir, stream part, ♀	30	10.50±0.20	8.00–13.20	0.69±0.04	0.25–1.11	0.0006	3.016	0.853	I
Kremenchug Reservoir, stream part, ♂	30	10.94±0.26	6.90–13.10	0.71±0.05	0.18–1.20	0.0004	3.142	0.875	A+
Kremenchug Reservoir, lacustrine part, ♀+ ♂	60	10.53±0.18	6.90–13.10	0.73±0.04	0.15–1.53	0.0003	3.241	0.778	A+
Kremenchug Reservoir, lacustrine part, ♀	30	10.50±0.29	6.90–13.10	0.85±0.07	0.15–1.53	0.0007	3.013	0.871	I
Kremenchug Reservoir, lacustrine part, ♂	30	10.55±0.20	8.00–12.60	0.60±0.04	0.22–0.93	0.0001	3.670	0.946	A+
Dneprodzerzhinsk Reservoir, ♀+ ♂	60	10.98±0.17	8.60–14.10	0.64±0.03	0.23–1.41	0.0003	3.167	0.919	A+
Dneprodzerzhinsk Reservoir, ♀;	30	10.95±0.21	8.60–12.80	0.66±0.04	0.27–1.10	0.0005	3.017	0.869	I
Dneprodzerzhinsk Reservoir, ♂	30	11.02±0.26	8.60–14.10	0.65±0.05	0.23–1.41	0.0002	3.338	0.949	A+

Notes: SL – standard length, SE – standard error of mean, n = sample size; a and b = parameters of the length-weight relationship; R^2 = coefficient of determination, Groth type: A+ – positive allometry, I – isometric

Table 2. Morphometric characteristics of the black-striped pipefish

Characters	Water bodies											
	Kremenchug Reservoir. stream part(our data)		Kremenchug Reservoir. lacustrine part (our data)		Dneprodzerzhinsk Reservoir(our data)		Tendrovsky Bay (Movchan, 1988)		Berdyansk Spit (Movchan, 1988)		Berezansky Estuary (Movchan, 1988)	
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	♀; n=30	♂; n=30	♀; n=30	♂; n=30	♀; n=30	♂; n=30	♀; n=25	♂; n=25	♀; n=16	♂; n=16	♀; n=13	♂; n=13
	% SL											
H	3.95±0.04	4.89±0.02	4.31±0.05	4.89±0.05	3.25±0.01	4.00±0.02	3.63±0.11	4.23±0.10	3.22±0.13	4.08±0.15	3.22±0.21	4.13±0.10
h	0.99±0.01	1.36±0.01	1.36±0.03	1.76±0.03	0.60±0.01	0.52±0.01	0.77±0.03	0.55±0.05	0.66±0.04	0.78±0.06	0.58±0.04	0.51±0.04
iH	3.00±0.02	3.22±0.01	3.00±0.05	3.22±0.02	2.72±0.01	3.05±0.02	2.94±0.08	3.24±0.06	2.70±0.09	3.36±0.08	2.76±0.16	3.22±0.06
aD	40.90±0.15	42.49±0.06	40.90±0.18	42.49±0.25	37.20±0.04	39.10±0.03	37.27±0.17	39.79±0.18	37.15±0.28	39.95±0.29	38.13±0.27	40.05±0.26
pD	48.41±0.07	47.19±0.04	48.41±0.23	47.19±0.18	50.21±0.01	49.70±0.03	49.95±0.17	48.15±0.20	50.15±0.30	47.85±0.24	49.47±0.24	48.05±0.26
aA	42.02±0.03	42.03±0.04	42.03±0.15	42.03±0.15	38.30±0.03	39.40±0.01	38.67±0.18	40.67±0.16	38.28±0.33	41.48±0.31	39.13±0.33	41.47±0.21
hD	2.74±0.02	2.22±0.02	2.22±0.04	2.22±0.04	2.80±0.01	2.41±0.01	3.35±0.10	2.91±0.08	2.75±0.15	2.28±0.10	2.47±0.12	2.80±0.14
HL	12.75±0.03	13.28±0.02	13.28±0.09	13.28±0.09	12.73±0.01	13.37±0.01	12.59±0.15	13.35±0.13	12.48±0.20	13.82±0.17	12.88±0.21	13.97±0.21
	% HL											
hc	30.28±0.08	33.23±0.03	33.23±0.30	33.23±0.30	30.10±0.01	32.92±0.02	28.37±0.47	27.09±0.40	26.99±0.45	25.79±0.66	25.21±0.36	25.05±0.48
hc1	22.19±0.04	20.11±0.02	22.19±0.20	22.19±0.20	22.41±0.01	20.21±0.02	22.17±0.39	20.41±0.46	20.11±0.39	18.51±0.66	18.55±0.57	18.89±0.51
lr	48.50±0.09	49.52±0.03	49.52±0.36	49.52±0.36	48.80±0.02	49.94±0.02	41.01±0.59	41.57±0.51	41.79±0.51	44.99±0.48	45.39±0.53	47.89±0.83
ic	22.20±0.04	20.34±0.01	22.22±0.29	22.22±0.29	22.70±0.01	20.50±0.01	27.21±0.49	25.77±0.52	26.25±0.75	23.99±0.48	26.39±0.83	23.71±1.11
io	12.24±0.04	10.82±0.01	12.89±0.31	12.89±0.31	11.60±0.01	9.96±0.01	8.89±0.27	7.69±0.38	8.11±0.60	7.99±0.54	6.89±0.33	6.55±0.22

(mean ± standard error)

to estimate the length-weight relationships were significant (P≤ 0.05) for all samples (Table 2). The R^2 values ranged from 0.869 to 0.949. The median value of *b* was 3.226 with a minimum *b* of 3.017 for females in Dneprodzerzhinsk Reservoir and a maximum *b* of 3.670 for males in lacustrine part of Kremenchug Reservoir. Length-weight equations by sex revealed that in all studied areas, males were heavier (b > 3) than females; the latter have shown an isometric growth in weight (b = 3). The parameter b values varied in various studies for this fish species in different regions. In some areas *b* was < 3, such as 2.859 in the Candarli Bay, north Aegean Sea (Gurkan, *et al.*, 2010), 2.910 in the Bulgarian stretch of the Danube River (Ondrackova *et al.*, 2012) and 2.922 in Mar Menor coastal lagoon (Verdiell-Cubedo *et al.*, 2006). In others *b* was > 3, for instance 3.156 in the Strymon estuary, Aegean Sea (Koutrakis and Tsikliras, 2003), 3.181 in Erdek Bay, Sea of Marmara (Keskin and Gaygusuz, 2010.), 3.36 in Ria Formosa, South-West Iberian coast (Vieira *et al.*, 2014), 3.53 in the Arade estuary, Atlantic Ocean (Veiga *et al.*, 2009). These data was calculated on mixed samples (males and females), that is why we calculated pooled data for a comparison as well. Our mixed data had parameter b > 3 (Table 2). Length–weight relationship could be affected by several factors (Tesch, 1971; Wootton, 1998). Some of them, like degree of stomach fullness, gonad maturity and health were not considered in the present study. Despite this fact, current investigations could serve for comparison with similar studies of different water bodies of the Ponto-Caspian Basin and could be of use when fish populations would be subjected to recovery programs or any other management activity.

Studied morphometric characters of *S. abaster* shown in Table 1. All researched populations were characterized by rather high morphological plasticity that could explain the successful settlement of black-striped pipefish. Differences with P values no more than 0.05were found in the indices expressed in *HL–ic, io, hc, hc1, lr* (Table 3 and Table 4). They could be functionally connected with the peculiarities of breathing and nutrition. (Mitrofanov, 1977). Differences in such characteristics as *aD*, p*D* and *aA*usually caused by changes of fins location and enhancing their role as stabilizers. Changes of *h* and *H* are directly related to fish swimming activity. For example an increase of *h* index is related to strengthening of the role of the caudal fin in motion amplifying currents (Mitrofanov, 1977).

In addition, the distribution of the studied samples of *S. abaster* in space of principal components analysis demonstrated the reliable differentiation of samples by set of morphometric indices (Figure 2). Two distinct scatters were formed. They were differentiated on the first and second principal components (Factor 1 and Factor 2). Fish from the freshwater (the lacustrine part of Kremenchug Reservoir) and saltwater (Tendrovsky Bay, Berdyansk Spit and Berezansky Estuary) ecosystems grouped the first scatter. At the same time, the second scatter was formed only by fish from the fresh waters (the Dneprodzerzhinsk Reservoir and the stream part of Kremenchug Reservoir). Therefore, the most likely connecting factor is the fact that the first group lives in lotic and the second – in lentic ecosystems.

Factor coordinates of the variables, based on correlations (Table 5) showed that the largest contribution in the differentiation of the first component made characters of external morphology, which characterize body shape and proportions (*aD, ic, aA, pD, lr, H).* In the same time, the main contribution to the second component made indeces that characterize head proportions *hc, hc1*and *io*.

The analysis of the relationship of the first principal component cases coordinates with the head length (Figure 3) showed formation of an independent scatter, which consisted of samples from the Dneprodzerzhinsk Reservoir and the stream part of the Kremenchug Reservoir. The forming of independent scatters with a distinct hiatus in the analysis of the relationship of Factor 1 (Figure 3 a) and Factor 2 (Figure 3 b) with head length indicates the implementation of two ckreods (development programs) (Schmalhausen, 1938) or two ontogenetic channels (Mina, 2001) and their confinement to a clear lacustrine or stream habitats. In our opinion, there was the isolation of the so-called "stream" group by body/head shapes (Tissot, 1988). Naturalization of the *S. abaster* in heterogeneous reservoirs of Ukraine, most likely, was a process of adaptation to specific habitats in lotic freshwaters, which was reflected in the observed changes in the external appearance of the studied species.

Overall, in the fluvial reservoirs and rivers on one hand, and the lacustrine reservoirs and basins of Azov and Black seas on the other, there were implemented two different ontogenetic channels or development programs of fish with different body and head proportions. These transformations could be associated with changes in feeding and motion activity of *S. abaster* (Mitrofanov, 1977), which provide better survival and adaptation to different environmental conditions.

Conclusion

It was found that in terms of growth males were positively allometric, while females were isometric. Poled samples (males + females) were positively allometric. Further studies for the species in other areas undoubtedly would provide us with a more comprehensive picture of these basic variables in response to gender, habitat and geographic region.

The comparative analysis of black-striped pipe fish *S. abaster* morphotypein Dneiper reservoirs detected significant differences of development programs in water bodies with different hydrological

Table 3. Samples comparison by t-test, females

Characters	I-III	I-V	I-VII	I-IX	I-XI	III-V	III-VII	III-IX	III-XI	V-VII	V-IX	V-XI	VII-IX	VII-XI	IX-XI
H	-1.20	-1.61	0.83	1.77	-0.48	4.33**	1.70	2.57*	0.46	-1.10	0.08	-2.65*	0.84	-1.09	-1.90
h	-1.85	-2.62*	1.10	1.48	2.15*	3.80**	2.41*	2.65*	3.21**	-0.85	-0.27	0.40	0.42	0.98	0.53
iH	0.00	0.00	0.19	0.90	-0.78	1.14	0.17	0.80	-0.66	-0.73	0.06	-1.89	0.58	-0.75	-1.34
aD	0.00	0.00	6.42**	5.72**	1.33	7.89**	6.14**	5.53**	1.28	-0.15	0.09	-5.20**	0.18	-4.24**	-3.95**
pD	0.11	0.21	-3.02**	-2.76*	0.73	-3.67**	-2.43*	-2.39*	0.51	0.61	0.11	4.16**	-0.29	2.90*	2.81*
aA	-0.02	-0.04	7.31**	6.23**	1.12	8.79**	5.85**	5.41**	0.93	-0.81	0.03	-6.47**	0.55	-4.48**	-4.34**
hD	2.12*	3.00**	-1.76	-0.02	-0.15	-2.59*	-3.02**	-1.22	-1.37	-1.66	0.13	0.00	1.20	1.12	-0.09
HL	-1.53	-2.65*	0.38	0.56	-2.49*	1.74	1.41	1.49	-1.26	0.35	0.55	-2.64*	0.19	-2.30*	-2.33*
hc	-4.79**	-9.83**	2.58*	4.52**	6.99**	5.62**	5.54**	7.21**	9.26**	2.50*	4.59**	7.21**	1.44	3.41**	2.01*
hc1	0.00	0.00	0.03	3.17**	4.45**	-0.48	0.03	2.71*	3.92**	0.38	3.64**	4.88**	2.33*	3.46**	1.29
lr	-1.52	-3.08**	9.08**	8.66**	0.64	1.17	8.73**	8.29*	1.49	9.97**	9.63**	0.99	-0.74	-5.77**	-5.27**
ic	-0.03	-0.09	-6.88**	-4.56**	-1.41	-0.88	-5.65**	-3.95**	-1.26	-6.38**	-4.07**	-0.95	0.86	2.77*	1.86
io	-1.10	-2.91*	6.02**	5.16**	11.16**	2.28*	5.25**	5.01**	8.71**	5.12**	4.47**	10.53**	0.84	3.34**	1.72

Notes: 1) I -XII see. tab. 1; 2) the significance level: * $P \leq 0.05$; ** $P \leq 0.001$.

Table 4. Samples comparison by *t-test*, males

Characters	II-IV	II-VI	II-VIII	II-X	II-XII	IV-VI	IV-VIII	IV-X	IV-XII	VI-VIII	VI-X	VI-XII	VIII-X	VIII-XII	X-XII
H	0.00	0.00	1.91	1.96	3.48**	3.36**	1.70	1.81	3.28**	-0.66	-0.19	1.63	0.30	1.81	1.43
h	-2.00*	-2.83*	3.31**	2.19	3.49**	6.20**	4.28**	3.27**	4.46**	-0.12	-0.98	-0.27	-0.69	-0.10	0.63
iH	0.00	0.00	-0.08	-0.47	1.12	0.85	-0.07	-0.44	1.08	-0.67	-0.98	0.68	-0.32	1.02	1.22
aD	0.00	0.00	5.51**	4.29**	7.59**	6.41**	4.12**	3.46**	6.05**	-1.51	-1.50	1.77	-0.23	2.47*	2.43*
pD	0.00	0.00	-1.96	-1.25	-4.31**	-5.48**	-1.56	-1.02	-3.52**	3.23**	3.56**	0.44	0.45	-1.99	-2.34*
aA	0.00	0.00	3.04**	0.93	4.77**	6.58**	2.44*	0.81	4.19**	-3.08**	-3.68**	0.46	-1.18	2.20*	2.94*
hD	0.00	0.00	-2.18*	-0.17	-0.67	-0.85	-1.99	-0.16	-0.63	-1.67	0.39	-0.17	1.48	0.98	-0.41
HL	0.00	0.00	-0.18	-1.24	0.83	-0.28	-0.15	-1.06	0.73	0.05	-1.06	1.04	-0.86	0.81	1.52
hc	0.00	0.00	9.36**	8.96**	12.84**	0.55	7.34**	7.59**	9.87**	9.00**	8.65**	12.51**	1.26	2.16*	0.57
hc1	-4.43**	-10.40**	-0.43	1.94	2.03*	4.22**	2.19*	3.97**	4.15**	-0.29	2.06*	2.16*	1.80	1.83	-0.04
lr	0.00	0.00	10.82**	6.34**	5.52**	-0.68	8.52**	4.94**	4.38**	11.50**	7.00**	6.14**	-3.44**	-3.75**	-0.40
ic	-3.43**	-13.29**	-7.46**	-5.21**	-6.60**	3.14**	-3.94**	-2.02*	-3.94**	-7.24**	-4.99**	-6.43**	1.78	-0.53	-2.10*
io	-3.66**	-14.64**	5.01**	3.82**	6.74**	5.18**	6.26**	5.31**	7.50**	3.63**	2.66*	5.27**	-0.31	0.95	1.18

Notes: 1) I -XII see. tab. 1; 2) the significance level: * $P \leq 0.05$; ** $P \leq 0.001$.

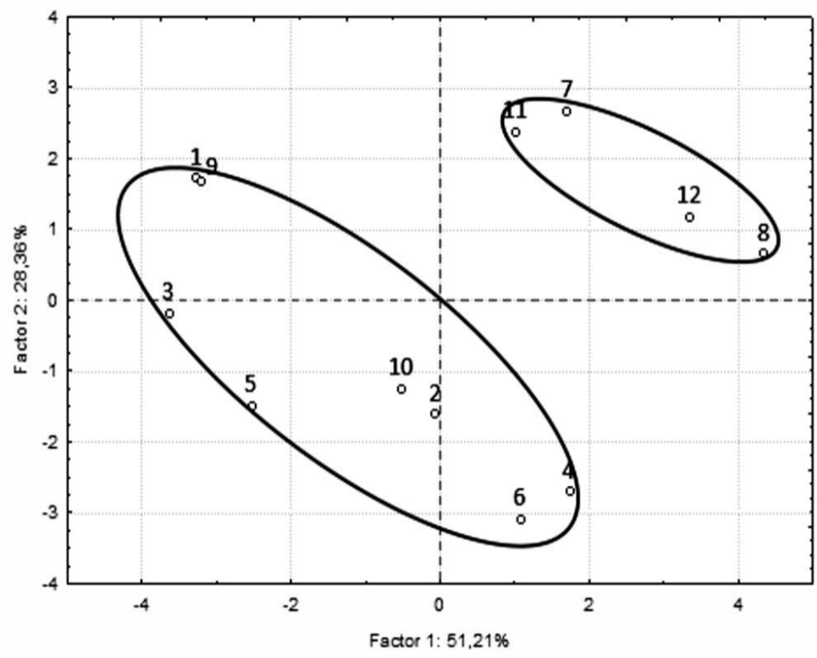

Figure 2. Distribution of the black-striped pipefish populations in the principal components space on morphometric characters.

Table 5. Factor coordinates of the variables, based on correlations

Characters	Factor 1	Factor 2
H	0.789219	-0.093376
h	0.683650	0.563447
iH	0.747917	-0.377821
aD	0.948410	-0.076261
pD	-0.929361	0.195865
aA	0.906056	-0.024572
hD	-0.635410	0.343030
HL	0.622072	-0.731257
hc	0.579152	0.722394
hc1	-0.165316	0.891189
lr	0.815064	0.182397
ic	-0.943897	-0.211743
io	0.463748	0.844780

conditions. These differences were based on transformation of body proportions, position of dorsal fin and ratio of head parts. Thus, on the level of plasticity morphometric characters had revealed basic differences in the number of implemented development programs. One of them was implemented in lotic ecosystems of the lacustrine parts of Dnieper reservoirs, basins of Black and Azov seas, and another in lentic stream parts of Dnieper reservoirs. The study showed that implementation of two development programs of black-striped pipefish in the Kremenchug reservoir directly associated with its invasion in the stream ecosystems. Identified the direction of morphological changes clearly demonstrated the process of black-striped pipefish freshwater adaptation in the stream sections of Dnieper reservoirs. The presence of such tendencies clearly demonstrated the process of successful adaptation of this invader to the new habitats and indicates possibility for its further expansion in the fresh waters of Europe.

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Authors' Contributions

All authors contributed in process of manuscript writing. We confirm that the manuscript has been

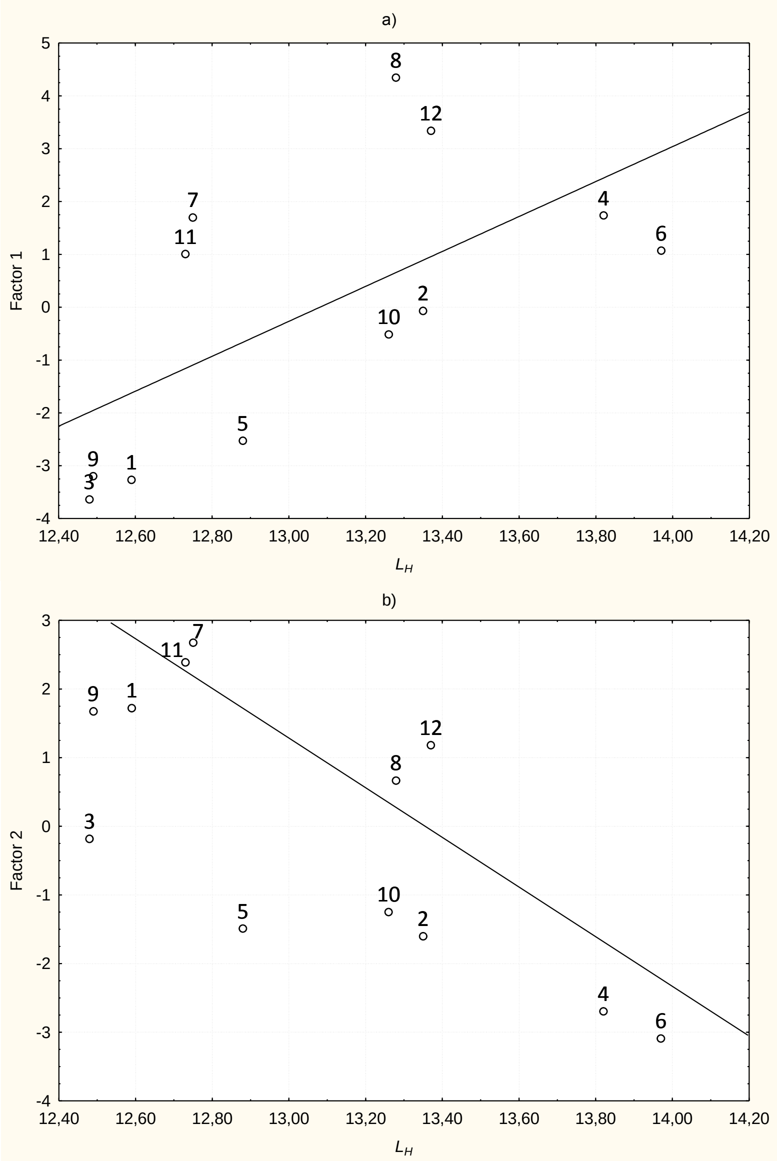

Figure 3. Two-dimensional samples distribution.

submitted solely to this journal and is not published, in press, or submitted elsewhere. All authors agree to the terms and conditions. We confirm that all the research meets the ethical guidelines, including adherence to the legal requirements of the study country. We disclose there are no sources of support and no conflicts of interest. All authors read and approved the final manuscript.

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