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EARLY VIEW
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Seasonal variability of length-weight relationships of Arctic grayling (*Thymallus arcticus*) and Siberian dace (*Leuciscus baicalensis*) inhabiting the middle reaches of the Yenisei River, Siberia, Russia

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Abstract

The present study proves the presence of seasonal variability of LWRs of Arctic grayling and Siberian dace inhabiting the middle reaches of the Yenisei River. LWRs were estimated using total length (cm) and total body weight (g). The literature data on LWRs of dace and grayling from different regions were compared using log *a* over *b* plot. The comparison revealed that seasonal variability of LWRs was wider than the geographic variability for these species. The position of points on the plot can be used to predict the season of sample collection and vice versa.

Introduction

Length-weight relationships (LWRs) are an important tool for fishery research. It can be used to convert growth-in-length equations to growth-in-weight ones in stock assessment models, estimate biomass from length frequency distributions, determine fish condition, and compare the life history and morphology of populations inhabiting different regions (Moutopoulos & Stergiou, 2002; Froese, Tsikliras & Stergiou, 2011). Within a single population, the condition of fish and, as a consequence, LWR can change between seasons (Tesch, 1971; Bolger & Connolly, 1989). Thus, samples collected throughout the year should be analyzed seasonally (Froese, 2006; Froese et al., 2011). However, for the majority of species there are no data on the range of seasonal variability of LWRs in the available literature and the FishBase (Froese & Pauly, 2018).

Arctic grayling (*Thymallus arcticus*) and Siberian dace (*Leuciscus baicalensis*) are widespread across the Palearctic (Kottelat, 2006; Chernova, 2011). Although they have been studied quite well, there are relatively little published data on their LWRs, and none of them provides data of a seasonal study obtained for a single population. Both species inhabit the middle reaches of the Yenisei River, a 360-km-long stretch from the dam of the Krasnoyarsk Hydroelectric Power Plant (HEPP) to the mouth of the Angara River. During the wintertime, tail water downstream of the dam does not freeze over a distance of up to 80-300 km depending on the winter severity (FGU Yeniseirechtrans, 2008). Thus, sampling can be performed throughout a year, in order to study the seasonal patterns of fish ecology (Sushchik, Gladyshev & Kalachova, 2007; Zuev, Shulepina,

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Trofimova & Zotina, 2017).

In the current study, we investigated seasonal variability of LWRs for the two most abundant commercial fish species inhabiting the middle reaches of the Yenisei: Arctic grayling and Siberian dace.

Materials and Methods

Fish samples were gillnetted monthly in the Yenisei River in 2007-2017. Mesh size of gillnets was 22-30 mm. Most of the samples were collected 80-110 km downstream of the Krasnoyarsk. Several samples of grayling were caught about 20 km upstream of the Krasnoyarsk. All subsamples of grayling collected at two sampling sites were considered as one sample, because of identical feeding spectra of grayling (Zuev et al., 2017) and similar food supply at the two sampling sites (Gladyshev & Moskvicheva, 2002).

Fish samples were frozen after sampling and stored packed in plastic foil at - 30 ºC until measurement. Before measurement, the fish were defrosted at room temperature. Total length (TL, cm), total body weight (TW, g), and sex were determined. LWR parameters were estimated using the linear equation: log (TW, g) = log (*a*) + *b* · log (TL, cm). The 95% confidence intervals (CIs) of the parameters and statistical significance of the regression relationships (R^2) were estimated. Statistical comparison for isometry (*b* = 3) was done using Student's t-test (Economou, Daoulas & Psarras, 1991). Analysis of covariance (ANCOVA) was used for comparing seasonal LWR models.

Results

The calculated parameters of LWRs are given in the Table 1. Seasonal subsamples for both species had close ranges of length and weight and a volume above 100 individuals each, unlike a small-sized winter subsample for dace. All regressions were highly significant (*P* < 0.01), with R^2 above 0.8 for grayling. LWR for dace had a relatively low R^2, despite the large sample size. In further analysis, we excluded the winter subsample of dace because of its narrow size range.

The range of *b*-value of grayling varies from 2.793 in summer to 3.604 in winter, and significantly differs (*P* < 0.01) between all seasons. The isometry (*b* = 3) was noted only for the autumn subsample. Slope *b* for dace varies from 2.463 in autumn to 3.025 in summer and differs between autumn (< 3, t-test; *P* < 0.01) and other seasons (*P* < 0.01).

Discussion

In temperate and Arctic regions, many factors that influence freshwater fish change with the seasons (Berg & Bremset, 1998). This leads to the corresponding seasonal changes in fish biology, including the patterns of LWR. There are many publications on variability of fish condition between seasons or months. The general pattern of seasonal variability of fish condition is well-known: it decreases during periods of low temperatures and/or low availability of food, and increases towards the spawning season (Froese, 2006). By contrast, there are very few published data to estimate the seasonal pattern in the LW regressions (Moutopoulos & Stergiou, 2002; Zargar, Yousuf, Mushtaq & Jan, 2012; De Giosa, Czerniejewski & Rybczyk, 2014).

Our results show the existence of seasonal variability of LWR coefficients for two abundant fish species from the Yenisei River (Fig. 1). For grayling, the significant change of *b*-value occurs between winter and summer and between autumn and winter (Table 1). Furthermore, LWR during the year changes from hypometric in summer to hypermetric in winter and spring. Previously, seasonal variabilities in the relative condition, feeding spectra, and the content of polyunsaturated fatty acids in muscles were noted for grayling inhabiting the middle reaches of the Yenisei River (Zuev et al., 2017; Sushchik et al., 2007).

Unlike grayling, LWR for dace has a considerable shift between summer and autumn (Table 1). High values of slope *b* from LWR of Siberian dace in spring and summer obtained in our research (Fig. 1) are indicative of low growth rate of dace. Based on the assumption that Siberian dace is more thermophilic than Arctic grayling, we suppose that growth of the dace is shifted closer to autumn since the maximum warming up of the water in the middle reaches of Yenisei is only observed at the end of summer (Kosmakov, 2001). A similar high *b* value, 3.248, was obtained for Siberian dace sampled in June in the lower reaches of the Yenisei (66º15 N 89º E) (Lobón-Cerviá, Dgebuadze, Utrilla, Rincon & Granado-Lorencio, 1996). That was probably the consequence of the spawning of dace that occurred in June.

The LWRs can be used to compare populations from different regions. A convenient way to compare LWRs is to plot the graph of log *a* over *b* (Frose, 2006). We used LWRs (TL, cm vs. TW, g) from our data, FishBase (Froese & Pauly, 2018) and original publications to make the plots for Arctic grayling and Siberian dace (Fig. 1). Unfortunately, we could not use the results for dace and grayling where standard length, cm, or TL, mm, was used to calculate LWRs, as it was done in other studies (Reed & McCann, 1971; Lobón-Cerviá et al., 1996). LWRs for Baikal grayling (Tsogtsaikhan et al., 2016) were also included in the plot because of the debate about the taxonomic status of the Yenisei grayling. There is an opinion that grayling from the middle reaches of the Yenisei is of the same species as the Baikal grayling (*Thymallus baicalensis*) (Weiss, Knizhin, Romanov & Kopun, 2007).

The seasonal points of LWR parameters for dace and grayling form straight lines, with annual points in the

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middle (Fig. 1). On the plot for grayling, summer and autumn subsamples correspond to the high values of Le Cran's relative condition of grayling, and winter and spring subsamples correspond to low values of the relative condition obtained in our previous work (Zuev et al., 2017). Points from other populations of grayling lay close to straight line although robust regression analysis (robust weight 0.00) detected data from the Yenisei River (Podlesny, 1958) and the Ergis River (Huo, Yuan & Jiang, 2011) as outliers (Points 1 and 2 in Fig. 1, respectively). According to Froese (2006), outliers can be considered as misidentification of a similar-looking species, or a population that differs in body shape from the others. However, Podlesny (1958) obtained the data on the same population of grayling inhabiting the middle reaches of the Yenisei as we did, but before the construction of the Krasnoyarsk HEPP. The distribution along the straight line generally corresponded to the season of catching of the fish. The grayling samples for points 1, 3, 4, and 5 (Fig. 1) were collected in summer and for point 2 - during one year. The position of point 2 is close to our all-year point (Y-all). Unlike the data on grayling, published data on LWRs for Siberian dace are scant (Fig. 1).

Conclusions

Our data prove the presence of seasonal variability of LWRs of Arctic grayling and Siberian dace in the Yenisei River. The range of seasonal variability of LWRs is wider than the geographic variability for these species. The positions of points on the plot of log *a* over *b* correspond to a definite condition of a species. As the fish condition changes seasonally, the position of points on the plot of log *a* over *b* can be used to predict the season of sample collection and vice versa. Hence, addition of information about the time of fish sampling to LWR tables of FishBase (Froese, Pauly, 2018) could be very useful.

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Table 1. Descriptive statistics and estimated parameters of length-weight relationships for two fish species from the Yenisei River. TL, total length; TW, total weight

Species	Sample type	Sex ratio, m : f,%	N	TL range (cm)	TW range (g)	*a*	95% CI *a*	*b*	95% CI *b*	R^2	t-test
Thymallus arcticus	All	48:52	547	16.7-33.2	36.7-389.8	0.0030	0.0024-0.0039	3.363	3.288-3.439	0.933	<0.01
	Winter[a]	49:51	157	16.7-33.1	36.7-389.8	0.0014	0.0010-0.0019	3.604	3.503-3.705	0.969	<0.01
	Spring[b]	47:53	111	17.8-33.2	42.1-318.9	0.0027	0.0016-0.0044	3.385	3.231-3.540	0.945	<0.01
	Summer[c]	50:50	129	18.3-33.2	54.4-325.5	0.0198	0.0106-0.0367	2.793	2.600-2.985	0.866	<0.05
	Autumn[c]	45:55	150	18.3-30.3	61.1-348.2	0.0105	0.0060-0.0182	2.993	2.822-3.164	0.889	>0.05
Leuciscus leuciscus	All	51:49	718	13.7-23.1	19.9-136.0	0.0160	0.0115-0.0224	2.848	2.733-2.963	0.768	<0.05
	Winter[a]	0:100	10	17.6-21.0	62.9-93.9	0.2037	0.0126-0.3.2873	1.997	1.050-2.944	0.747	<0.05
	Spring[b]	48:52	246	13.7-23.1	19.9-136.0	0.0122	0.0072-0.0205	2.942	2.761-3.123	0.807	>0.05
	Summer[b]	50:50	128	15.2-22.5	33.1-111.1	0.0094	0.0042-0.0208	3.025	2.750-3.299	0.790	>0.05
	Autumn[c]	56:44	334	15.8-22.5	48.2-112.2	0.0500	0.0276-0.0909	2.463	2.259-2.666	0.730	<0.01

N, number of individuals; *a,* intercept; *b*, slope; CI, confidence interval; R^2, coefficient of determination.

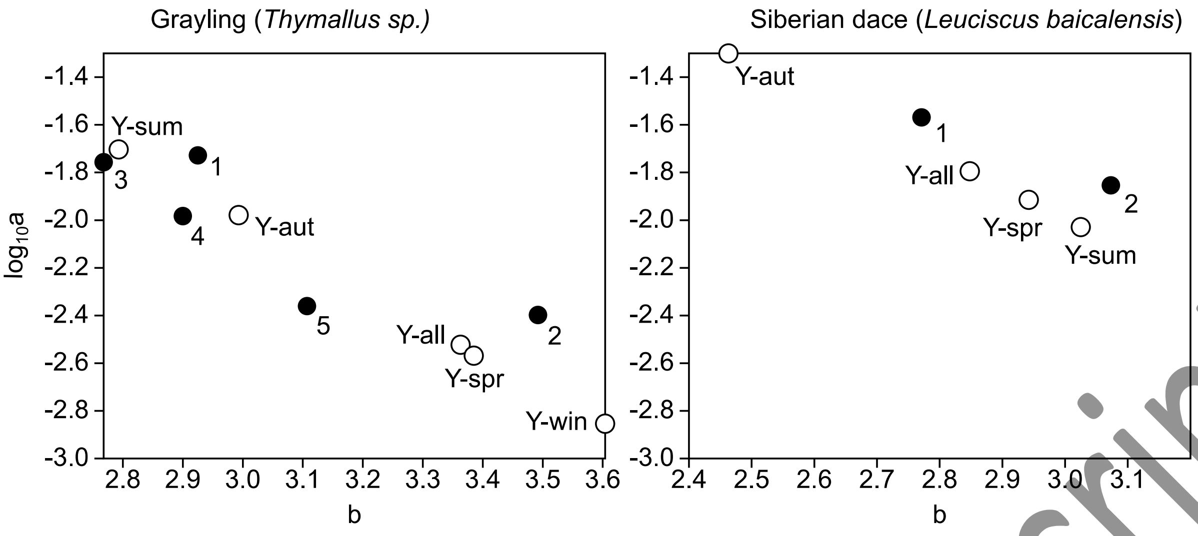

Figure 1. Plot of log *a* over *b* for LWRs for Arctic and Baikal grayling and Siberian dace. Our data for Arctic grayling: Y – the Yenisei River (all – all samples, win – winter, spr – spring, sum – summer, aut – autumn); 1 – Arctic grayling and Siberian dace, the Yenisei River, Russia, season was not indicated (Podlesnyi, 1958); 2 – Arctic grayling and Siberian dace, the Ergis River, China, year sample (Huo et al., 2011); 3 – Arctic grayling, the Grebe Lake, U.S. (Carlander, 1969); 4 – Baikal grayling, Lake Hovsgol, Mongolia, July (Tsogtsaikhan et al., 2016); 5 - Baikal grayling, the Eg River, Mongolia, July (Tsogtsaikhan et al., 2016).