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Changes in the Hepatosomatic Index of Semianadromous Burbot, *Lota lota* L. (Lotidae), in the Ob River Depending on Fish Physiological State and Foraging Conditions

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Abstract—The results of long-term observations on changes in the hepatosomatic index of burbot in the Lower Ob basin are presented. The dynamics of this index are considered as dependent on fish sex, stage of gonad maturity, period of reproductive cycle, body damage or abnormalities, and feeding intensity.

Keywords: burbot, hepatosomatic index, reproductive cycle, foraging, developmental abnormalities

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The problem of responses of animal organisms to changes in environmental conditions depending on their physiological state has been repeatedly addressed by Russian scientists (Shvarts, 1956, 1958; Smirnov et al., 1972; etc.). In continuation of this research, the present paper deals with the pattern of changes in the relative weight of the liver in semianadromous burbot (*Lota lota* L.) from the Ob River basin depending on the period of the reproductive cycle and foraging conditions.

These fish in the Ob–Irtysh basin perform long-distance migrations during their life cycle, traveling for over a thousand kilometers (Bogdanov and Koporikov, 2011). They forage both in the Gulf of Ob and in the Ob floodplain (Koporikov and Bogdanov, 2010, 2011), and their spawning range extends from left-bank tributaries of the Urals to the Novosibirsk Reservoir. Adult fish with gonads at different stages of maturity occur simultaneously in the Ob basin (Koporikov, 2007). The diversity of environmental conditions in the region accounts for the situation that fish of the same population collected at the same time from different parts of their range often differ in body condition factor.

In gadiform fishes, including burbot, the liver is the main fat depot (Bull, 1928; Mittel'man, 1932), with fat content in muscles being less than 1% (Sorokin,1976). Thus, it is the size of the liver that determines the amount of reserve substances stored in the body, which, in turn, is a factor of both reproductive success and survival of a given individual in the changing environment. Therefore, elucidation of conditions that have an effect on the size of the liver (the amount of accumulated fat) is a prerequisite for predicting the dynamics of burbot population.

The morphophysiological parameter expressing the liver weight as a percentage of the carcass weight is named the hepatosomatic index. The assessment of fat reserves in gadiform fishes by determining this index makes it possible to minimize measurement error, compared to the results obtained using the absolute liver weight.

The purposes of this study were to reveal differentiation between male and female burbot with respect to hepatosomatic index and evaluate the pattern of its changes depending on the physiological state of an individual (the stage of reproductive cycle, occurrence of body damage or abnormalities, and feeding intensity).

MATERIAL AND METHODS

The study area covered the Ob River segment upstream of the river mouth near the village of Aksarka, the segment of the Lower Ob channel near the city of Berezovo, and spawning tributaries of the Urals: the Severnaya Sos'va, Synya, Voikar, and Sob' rivers. The material was collected in 1996 to 2011 during the periods of spring–summer foraging migration upstream in the Ob River, autumn foraging–prespawning migration upstream in tributaries of the Ural, spawning, and winter downstream migration (to escape fish kill) in the Ob. A seine, stake and drift nets, and hook-and-line gear were used. A total of 450 burbot were examined.

The fish and their organs were weighed using a Kern CH15K20 digital hanging scales and a Kern 442-51

Table 1. Evaluation of differences in hepatosomatic index between male and female burbot at different stages of reproductive cycle

Statistical parameter	Winter downstream migration to escape fish kill	Spring–summer foraging migration upstream	Autumn foraging–spawning migration upstream	Spawning
Lehmann–Rosenblatt test	0.20 ($p > 0.1$)	0.10 ($p > 0.1$)	0.34 ($p > 0.1$)	0.78 ($p \leq 0.01$)
Sample size (males : females)	58 : 65	12 : 26	117 : 55	43 : 27
Average hepatosomatic index (males : females)	22.3 : 22.0	11.9 : 12.2	8.7 : 9.5	8.7 : 10.9

balance (Kern & Sohn GmbH, Germany). Their age was determined by examining otoliths and vertebrae. The hepatosomatic index was calculated as the percent ratio of liver weight to carcass weight (*Instruktsii*..., 2001). The state of gonads was evaluated with reference to a six-grade scale of maturity (Pravdin, 1966; Sorokin, 1976) and the gonadosomatic index was calculated as the percent ratio of gonad weight to carcass weight (Pravdin, 1966; Sorokin, 1976; *Instruktsii*..., 2001). The values of hepatosomatic index in males and females were compared at different stages of the reproductive cycle. The fish were examined for external and internal signs of damage to the body and organs. The food spectrum and feeding intensity were determined from stomach contents, and relative numbers of fed and starved fish were estimated.

The pattern of dependence of the hepatosomatic index on fish physiological state (sex, stages of gonad maturity and reproductive cycle, body damage or anomaly, feeding intensity, etc.) was evaluated using the Lehmann–Rosenblatt test (Orlov, 2003; Sidorenko, 2003; Lemeshko and Lemeshko, 2005).

Mathematical data processing was performed using programs Excel 2003, SPSS Statistics 17.0, and a package for statistical analysis of interval-censored observations on one-dimensional continuous random variables, version 4.2.41.21.

RESULTS AND DISCUSSION

Sex-related Differences in Hepatosomatic Index

Many authors have noted that sexual dimorphism is weakly expressed in burbot (Mel'yantsev, 1948; Tyul'panov, 1967; Sorokin, 1976; etc.). In our study (Bogdanov and Koporikov, 2011), semianadromous burbot from the Ob River showed sexual dimorphism in only 4 out of 35 morphological characters included in analysis. Sergeev (1959), who examined 756 immature, mature, and spawned fish from Volga reservoirs, revealed no appreciable differences in hepatosomatic index between male and female burbot and found it inexpedient to differentiate these fish by sex in samples for study. We also revealed no statistically significant sex-related differences in this character among foraging burbot (gonad maturity stage II) samples during winter downstream and spring–summer upstream migrations (Table 1). These differences proved to increase in the course of gonad maturation and reach a peak during spawning: they still lacked statistical significance in samples taken during the autumn upstream migration (gonad maturity stage III) but were already significant ($p \leq 0.01$) in samples of spawning fish (stages IV–VI).

The gonadosomatic index in burbot during the rest period (winter downstream and spring–summer upstream migrations) had relatively low values, averaging about 0.13 in males and 0.53 in females. This is evidence that all fish, irrespective of sex, do not expend energy for gonad growth during this period, which allows them to forage more effectively and accumulate fat reserves in the liver. During the autumn prespawning migration and in winter, during spawning, considerable energy reserves are or have already been expended for gonad growth, which is reflected in values of the gonadosomatic index (24.6 in male and 11.8 in female spawners). Since these expenditures in males are higher, their hepatosomatic index is lower than in females (Table 1).

It is noteworthy that sex-related differences in hepatosomatic index during spawning have also been observed in nonmigratory groups of burbot. Thus, its values in burbot spawners from Varchato Lake (December 2000) averaged 8.6 in males and 13.3 in females, the difference being statistically significant (Lehmann–Rosenblatt test, 0.96; $p \leq 0.01$).

Changes in Hepatosomatic Index at Different Stages of Reproductive Cycle (Seasonal Variation)

According to published data (Sergeev, 1959; Sorokin, 1976), the hepatosomatic index in burbot markedly varies by seasons. On the other hand, there is evidence that, in the same season, its values in fish from the same water body may differ by an order of magnitude, e.g., ranging from 2.2 to 24.2 in Volga reservoirs and from 3 to 25 in Lake Baikal tributaries. Sergeev (1959) noted that fat contents in spawning burbot

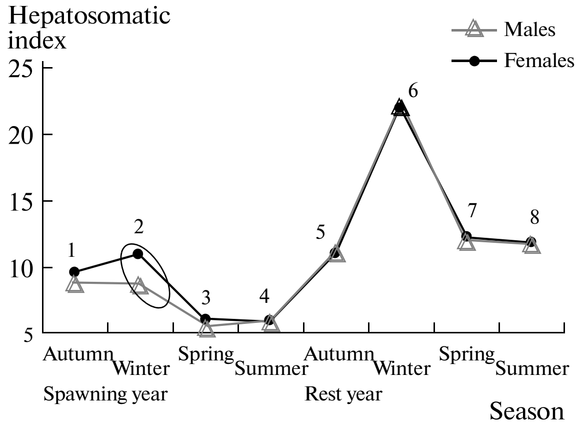

Fig. 1. Seasonal changes in hepatosomatic indices of male and female burbot in spawning years alternating with rest years. Periods of life cycle (Here and in Fig. 2): (1) autumn upstream foraging–prespawning migration, (2) spawning, (3) spring postspawning migration, (4, 8) summer foraging in the Ob floodplain, (5) summer–autumn foraging migration upstream in the Ob floodplain system, (6) winter downstream migration to the Gulf of Ob, (7) spring–summer foraging migration upstream from the Gulf of Ob; ovals indicate spawning seasons.

were significantly lower than in immature individuals caught at the same time. Similar observations were also made in northern Finland (Pulliainen and Korhonen, 1990, 1993).

To estimate the significance of seasonal changes in hepatosomatic index, we compared its values in fish caught during the winter downstream migration (missed spawning, gonad maturity stage II), spring–summer upstream migration to foraging grounds in the Ob floodplain (stage II), autumn upstream migration to spawning grounds (stage III), and spawning (stages IV–VI) (Fig. 1).

Differences in this index proved to be statistically significant at almost all stages of the reproductive cycle (Table 2), except for fish migrating upstream to spawning grounds in autumn and spawning in winter. Figures 1 and 2 show seasonal changes in the hepatosomatic index with account of differences in the rate of maturation of spawners. Unlike females, males can come to spawning grounds during two or more years in a row (Koporikov, 2007). When males spawn every year (Fig. 2), their hepatosomatic index fails to reach the winter peak observed in males that miss spawning (Fig. 1).

The hepatosomatic index in both male and female burbot reaches the highest values (on average, 22.1) in the winter of the rest (nonspawning) year, when they migrate downstream to the Gulf of Ob to escape fish kill, and significantly decreases in fish migrating from the gulf upstream, to the Ob floodplain. This fact may be regarded as indirect evidence that conditions for burbot foraging in the Gulf of Ob are less favorable than in the Lower Ob floodplain. The hepatosomatic index decreases again during summer, concurrently with the growth of gonads. Differences in its values between males and females increase in autumn, reaching statistical significance by the time of spawning (Fig. 1, Table 1). During the winter–spring postnesting period, this index falls to its minimum over the reproductive cycle (5.7). Males that spawned last winter and those that migrate to the Ob floodplain after a rest season may forage in the same biotopes in summer. Differences between them are reflected in the values of hepatosomatic and gonadosomatic indices: the

Table 2. Significance of differences in hepatosomatic index at different stages of burbot reproductive cycle

Stage	Spring–summer foraging migration upstream	Autumn foraging–spawning migration upstream	Spawning
Winter downstream migration to escape fish kill	7.96 ($p \le 0.001$)	22.31 ($p \le 0.001$)	13.49 ($p \le 0.001$)
Spring–summer foraging migration upstream	–	3.07 ($p \le 0.001$)	1.47 ($p \le 0.001$)
Autumn foraging–spawning migration upstream	–	–	0.26 ($p > 0.1$)

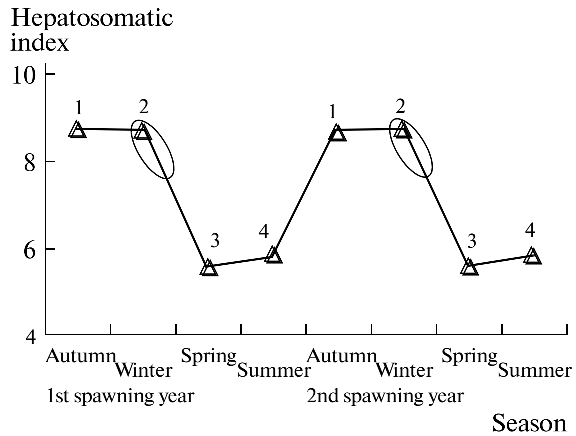

Fig. 2. Changes in hepatosomatic index of males spawning every year.

former index in summer is always lower in males that spawned last winter (Fig. 1).

Thus, the hepatosomatic index in burbot changes by seasons and at different stages of the reproductive cycle, dropping to a minimum in the postnesting period and reaching a maximum during the winter downstream migration (rest year). Its value may serve as an indirect indicator of sexual maturation.

Dependence of Hepatosomatic Index on Developmental Abnormalities or Diseases

The proportion of fish with serious abnormalities (fused or deformed vertebrae, asymmetric gonads, tumors, body damage, heavy parasite infestation, etc.) among semianadromous burbot from the Ob basin averages no more than 5%. In some cases, however, their proportion may be greater (e.g., 20% among fish from the Sob' river in the autumn of 2010).

Theoretically, it could be assumed that hepatosomatic index in fish with abnormalities should be decreased. To test this assumption, we performed a special analysis of samples that contained more than two such fish but failed to reveal any distinct trends of changes in the values of this index, compared to the norm (Table 3). The absence of consistent differences from the norm in this case appears to be due to a compensatory adaptation.

Dependence of Hepatosomatic Index on Feeding Intensity

Another assumption to be tested was that feeding intensity would have an effect on the amount of fat stored in the body and, hence, on the hepatosomatic index. To this end, we compared the values of this index in fish with different degrees of stomach filling from different samples. The presence of half-digested food in the stomach was regarded as indication that fish ate last time 2–4 days ago (in autumn) or 2–6 days ago (in winter); empty stomach indicated that the interval after the last food intake was greater than 4 or 6 days, respectively (Ananichev and Gomazkov, 1960). Only fish collected with a seine or net were analyzed, because specimens caught with hook-and-line gear were a priori fed with bait. The results (Table 4) did not confirm the above assumption: the values of hepatosomatic index did not differ significantly between fed and starved fish ($p > 0.1$).

Thus, the accumulation of fat reserves in the liver is a long process dependent on conditions during the entire foraging period. Consequently, the hepatosomatic index shows no significant dependence on the degree of stomach filling during migrations or spawning.

CONCLUSIONS

(1) No sex-related differences in the hepatosomatic index are observed among burbot with gonads at maturity stage II, but such differences manifest themselves with statistical significance during the spawning period, with the values of this index being markedly smaller in males than in females.

(2) The hepatosomatic index of burbot changes significantly by seasons and at different stages of the

Table 3. Significance of differences in burbot hepatosomatic index between fish with deviations in development and normal fish

Statistical parameter	Place and time of sampling		
	The Voikar River, spawning, December 2000	The Ob River channel near the mouth, upstream foraging migration, June 2010	The Sob' River, upstream foraging–spawning migration, September 2010
Lehmann–Rosenblatt test	0.06 ($p > 0.1$)	0.31 ($p > 0.1$)	0.16 ($p > 0.1$)
Sample size (norm : deviation)	55 : 3	33 : 5	20 : 5
Average hepatosomatic index (norm : deviation)	9.49 : 8.72	11.76 : 14.26	8.28 : 7.10

Table 4. Comparison of hepatosomatic index values in burbot individuals with different degrees of stomach filling, Lehmann–Rosenblatt test

Degree of stomach filling	Half-digested food	Empty stomach
The Ob River channel, Verkhnetogotskii rapids; downstream migration, December 1999		
Food in the stomach	$\frac{0.05(p > 0.1)}{22.59 : 21.60^*}$	$\frac{0.34(p > 0.1)}{22.59 : 20.74}$
Half-digested food	–	$\frac{0.12(p > 0.1)}{21.60 : 20.74}$
The Synya River, upstream foraging–spawning migration, autumn 2004		
Food in the stomach	–	$\frac{0.10(p > 0.1)}{9.36 : 8.41}$
The Sob' River, upstream foraging–spawning migration, autumn 2010		
Food in the stomach	$\frac{0.08(p > 0.1)}{7.77 : 7.64}$	$\frac{0.14(p > 0.1)}{7.77 : 8.99}$
Half-digested food	–	$\frac{0.12(p > 0.1)}{7.64 : 8.99}$
The Voikar River, spawning, December 2000		
Food in the stomach	$\frac{0.07(p > 0.1)}{10.34 : 9.63}$	$\frac{0.13(p > 0.1)}{10.34 : 9.22}$
Half-digested food	–	$\frac{0.15(p > 0.1)}{9.63 : 9.22}$

* Figures below the line show sample average values.

reproductive cycle, reaching a peak of 22.1 during winter foraging (prior to fish kill) and dropping to a minimum of 5.7 in the postspawning period.

(3) Fish with developmental abnormalities or diseases do not differ significantly from normal fish in the hepatosomatic index.

(4) The hepatosomatic index shows no significant dependence on intensity of feeding. The accumulation of fat reserves in the liver of burbot is a long process dependent on conditions during the entire foraging period.

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