

Distribution of cyprinids in the stream during their spring upstream migration

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Abstract. The researches were carry out by stationary and mobile hydroacoustic computerized complexes in the floodplain-riverbed complex of the Irtysh River (Western Siberia, Russian Federation). It was established that during the migration period during the spring flood, patterns of distribution of fish in the stream are observe due to the size-taxonomic characteristics of the fish population and the physiological capabilities of the organism of fish. With an increase in the flow velocity characteristic from the near bank part of the river to its midstream, the proportion of cyprinids in the watercourse decreases, and the proportion of fish with body sizes > 15 cm increases. The number of fish smaller at high-speed sections of the river increases with an increase in water temperature, which in turn indicates the increasing physiological capabilities of representatives of Cyprinidae family. Absolute numerical dominance of migratory fish and the largest proportion of cyprinids were observed in the low velocity section of the river, located closer to the shore. The indicator of the proportion of cyprinids have a direct strong correlative relationship with the temperature factor (0.70-0.73, $P < 0.05$).

1 Introduction

Recently, with the development of hydropower, the number of dams on rivers has increased, as a result of this anthropogenic transformation, watercourses are fragmented and insurmountable barriers are created for migrating fish: disruption in the ecological connection of natural watercourses, fish migration paths are blocked, and reproduction and genetic exchange of populations fish are disrupted. [1]. In this regard, fish passage constructions (fishways) are arranged with certain characteristics that determine the successful passage of a complex of local fish species to ensure their access to spawning and feeding grounds [2]. However, the efficiency of the fish passage can vary depending on the type and location relative to the dam structure [2]. For example, some researchers noted [3-5] that many fish passage facilities do not fulfill their targets for fish passage [1, 3] especially for small individuals (i.e. ≤ 100 mm), including for cyprinids, which can form large aggregations below the barriers of the watercourse. In addition, it was show [2] that the peak use by fish of these fishways can vary both in the seasonal and in the diurnal aspect [6, 7]. For the successful exploitation of fish passages, it is proposed [4] to evaluate

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various environmental parameters: quantitative descriptions of flow velocity, turbulence and other hydraulic indicators, as well as take into account swimming possibilities, morphology, and other characteristics of migratory fish species [1]. In this regard, it is necessary [8, 9]: to combine studies of the behavioral characteristics of fish and hydraulic flow indicators when determining the characteristics of a fish passage, and also use software for hydrodynamic modeling. It is worth noting [10] that the majority of fish passage structures turned out to be difficult to overcome for fish not belonging to the Salmonidae family, since [3, 11–13] the majority of fish passage structures are oriented to commercially important species, and these are usually fish from the Salmonidae. Currently, more and more emphasis is placed on the possibility of designing and creating fish passage structures for a wider range of species and sizes of fish migrating both upstream and downstream [1, 14], for example, [1], simultaneous use of fish passage facilities for bottom and pelagic fish species. It is worth noting [15] that studies of diurnal activity in fish under laboratory and environmental conditions for the same species may show oppositely different results. In this regard, the aim of the work was to determine the preferred biotopes during the migration period for fish of the Cyprinidae family, taking into account their size characteristics and the influence of abiotic factors - depth, speed and temperature of the water.

2 Material and methods

The studies were carried out using mobile and stationary hydroacoustic computerized complexes (LLC Promhydroacoustics, Russian Federation) on the mouth section of the Konda River located at coordinates 60.7052 ° N.L. and 69.6688 ° E.L. (Fig. 1), during the period from 17 to 18 hours on days 9 May, 10 May, 13 May, 15-20 May (2017).



Fig. 1. Satellite image of the investigated section of the Konda River (arrows indicate the direction of the river flow).

The study carried out a period of mass migration of fish to the flooded floodplain of the Konda River, which is a first-order tributary of the large transboundary Irtysh River (Western Siberia, Russian Federation) and an important component of the Ob-Irtysh basin. To assess the number and size composition of migratory fish in the Konda River used the «NetCor» complex (455 kHz), to study the taxonomic structure and proportion of cyprinids, the «AsCor» complex (50 kHz) was use from the side of a boat. Postprocessing of data

obtained using the «AsCor» complex provides for the possibility of taxonomic identification of recorded fish based on the shape of the swimming bladder [16]. The flow rate was measured by a river spinner; the depth was determined by the sonar data. For the study, three longitudinal sections of the riverbed with varying depth and velocity characteristics of the stream were selected: No.1 - depth 5 m, velocity $27.8 \text{ cm}\cdot\text{s}^{-1}$, No.2 - depth 8 m and velocity $44.4 \text{ cm}\cdot\text{s}^{-1}$, No.3 - depth 11 m and velocity $55.6 \text{ cm}\cdot\text{s}^{-1}$ (Fig.2).

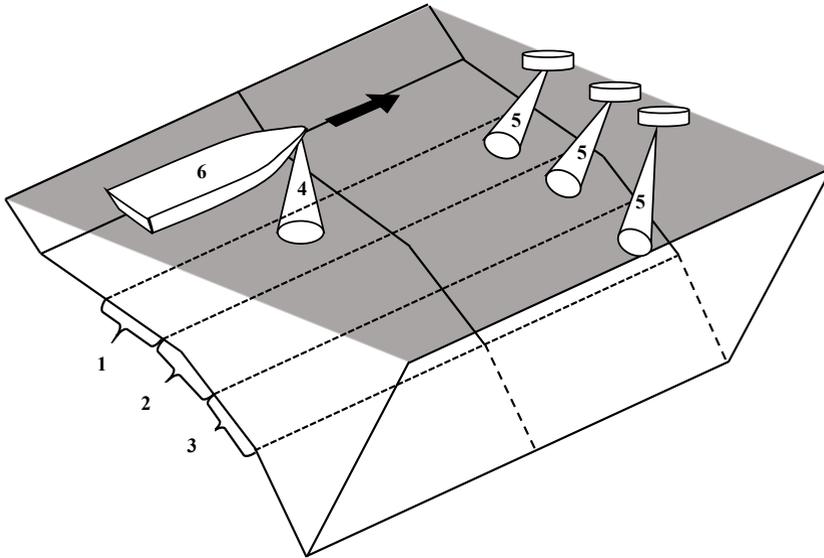


Fig. 2. The scheme of hydroacoustic surveys on the riverbed of Konda River: 1 – Section of river No. 1; 2 – Section of river No. 2; 3 – Section of river No. 3; 4 – Acoustic beam of the AsCor mobile complex; 5 – Acoustic beams of the stationary complex NetCor; 6 – Boat (the arrow shows the direction of movement of the boat and the course of the river).

A correlation was also calculated between the proportion of cyprinids in river sections and the values of water temperature and water level. The correlation value was evaluated on the following scale: weak (0.1–0.3), moderate (0.3–0.5), noticeable (0.5–0.7), high (0.7–0.9) very high (0.9–1). To assess the species composition of the fish population, control fishing was performed using stationary control gill nets with mesh from 12 to 100 mm.

3 Results

According to the results of control fishing, it was found that the cyprinid family in this section of the river is represented by 6 species from 4 genera: roach (*Rutilus rutilus* Linnaeus, 1758); ide (*Leuciscus idus* Linnaeus, 1758); dace (*Leuciscus leuciscus* Linnaeus, 1758); bream (*Abramis brama* Linnaeus, 1758); crucian carp (*Carassius carassius* Linnaeus, 1758); silver crucian carp (*Carrassius auratus* Linnaeus, 1758). The dominant species in descending order is crucian carp, roach, dace, ide, and bream. The share of roach, dace and crucian carp in the fishing catches decreases in the direction from the bank to the midstream, for the ide and bream; on the contrary, it increases. During the study period, the number of fish recorded in river sections No. 1, 2 and 3 amounted to 1215, 796 and 390 individuals of fish accordingly. In this case, the average velocity in the studied sections of the river in the direction from the bank to the midstream was 0.28, 0.44 and $0.56 \text{ m}\cdot\text{s}^{-1}$. As a result of the ANOVA analysis of variance, a significant difference was found in indicator of the proportion of cyprinids in the structure of migratory fish in river sections ($F =$

12.906, $p < 0.001$). Further, a statistical analysis of the distribution of cyprinids in the structure of the migratory fish population revealed a significant difference when comparing sections No. 1 and No. 2 ($p = 0.018$), No. 1 and No. 3 ($p < 0.001$), comparing the proportion of cyprinids in sections No. 2 and No. 3 did not reveal a significant difference. The average proportion of cyprinids in the structure of migratory fish displayed in Fig. 3.

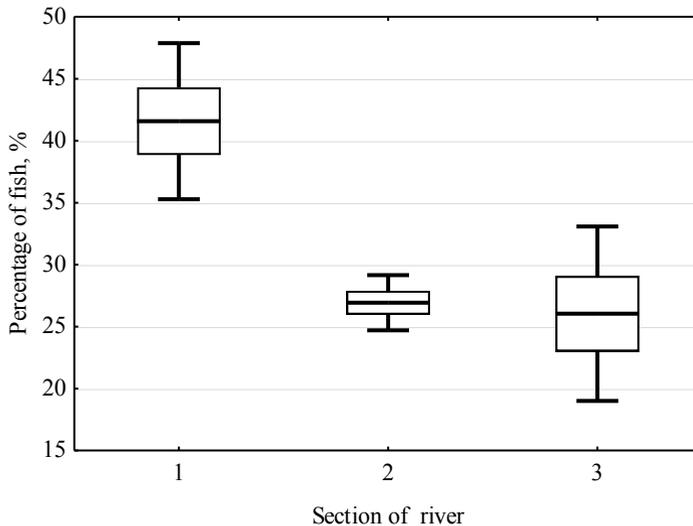


Fig. 3. The average value of the proportion of cyprinids in river sections (line - average value, boxing confidence interval at $P < 0.05$, whiskers - min-max range).

On section No. 1, the considered indicator averaged 41.78% with a range of minimum and maximum values from 26.67 and 50%, respectively. In section No. 2 and No. 3, the average proportion of cyprinids was 31.87 and 24.26% with a range of 29.98 and 37% in section No. 2 and 10.71 and 39.67% in section No. 3.

It should be noted that with an increasing indicator of the level and temperature of the water, a trend is also observed in the increase in the proportion of cyprinids in the considered sections of the river (Fig. 4). In the area with the lowest depth-velocity characteristics, the proportion of cyprinids reaches 50% of the total number of migrants by the end of the observation period in this section. In section No. 2, the proportion of cyprinids increases to a lesser extent, in section No. 3 with the highest depth-velocity characteristics, a more noticeable increase in the proportion of cyprinids (from 16.61 to 25.72%) is observed, in contrast to section No. 2 (from 31.57 to 31.42%). At the same time, the water level during the observation period increased by the amount of 1,052 m, and the water temperature reached 10.10 °C, i.e. increased from the initial value by 4.90 °C. After a short increase in water temperature, a slight decrease by the amount of 0.60 °C was noted (from 7.90 to 7.30 °C) in the period 13-15 May, and there was a decrease in the proportion of cyprinids in the considered river sections from 1.1 to 1.83 times in sections No. 3 and 1, respectively (Fig. 4).

In addition to the dynamics of the proportion of cyprinids among the fish population, changes were also observed in the dimensional structure of migrating fish of the studied family: at the initial stage (May 9 and 10), the percentage of fish with smaller body sizes dominated in percentage terms in the near-bank section of the river - No. 1. The proportion of groups of individuals with body sizes of 5-10, 10-15 cm was 38.89-56.25%, in sections No.2 and No.3 it was 16.67-35 and 33.33-45.16%, respectively (Fig.5).

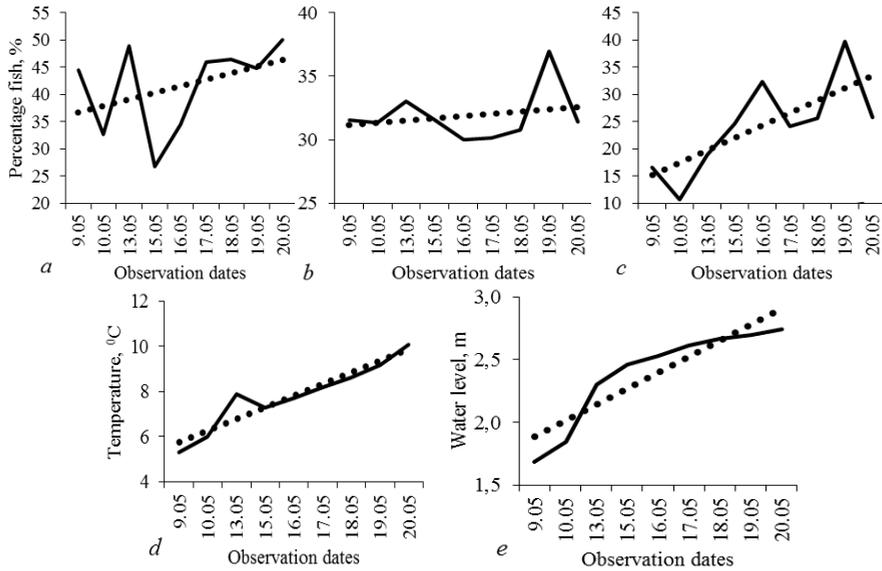


Fig. 4. The dynamics of the proportion of cyprinids in the studied sections of the river and the change in temperature and water level: *a* – Section of river No. 1; *b* – Section of river No. 2; *c* – Section of river No. 3; *d* – Temperature of water; *e* – Level of water (solid line - indicator; dotted line - trend).

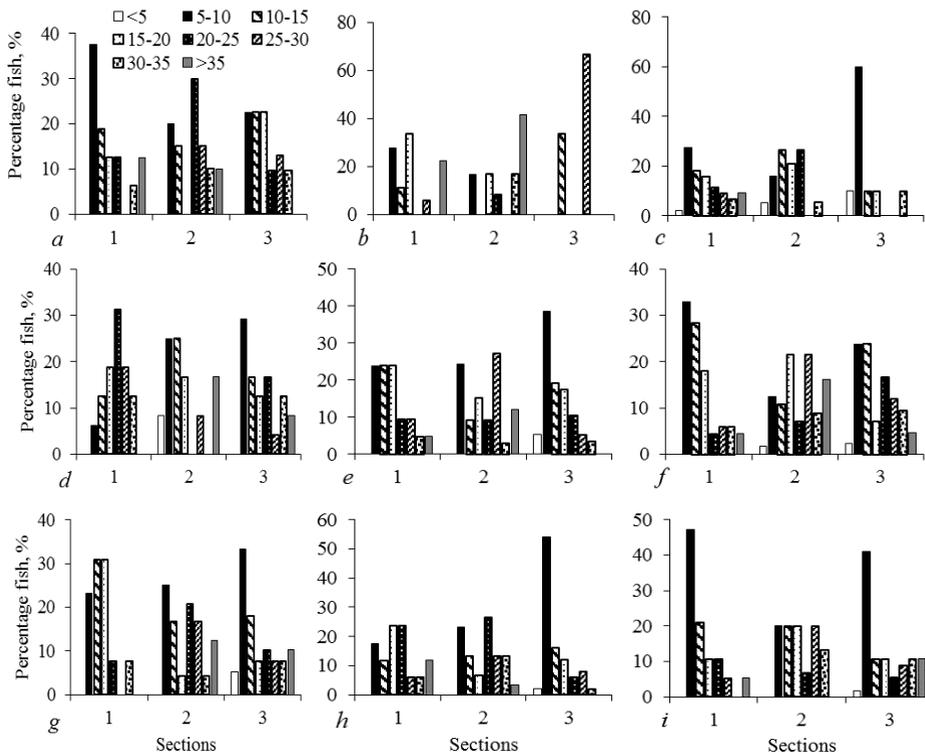


Fig. 5. Dynamics of the dimensional structure of migratory fish (Cyprinidae) on the river sections (column-sized groups): *a* – 9 May; *b* – 10 May; *c* – 13 May; *d* – 15 May; *e* – 16 May; *f* – 17 May; *g* – 18 May; *h* – 19 May; *i* – 20 May.

However, with a further increase in water temperature above 6 °C, their significant proportions were also noted in river sections No.2 and 3 to 50 and 70%, respectively. The smallest individuals with body sizes <5 cm were also recorded in these sections; their shares reached 5.26 and 10% of the total number of fish recorded in relevant sections of the river (Fig.5). The general pattern of distribution of fish of the studied family consisted in the numerical dominance of recorded fish in section No. 1, percentage of smaller fish (<15 cm) dominated in section No. 1, and larger fish (> 15 cm) in sections No. 2 and 3.

As a result of the statistical analysis, a significant high direct correlation was established between the water temperature and the proportion of cyprinids in sections No. 1 and No. 3 (0.73 and 0.70, $P < 0.05$); also relationship was note between the water level indicator and the proportion of cyprinids fish in the section No. 3 (0.82, $P < 0.01$). A very high direct correlation was established between the temperature and water level (0.95, $P < 0.001$) (Table).

Table 1. Analysis of the presence of Spearman's correlation between the proportion of cyprinids in river sections with indicators of temperature and water level*.

No.	Indicators	Indicators				
		WL	WT	S1	S2	S3
1	WL	1.00	0.95***	0.53	-0.07	0.82**
2	WT		1.00	0.73*	0.07	0.70*
3	S1			1.00	0.07	0.20
4	S2				1.00	0.00
5	S3					1.00

Note: WL – water level; WT – temperature of water; S1, S2, S3 – sections of river; * – correlation is significant at $P < 0.05$; ** – correlation is significant at $P < 0.01$; *** correlation is significant at $P < 0.001$.

4 Discussion

Researchers [17–20], when studying swimming characteristics in several species from the family of Cyprinidae, noted significant differences between individuals of different sizes and species; with increasing age and size of the fish's body, the swimming characteristics of the individual also increase, while it was established [21] that the water flow velocity and substrate are the main factors affecting the choice of biotope, while the first of them is considered the most significant. This pattern explains the distribution of a larger percentage of large fish from the family Cyprinidae at a high-velocity section of the watercourse - No. 3, as well as the increase and numerical dominance of fish of the studied family in river sections with lower depth-velocity characteristics - No. 1 and 2.

In addition to this, it is known [22, 23] that juveniles and small individuals of cyprinids in a stream with flow velocity exceeding their swimming characteristics in the presence of a choice of different speed sections actively use low-speed parts of the stream located along the bottom and bank.

However, sometimes a higher intensity of turbulence in low-speed sections of the watercourse can affect the endurance of fish and displace them from these sections [24], due to [25, 26] the instability of the position of the body of fish and increasing energy costs. It is worth noting [27, 28] that for certain turbulence indicators (periodicity, directivity, etc.), swimming characteristics can improve, and obstacles, for example, in the form of irregularities located at the bottom of the stream, also contribute to reducing the cost of activity of fish individuals compared with the free flow [29].

However, regions of low flow velocity with high turbulence indices cannot fully neutralize the negative effects of a higher flow velocity [26]. With a significant excess of the flow velocity, fish individuals switch from swimming to holding their position in the stream [23], as a result, [11] small individuals of cyprinids may not be able to overcome fish passage facilities. A factor affecting the distribution in the flow of migratory individuals of the Cyprinidae family and their proportion in the structure of the fish population is also water temperature [23, 30] and body morphology [30], which determine the physiological limit of swimming of an individual [30], for example comparing the swimming characteristics of several species of the cyprinids at different temperatures, a significant difference in the studied parameters between the species and in one species at different swimming temperatures. Similarly, in our studies, it showed that with an increase in water temperature in all studied sections of the river, the proportion of cyprinids increases that is, their physiological capabilities increase [23, 30]; as a result, smaller individuals of cyprinids are recorded in high velocity sections of the river. Then by lowering the water temperature from 7.9 to 7.30 °C, a limiting effect of the temperature factor is observe - there is a decrease in the proportion of cyprinids in all sections of the watercourse. The improvement in swimming characteristics at higher temperatures is due to a combination of physiological, biochemical, and physical changes in the fish organism [30], that is, an increase in the water temperature to a certain limit contributes to an increase in the fish organism's capabilities, which in turn affects its abundance in the stream, which is also observed in our study: the proportion of cyprinids in sections No. 1 and No. 3 has a high direct correlation with water temperature. A similar pattern was observed in the study of both cyprinids and percids [31]; in the spring-summer period, their migration upstream of the watercourse correlated with the water temperature. Thus, the spatial variability of the characteristics of the watercourse forms its heterogeneity, which in turn allows species to choose habitats for balanced energy costs, as shown by the carp *Cyprinus carpio* [32], that even large individuals during the movement in the watercourse need rest. The higher the flow rate, the longer rest time is required for fish individuals, especially the smallest ones [32]. Our study also confirms the numerical dominance of cyprinids in stream sections located closer to the bank zone of the river during their spawning migration; other researchers [13] also noted this pattern. Thus, the design of fish passage facilities should be designed taking into account the physiological state of the target species and the predominant season of operation of the structures for the passage of fish on regulated streams [33].

5 Conclusion

As a result, of the research work performed on the obtained supplementary data distribution in the flow migratory fishes of the family Cyprinidae in natural environment (in situ), reflecting their high relevance. The data often obtained in an experiment under laboratory conditions have some assumptions and limitations, which may make it difficult or impossible to use experimental data in natural conditions. The distribution of fish of various sizes is determined by the physiological capabilities of individuals, which in turn depend on the age of the fish, its body length, and ambient temperature. Our study shows the numerical dominance of cyprinids in the river section closest to the bank, where the minimum flow speed are noted, and an increase in the proportion of cyprinids in the structure of the fish population correlates with the temperature factor. In addition, with an increase in temperature, an increase in the proportion of small fish with body sizes <15 cm was observed in all sections of the river, including high-speed sections, which in turn indicates an increase in the physiological capabilities of this group of fish at higher water temperatures. Thus, when designing fish passage facilities, it is necessary to take into

account not only the size, morphology and species of fish for which these structures are intended, but also the dynamics of environmental indicators, which can both reduce and increase the physiological capabilities of the fish organism.

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