

Article

Insights into Daily Dynamics of Fish Migration during Spring in the Konda River

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Abstract: Hydrology and temperature are known as key drivers for fish migration in floodplain-channel systems of large rivers. The Lower Irtysh contains valuable species of whitefish and sturgeon. Thus, along the Konda River, a complex study was carried out in order to investigate fish migration in spring, with a focus on daily and monthly dynamics. To estimate the number of fish passing up- and downstream, a hydroacoustic system with a scanning beam frequency of 455 kHz was deployed in May 2017. The survey revealed the presence of three peaks in migration activity, as well as differences between a location close to the shore and another in the main channel. Regression analysis revealed a high degree of reliability of the influence of water temperature on the number of migrating fish ($p < 0.001$). The dataset also showed a daily rhythm of fish migration. An analysis of the daily variation in the illumination index and the intensity of fish migration revealed the presence of noticeable and high correlations for upstream ($RS = 0.55$; $p < 0.05$) and downstream migration ($RS = 0.71$; $p < 0.001$), respectively. Our data underline the importance of temperature as a trigger for fish migration and reveal diurnal patterns related to illumination.

Keywords: fish migration; hydroacoustic survey; water temperature; illumination; floodplain



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1. Introduction

Floodplain-channel complexes (rivers and associated floodplains) are one of the most variable and diverse ecosystems on Earth [1,2]. In such systems, the dynamics are determined by seasonal fluctuations of water temperature and discharge (water level), affecting the structure of the fish communities. Intact floodplain-channel complexes are characterized by a dynamic hydrological situation and diverse geomorphology, resulting in the formation of a wide range of habitats that support high biodiversity and fish productivity [3]. Thus, floodplains of large rivers are considered key habitats for many species of riverine fish, e.g., pike *Esox lucius*, roach *Rutilus rutilus*, and ide *Leuciscus idus*, etc. [4].

Understanding the response of fish to changes in the hydrological characteristics of habitats is important [5] because they live in highly variable environments. Here, the ability to perceive environmental signals and respond to them by moving to favorable habitats provides certain evolutionary advantages [6]. Furthermore, the habitat preferences of certain fish species are important, as this can help to develop appropriate measures for the conservation and protection of various fish species [7]. Overall, fish behavior associated with migrations in floodplain-channel ecosystems is one of the most poorly studied mechanisms of distribution of freshwater organisms in the temperate zone [8,9].

The hydrological and temperature regimes are known as key drivers for fish migration in floodplain-channel systems of large rivers and their tributaries [10–14]. However, there is a lack of information about the influence of these factors on the migration of fish into the floodplains of large rivers [3], with the exception of the well-studied family, Salmonidae [11].

Thus, the analysis of the distribution and dynamics of fish in the tributaries of the floodplain-channel system is an important but often neglected area of ichthyological research [15,16].

The Ob-Irtysh basin is located in Western Siberia and belongs to the Arctic Ocean basin [17]. The Ob River, as well as its largest tributary, Irtysh, holds significant biological resources [18]. The Lower Irtysh contains valuable species of whitefish—nelma (*Stenodus leucichthys nelma*), peled (*Coregonus peled*), muksun (*Coregonus muksun*). In addition, sturgeon live here—sterlet (*Acipenser ruthenus*), as well as the Siberian sturgeon (*Acipenser baerii*), which is a protected species and is included in the *Red Book of the Russian Federation* with the status of “endangered species” [19].

The Lower Irtysh basin also has specific hydrographic, hydrochemical, and climatic features: (a) The channel is located in a drainage area dominated by marsh-fed tributaries, where the physico-chemical conditions are determined by mires, i.e., humic acids, iron, and manganese compounds. The basis of the soil-forming rocks is eluvial–deluvial sediments of the quaternary period. The banks of the Irtysh River are characterized by erodibility; thus, numerous channels and oxbow lakes are formed, mainly on the flat left bank. The right bank of the Irtysh River is high and sometimes steep [20]. (b) Another equally important feature is the significant duration of freeze-up (up to 6 months). As a result of a long-term lack of aeration and a complete transition to feeding by tributaries from the marsh drainage area, “fish kills due to dissolved oxygen depletion” are common in the Irtysh basin [21]. In winter, fish concentrate in such pits [22], and in spring, they rise to feed and spawn in the floodplain along tributaries, including the Konda River.

In order to analyze fish migration in rivers, manifold systems are in use, such as acoustic and radio telemetry [23,24], PIT tagging [25,26], and hydroacoustics [27,28]. Hydroacoustic systems offer a suitable tool for monitoring fish migration in rivers (e.g., [29–34]) and lakes (e.g., [35–40]), as well as for analyses of fish behavior in the vicinity of hydropower plants (e.g., [41–44]).

In order to analyze fish migration in the Lower Irtysh basin of the Konda River, hydroacoustic monitoring is carried out regularly. Previous publications have considered the distribution [45,46] and the effects of water temperature [47]. In contrast, here, we aim to provide a holistic view of fish migration in the Konda River in spring, with a focus on daily and monthly dynamics.

2. Materials and Methods

2.1. Research Area

Konda River, which originates from the mires and swamps of the North Sosvinskaya Upland and flows through the Kondinskaya Lowland, is a 1097 km long left tributary of the Irtysh River (86 km from the mouth). The catchment area is 72,800 km², the share of mires amounts to 70%, and about 5% are lakes [48,49]. The Konda floodplain is mainly developed along the left bank, where most of the small tributaries and lakes are located. The right bank is high and steep [49]. However, the river valley close to the river is poorly expressed; thus, during periods of flood, the floodplains are almost completely flooded, especially on the left bank [49]. Upstream of the mouth of Konda into Irtysh, a large lake (“Kondinsky Sor”) has formed in the Konda valley. Its length is more than 50 km, the width is 5–10 km, and the water surface is more than 143 km²; thus, it represents an important spawning ground where the recruitment of fish also takes place [47].

This study was carried out immediately after the period of ice drift at the mouth of the Konda River (0–1 km from the mouth, 60°42.145' N, 69°39.872' E), which is located on the territory of the Khanty-Mansiysk autonomous area (Tyumen Region) (Figure 1). During fieldwork, the depth was more than 14 m, and the width of the channel exceeded 500 m.

The Konda channel is winding, its width in the lower reaches is 150–300 m, and its depth is more than 5 m. Current speeds range from 0.16–0.5 m/s to 0.6–0.8 m/s on riffles [20]. The water regime is characterized by spring–summer floods, as well as higher flows in late summer and autumn. The flood begins in the first ten days of April, peaking in the second half of May–early June. The mean discharge ranges from 84.9 m³/s (Chantyr'ya

village) in the upper reaches to 340.8 m³/s (Vykatnoy village) in the lower reaches (for the period 1962–2016) [50]. The annual flow near the mouth reaches 11 km³, and the average water flow is 250 m³/s, while 2/3 of the total volume flows during the flood period.

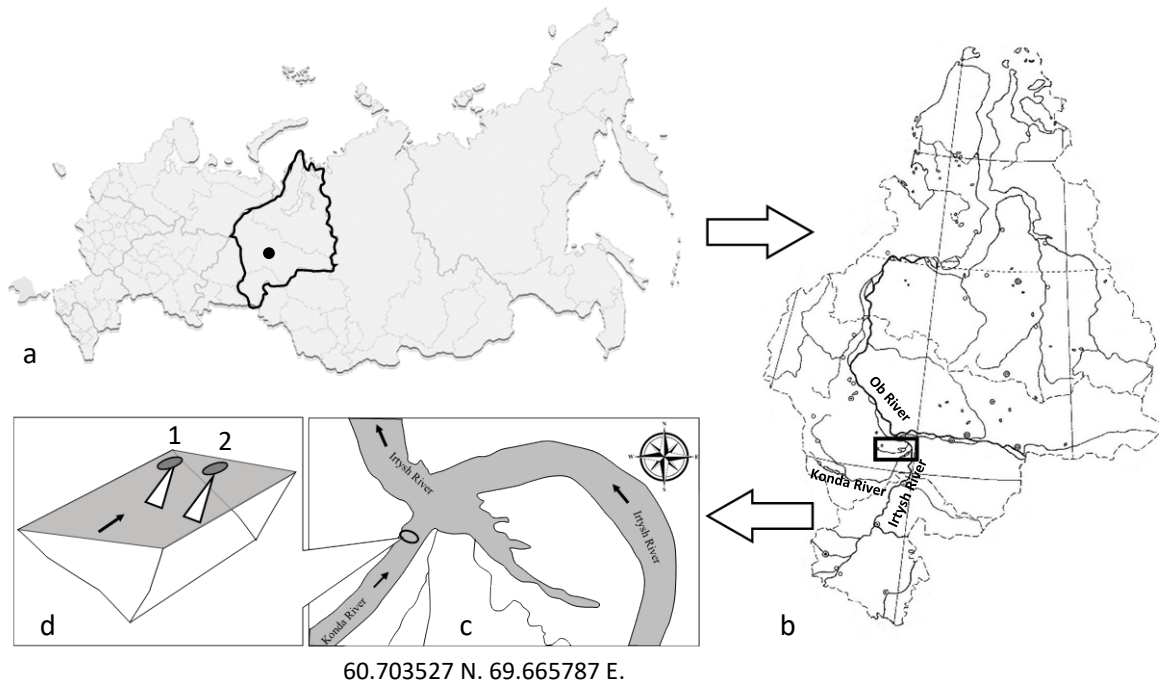


Figure 1. Research area: (a) Russian Federation, (b) Tyumen region, (c) mouth of the Konda River (research area), (d) schematic sketch of the hydroacoustic systems with scanning beams into the river (arrows in the figures indicate flow directions): 1—near bank, 2—main channel.

The studied area of the Khanty-Mansiysk Autonomous Okrug is characterized by mild winters and warm summers [49]. The average temperature in January is -20°C , and the duration of persistent frost is less than 150 days. There is a low depth of snow cover (less than 40 cm), with a stable occurrence of up to 180 days. Between April and October, the average temperature is positive. The average air temperature in July is more than $+17^{\circ}\text{C}$. The mean annual precipitation in the Konda River basin per year is 500 mm, and evaporation from the surface is 425–450 mm per year, i.e., precipitation predominates over evaporation.

2.2. Field Work

To estimate the number of fish passing up- and downstream the river, the NetCor computer-aided hydroacoustic system (referred to as NetCor complex) manufactured by LLC Promgidroakustika (Petrozavodsk, Russia) was used (External supplementary material S1). The modules were installed on floating platforms (dimensions: length—1.4 m, width—0.75 m, height—0.25 m; Figure 2) with a scanning beam frequency of 455 kHz. The platform bodies, manufactured by LLC Promgidroakustika, are made of fiberglass with a polyester coating. The platforms in the river alignment were fixed with anchor devices located upstream and downstream “in tension”. Data from the scanning stations (platforms) were transmitted via radio to a coastal control-and-measuring computerized station (“master” module). To ensure the accuracy and reliability of measurements, the NetCor complex was calibrated with a reference copper sphere ($D = 45\text{ mm}$, $TS = -39\text{ dB}$) before starting the research. When processing hydroacoustic surveys, the body length of the fish was calculated using the equation used for the abundant fish of the Lower Irtysh [50].

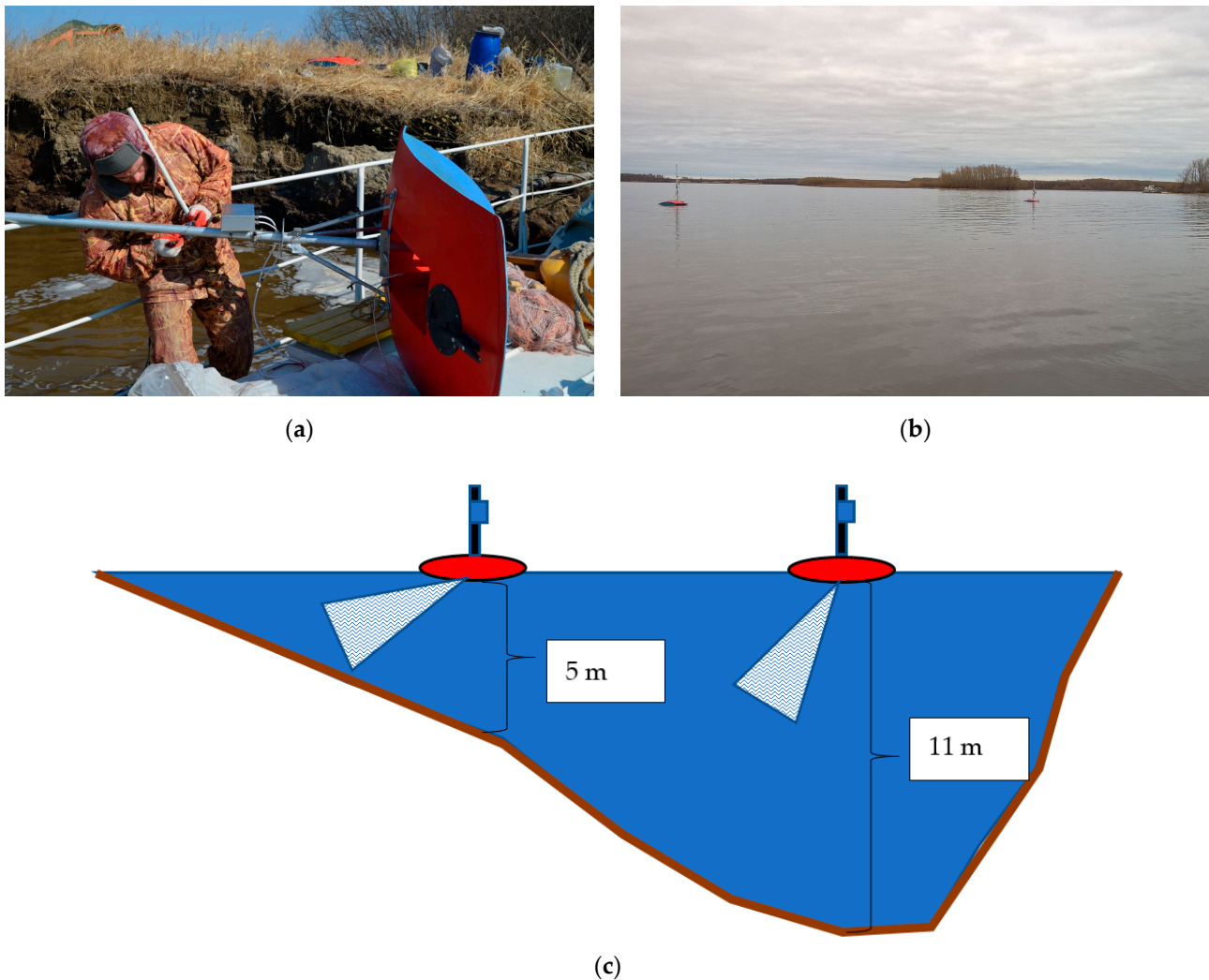


Figure 2. (a) Assembly of complexes, (b) floating platforms with hydroacoustic units, and (c) schematic cross-section of the river, the installed platforms, and the corresponding beams (angle 10° and 10 m length).

In the period 1–27 May 2017, the floating platforms were installed in sections of the riverbed with different depth–velocity characteristics: “near bank”—depth 5 m, current speed 0.279 m/s, and “main channel”—depth 11 m, current speed 0.556 m/s (Figure 3a). The total operating time for each platform was 648 h (Supplementary Material Table S1). The current speed was measured with a hydrometric river flowmeter ISP-1M manufactured by ZAO Prompribor (Kaluga, Russia). The area of the controlled live flow cross-section by each slave module was $\approx 8.75 \text{ m}^2$, i.e., a beam with an angle of 10° and 10 m length. The location and installation of the platforms are shown in Figures 1 and 2. A water level gauge was installed at the mouth of river Konda, and the water level (in cm) was measured once a day. Additionally, the water temperature at the mouth of the Konda River was measured using a submersible probe of the multi-parameter water quality assessment system, Horiba-22U (Horiba Inc., Japan, Kyoto). Illumination was determined every hour using a portable photoelectric luxmeter, Yu116. This lux meter is designed to measure illumination, including that created by natural light. Measurements were carried out over 3 days: at the beginning, middle, and end of the research period.

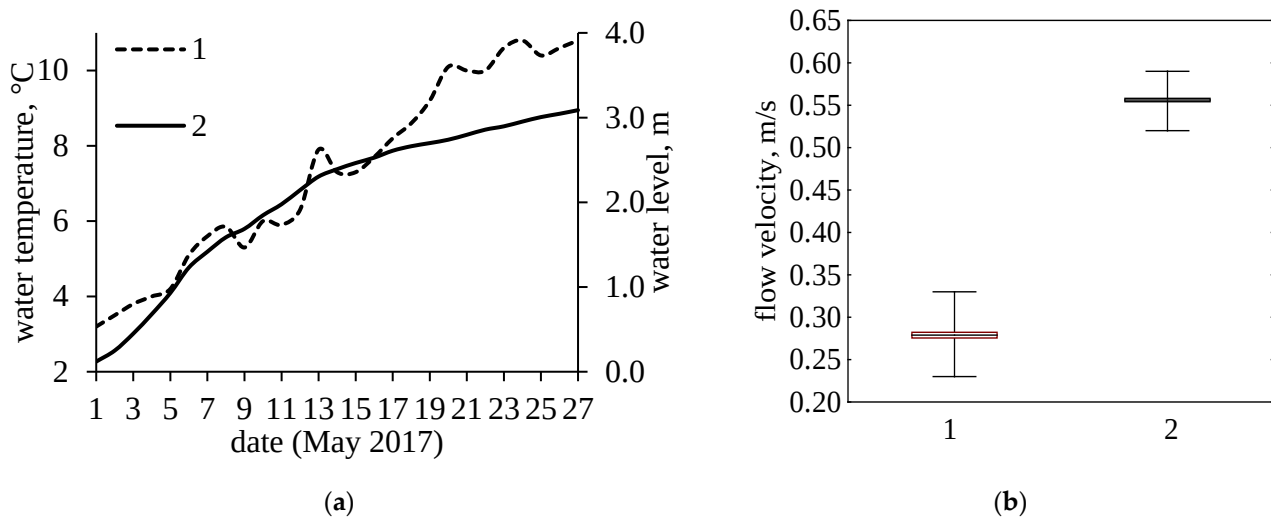


Figure 3. (a) Dynamics of water level and temperature in the Konda River in May 2017 (1—water level, 2—temperature), and (b) average current speed for the observation period (1–27 May) in different sections of the watercourse: 1—near bank; 2—main channel (line—average value, box—confidence interval (at $p < 0.05$), whiskers—min–max range).

2.3. Analyses

The data from the hydroacoustic systems were processed in the laboratory using the software “NetCor” (Unimus 2.1.0). Statistical data processing was performed in Statistica 10.0 (StatSoft Inc., Tulsa, OK, USA). The Spearman correlation (RS) was assessed using 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).

The significance of differences between the average daily indicators of the number of migrating fish by decade and channel section, as well as between the average indicators of water flow velocity, was assessed using Tukey’s test (ANOVA analysis). To assess the influence of temperature and water level on the number of migrant fish, we used multiple regression analysis.

3. Results

The survey in May 2017 revealed the presence of three peaks in migration activity, i.e., 1.05–10.05, 11.05–20.05, and 21.05–27.05 (Figure 4a). These peaks are most pronounced at the station close to the shore (“near bank”); the maximum number of recorded fish per day during these periods was 8635, 9412, and 5999 specimens/day, and in the section in the main channel, 6049, 6338, and 1692 specimens/day. The average daily values ($M \pm SE$) of fish in the observation decades (I, II, III) “near bank” amounted to 5365 ± 752 , 6534 ± 749 , and 3323 ± 584 specimens/day, and in the main channel, 3490 ± 382 , 4076 ± 481 , and 1477 ± 90 specimens/day, respectively. The differences in the average daily number of recorded fish in these areas reflect the high dynamics of the process of the spring fish migration under consideration. The significance of the difference was established for the near-bank data based on observation decades II and III ($p = 0.029$) and, for the main channel, based on observation decades I and III ($p = 0.011$), as well as decades II and III ($p = 0.001$).

With a comparable value of the controlled river cross-section of 8.75 m^2 , the number of recorded fish close to the bank compared to the main channel was 1.54–2.25 times higher (Figure 3b, Video S1). A statistical analysis based on Tukey’s criterion showed a significant difference in the average daily number of recorded fish in the low-velocity sections near the bank and the high-velocity sections in the main channel ($p < 0.001$). The difference in water temperature at the beginning and end of each corresponding decade was 6.0, 4.2, and $0.8 \text{ }^\circ\text{C}$, reaching final values of 6.0, 10.1, and $10.8 \text{ }^\circ\text{C}$. Regarding water levels, the difference

in the corresponding values over decades was 1.847, 0.762, and 0.291 m (Figure 3a). Flow velocity was significantly higher in the main channel (Figure 3b).

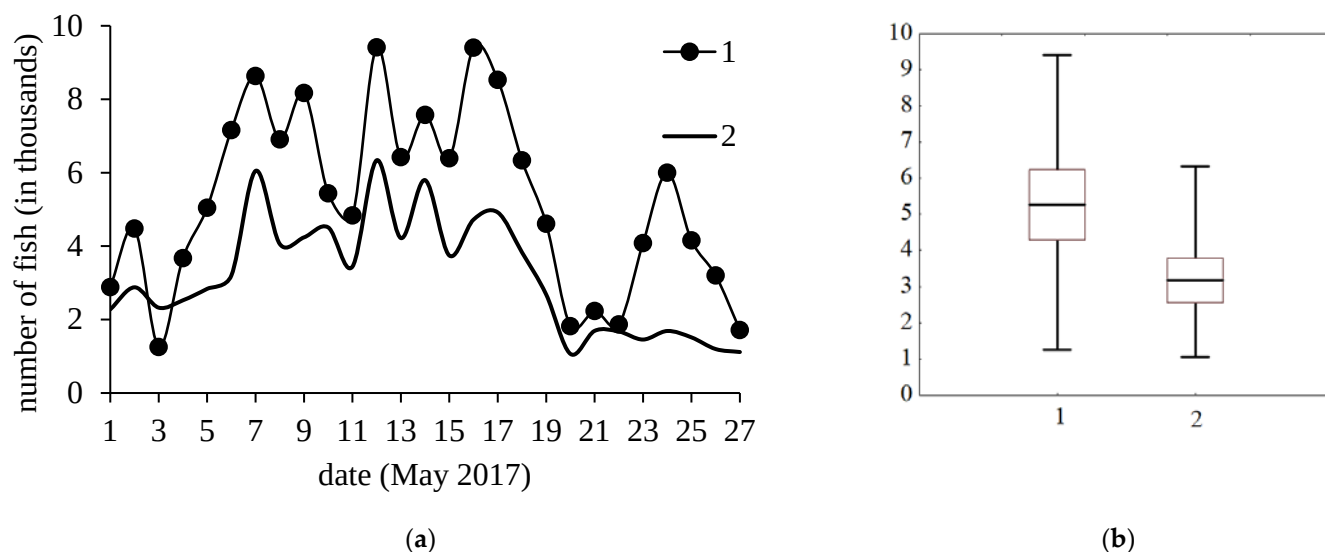


Figure 4. (a) Dynamics of the number of migrating fish in spring on the Konda River in May 2017 (1—“near bank”; 2—main channel), and (b) average daily number of migrating fish (in thousands) in different sections of the watercourse: 1—near bank; 2—main channel (line—average value, box—confidence interval (at $p < 0.05$), whiskers—min–max range).

The dependence of the intensity and, accordingly, the number of migrating fish during the spring seasonal migration on the factors of water level and temperature, both near the bank and in the main channel, is described by a polynomial trend line (Figure 5). Regression analysis revealed a high degree of reliability of the influence of water temperature on the number of migrating fish ($p < 0.001$). The water level factor was excluded from further analysis because it has multicollinearity with water temperature. The factor water temperature has a significant high influence, i.e., the influence of this factor on the number of migrating fish ranges from 0.561 (near bank) to 0.775 (main channel). Considering the total number of migrating fish, the influence of the water temperature is 0.678.

An analysis of the direction of fish migration revealed heterogeneity with upstream and downstream movements, although fish individuals migrating to the floodplain complex of the river (upstream) still dominated numerically. The average share of upstream migrating fish near the bank was 62.14% of the total number of registered fish, and in the main channel, a similar share of 61.64% was observed. During the observation period, there was a slight change in the ratio of fish migrating downstream and upstream (Figure 6).

The dataset also revealed a daily rhythm of fish migration both up- and downstream. The daily variation in the intensity of fish migration has similar peaks and declines, both near the bank and in the main channel (Figure 7).

The minimum values of the intensity of fish migration in all sections of the watercourse were noted in the twilight–night period (11:00 p.m.); their values were 102.45 and 56.67 specimens/h when fish migrated upstream and 54.61 and 29.67 specimens/h downstream near bank and in the main channel, respectively. Near the bank from 00:00 a.m. until the morning twilight at 5:30 a.m., an increase in migration intensity was observed, reaching maximum values in the morning between 8.00 and 9:00 a.m., with 172.27 specimens/h upstream and 103.08 specimens/h downstream, respectively. In the main channel, both upstream and downstream, the maximum values of the intensity of fish migration were observed during morning twilight, i.e., 120.66 specimens/hour upstream and 70.07 specimens/hour downstream (the recording period of this indicator was 5:00 until 6:00 a.m. in both cases). After 10:00 a.m., a noticeable decrease in the intensity of fish migration appeared.

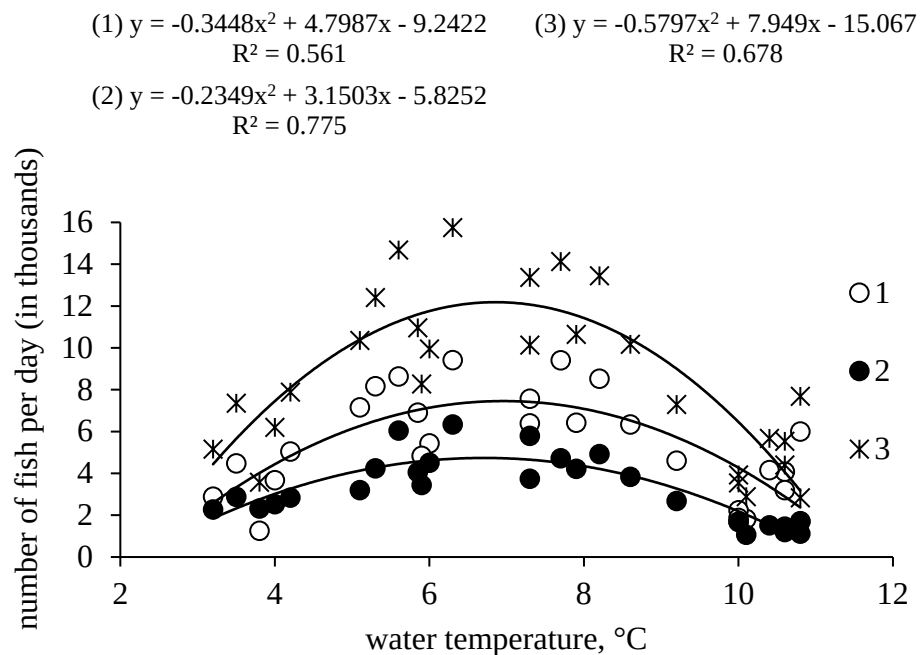


Figure 5. Dependence of the number of migrating fish on the water temperature: 1—near bank; 2—main channel; 3—entire watercourse (combined data).

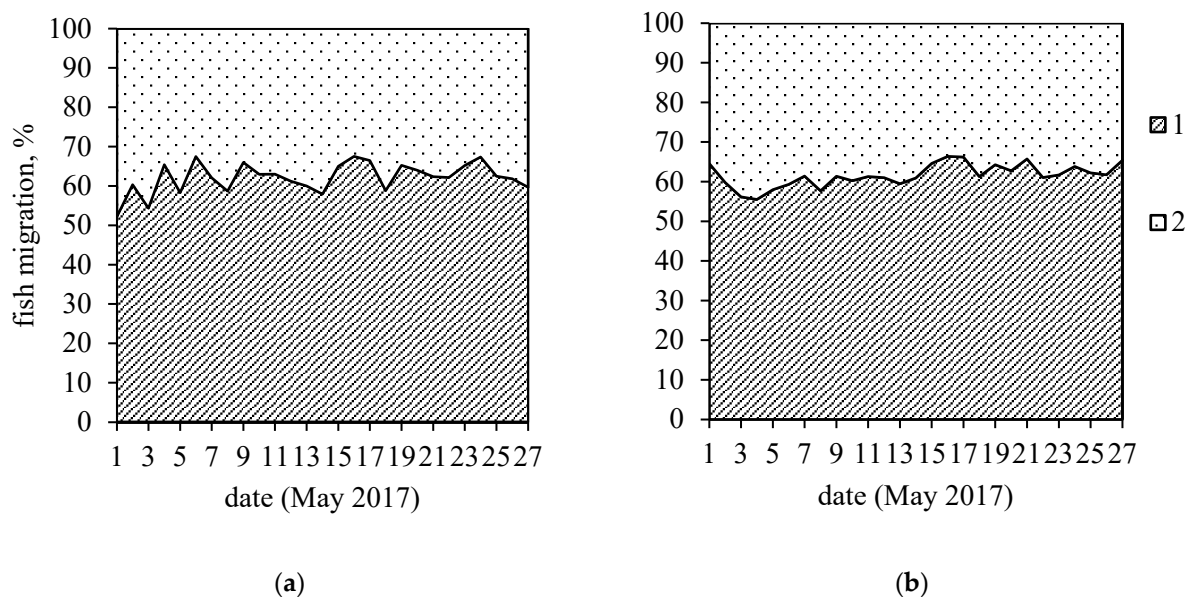


Figure 6. Dynamics of the proportion of fish migrating up- (1) and downstream (2) along the Konda River: (a) near bank, and (b) main channel.

The analysis of the daily movement of migrating fish revealed that most fish migrate during daylight, both upstream and downstream. Upstream migration during daylight near the bank was 65.72%, and in the main channel, it was 63.16%. Regarding downstream migration, similar percentages were observed, i.e., 68.07% near the bank and 66.1% in the main channel. A significant difference was established in the percentage distribution of the proportion of migrating fish on average per 1 h in the corresponding periods during daylight and twilight–night (Figure 8), both in the near-bank section ($p < 0.001$) and in the main channel ($p < 0.05$).

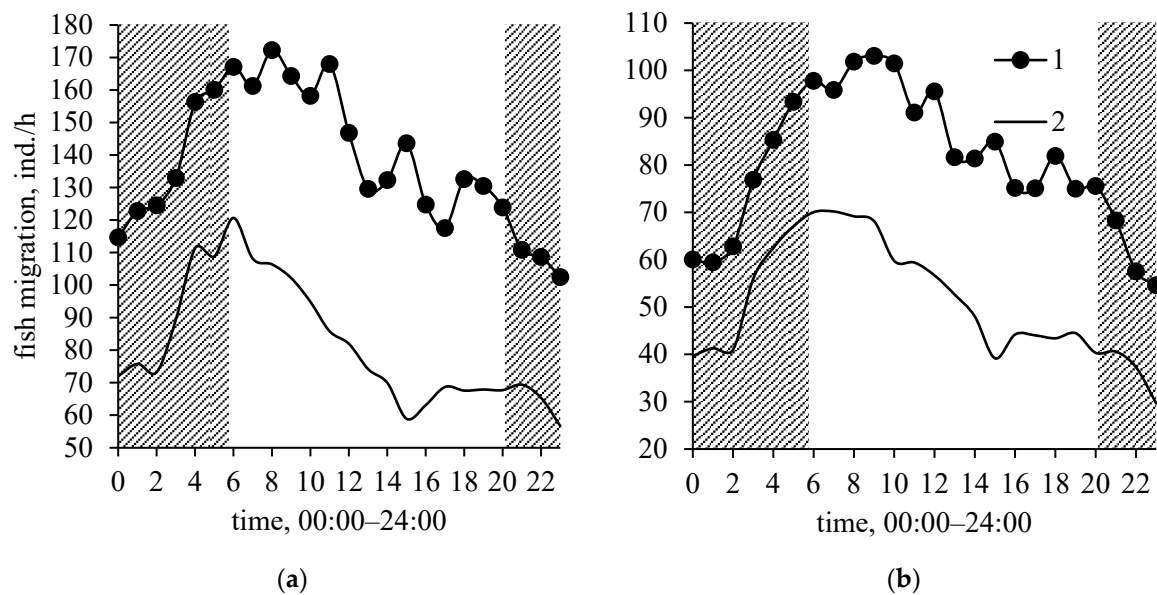


Figure 7. Daily variation in the intensity of fish migration upstream (a) and downstream (b) (shading shows the twilight–night period): 1—near bank; 2—main channel.

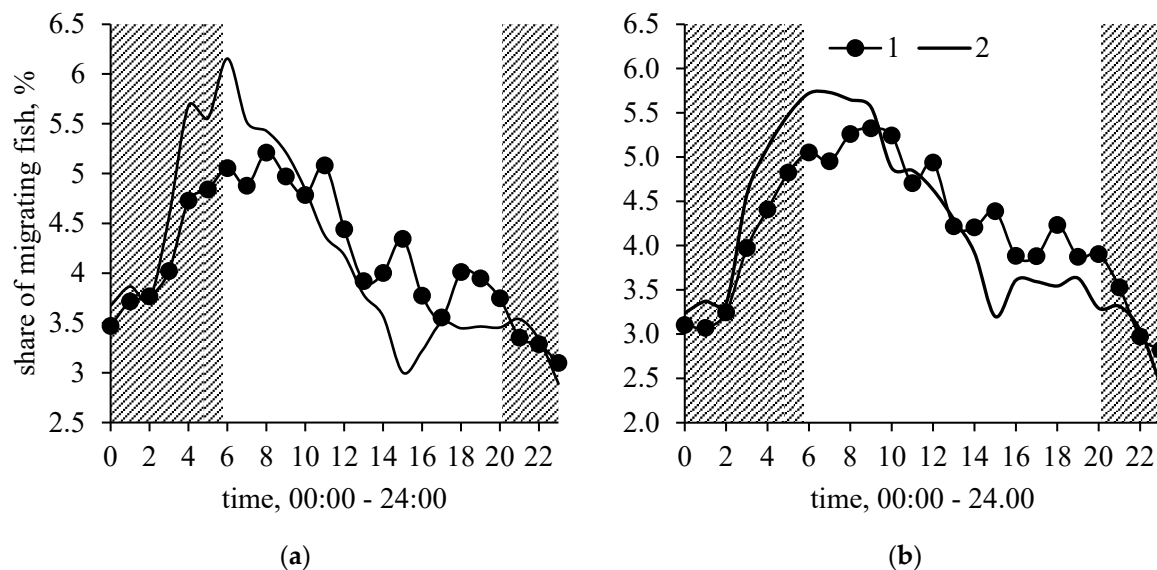


Figure 8. Percentage distribution of the daily variation in the intensity of fish migration upstream (a) and downstream (b) (shading shows the twilight–night period): 1—near bank, 2—main channel.

Further, a correlation analysis revealed a connection between the illumination indicator and the intensity of fish migration on a daily basis. A noticeable correlation was established near the bank during the upstream migration of fish ($RS = 0.63$; $p < 0.05$) and a high correlation for downstream migration ($RS = 0.73$; $p < 0.001$). In the main channel, a noticeable correlation was only established for the indicator of the intensity of fish migration downstream ($RS = 0.57$; $p < 0.05$). Further analysis of the daily variation in the illumination index and the intensity of fish migration in the entire watercourse revealed the presence of noticeable and high correlations for upstream ($RS = 0.55$; $p < 0.05$) and downstream migration ($RS = 0.71$; $p < 0.001$), respectively.

The intensification of the migratory activity of fish both upstream and downstream after the night period and lack of illumination (0 lux) is noted at 03:00 at a light level of 3 lux. Apparently, the intensity of fish migration in the daily aspect is determined by the diurnal variation in illumination, as the peak intensity of migration (6–9 h) precedes illumi-

nation values of 31×10^3 lux (9:00 a.m.), and during the period of maximum values, i.e., 65×10^3 – 69×10^3 lux (12:00–14:00 a.m.), the intensity of the migration decreases (Figure 9).

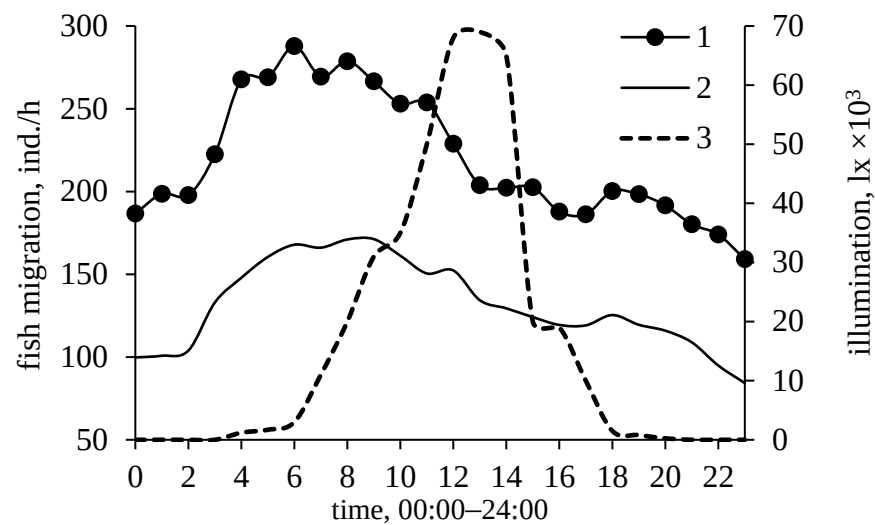


Figure 9. Daily variation in the total intensity of fish migration upstream (1), downstream (2), and illumination (3).

An analysis of the size structure of migrating fish in different parts of the watercourse revealed the following characteristics. Near the bank, the proportions of groups of upstream migrating fish with body sizes <5 (10.58%), 5–10 (14.8%), 10–15 (12.68%), and 20–25 cm (9.78%) prevailed over those from the main channel (6.51, 14.54, 12.53, and 9.2%). For fish of larger sizes, 30–35, 35–40, 40–45, and >50 cm, the opposite is true: more large fish were in the main channel than near the bank—7.97, 5.77, 4.56, and 16.74% versus 6.29, 5.13, 4.07, and 14.38%, respectively. For other size groups, the shares are comparable (Figure 10a).

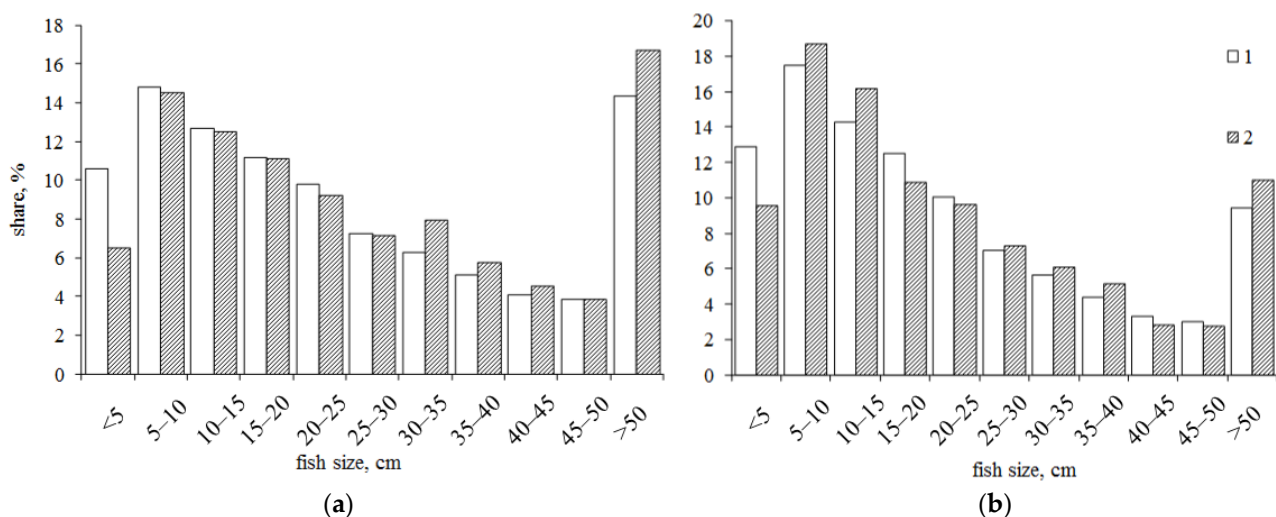


Figure 10. Percentage of the size ranges of fish migrating upstream (a) and downstream (b): 1—near bank; 2—main channel.

An analysis of the size structure of fish migrating downstream revealed a general trend of a decrease in the proportion of fish of larger sizes (40–45, 45–50, >50 cm) (Figure 10b) and an increase in the proportion of fish of smaller sizes (<5 , 5–10, 10–15 cm) compared to the size structure of fish migrating upstream. Among fish migrating downstream in the main channel, the proportion exceeded those of various size ranges of fish from the station “near bank”. This pattern was observed both for large individuals, with body sizes

of 25–30, 30–35, 35–40, and >50 cm, and for smaller fish of 5–10 and 10–15 cm. Their shares were 7.31, 6.11, 5.15, 11.02, 18.65, and 16.17% in the main channel, and near the bank, they were 7.04, 5.64, 4.41, 9.39, 17.48, and 14.3%, respectively. Near the bank, the fish size groups were <5 (12.9%), 15–20 (12.51%), 20–25 (10.02%), and 40–45 cm (3.32%) versus 9.55, 10.86, 9.63, and 2.81% in the main channel, respectively. Thus, this study shows that larger fish were migrating upstream during the spring migration in May 2017. In the main channel, larger fish were migrating up- and downstream, whereas smaller fish were migrating near the bank.

4. Discussion

The lower Irtysh River has a huge floodplain-channel complex, including a large number of wintering pits in the riverbed, which enables an analysis of patterns and triggers of fish migration. The Konda River was selected for a detailed analysis of fish ecology and migration using hydroacoustic systems. Here, an adaptive feature of the fish species in winter is their behavioral reaction, i.e., the concentration in special areas of the riverbed. Such areas are called “wintering pits” [50–52]. Such “wintering pits” are usually located at sharp turns of the river, where erosion processes occur and wash out the bottom of the riverbed. As a result, river sections with significant depths are formed, exceeding the average by two to four times and reaching values of more than 40 m. Favorable hydrodynamic conditions are created here—“spurs”, where fish individuals require significantly less energy and, accordingly, oxygen consumption to maintain body homeostasis [22]. Thus, the presence of fish in the water area of the wintering pit helps them survive the fish kills due to dissolved oxygen depletion.

In spring, the migration of sterlet and sturgeons [53,54], as well as whitefish [55–57], takes place in the Konda River, and we analyzed this period in May 2017. Our data show that the main factor influencing the dynamics of seasonal migration of mass fish species in the floodplain-channel complex of the Lower Irtysh in the direction of the floodplain is water temperature. Changing water temperatures are well-known triggers for fish migration (e.g., [58–60]), which is confirmed by our data.

The general trend and numerical patterns of fish movement in the spring at the mouth of the Konda River reflect the high migratory activity of fish in the spring after the ice breaks up (27–30 April). Apparently, the migration of fish from the main river to the flooded floodplain is determined by both the temperature and the hydrological regime of the watercourse. For example, nelma overwinters in the wintering pits of the Irtysh River, and during the spring break-up of the ice, it migrates into tributaries [61]. Our study confirms this, since analyses of control catches were also carried out during the research period, and all of the caught nelma were actively feeding. Walsh et al. [62] showed that the behavior of representatives of perch in terms of intensive movement up- and downstream in spring is due to their spawning behavior and changes in water temperature. The directed movement of cyprinids from a lowland river in Australia to the flooded floodplain indicates the influence of hydrology [63]. A study about the migration of carp and perch revealed that some of the main environmental factors influencing the intensity of migration of these fish during the spawning migration period are changes in water level, temperature, and lighting [64]. Another study showed that a number of abiotic factors, including temperature, influence seasonal changes in the structure and spatial distribution of fish population complexes in the river Yangtze [65].

In this study, it was found that the number of fish migrating upstream and downstream near the bank can be more than two times higher than in the main river. Near the bank, the size structure of the fish is dominated by fish of medium and small sizes (5–20 cm), while in the main channel, there are large-sized fish (>35 cm). The difference in the size groups of fish in the river sections is not only explained by the ability of larger fish to resist higher flow velocities but also to select zones of optimal speeds, which is confirmed by studies about cyprinid fish, including roach [66]. The numerical predominance of small-sized individuals near the bank is due to the presence of a necessary criterion for them during

the migration period—areas with lower flow velocities [67]. The preference for these areas is typical for both peaceful [68] and predatory fish species [69].

Such patterns are explained by the fact that in the direction from the center (main channel) to the bank, there is a decrease in the flow speed and, accordingly, fish individuals experience the least resistance to the water flow near the bank. In addition, the size redistribution of both fish of different species and individuals of the same species but of different lengths can occur in the flow since the critical velocity indicator has interspecific and ontogenetic differences [70–76]. Furthermore, our data show that the intensity of seasonal migration of fish into the floodplain with the diurnal aspect of the river is graphically distributed in antiphase to the diurnal variation in illumination. The daily movement of fish intensifies in the twilight–night period preceding morning twilight and also less significantly in the period preceding evening twilight. The diel (24 h) cycle and resulting behavior by day, night, and twilight are recognized [77], but in the literature, it is also pointed out that fish behavior in artificial light should be considered a stressor for fish health and persistence [78–80]. Furthermore, it has been shown that fish, based on photosensitive organs associated with the central nervous system, have a complex circadian mechanism that ensures their physiological adaptation to a periodically changing environment, including avoidance of predators, search for food, and selection of optimal migration conditions [81].

Overall, our study highlights the advantages of hydroacoustic surveys in order to analyze fish migration and ecology in large rivers, i.e., ecological functions related to changing abiotic factors. The knowledge about diel migration patterns in fish can support sustainable management. Thus, further studies are needed in order to gain an understanding of the process of intra- and interannual dynamics.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/d15121211/s1>, Table S1: Overview on the sonar data (1296 h) from the spring 2017 survey with the acoustic complex NetCor (455 kHz); Video S1: Fish migration (main channel—above, near bank—below) 05/17/2017 (0:00–1:00 a.m.); External supplementary material S1: <http://prom-ha.ru/netcor.html> (accessed on 21 October 2023).

Author Contributions: Conceptualization, A.A.C. and M.S.; methodology, A.A.C.; formal analysis, A.A.C.; investigation, A.A.C.; resources, A.A.C.; writing—original draft preparation, A.A.C. and M.S.; project administration, A.A.C. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Data are contained within the article and supplementary materials. Raw data related to this study is available upon request from A.A. Chemagin.

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Conflicts of Interest: The authors declare no conflict of interest.

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