Winter refuge for freshwater fish

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Abstract. The ecological aspect of the behavioral and physiological adaptation of fish in the autumn-winter period in water bodies of the temperate and subarctic climatic zones of the Northern Hemisphere is considered. It has been established that fish in the studied areas with a decrease in water temperature form aggregations in deep, low-speed sites for the successful wintering. In the considered period of the life cycle, the metabolism in fish slows down to reduce the depletion of lipid reserves; therefore, this group of aquatic organisms forms accumulations in areas with fundamental properties - depth and low flow rate. This phenomenon can be considered a behavioral-physiological adaptation developed as a result of evolutionary processes. The results of work on the discovery of such wintering grounds have been noted for the continents - Eurasia and North America. Fish families that use such winter refuge include Cyprinidae, Percidae, Coregonidae, Thymallidae, Salmonidae, Lotidae, Esocidae, Siluridae, and Acipenseridae.

1 Introduction

In the winter period of the life cycle of aquatic organisms the complex of abiotic and biotic factors forms certain restrictions on ecosystems located in temperate and subpolar latitudes, since the duration of the winter period exceeds the growing season. [1, 2, 3, 4]. Snow-ice cover limits the supply of oxygen to aquatic ecosystems [3], at the same time, changes in the availability of food resources and trophic relationships are also noted, food chains are fundamentally different from food webs in summer [4]. Winter is traditionally considered a dormant period, organisms actively or passively reduce metabolic activity or use warmer climatic zones before the onset of spring - seasonal migrations [3], that is, changes in the behavior of species are determined by the amplitudes of environmental fluctuations [2, 5]. It has been shown [6] that some invertebrate and vertebrate predators can maintain or even increase their level of activity in winter. As the water level goes down and the onset of the autumn-winter period, fish move from the floodplain [2] to the deep sections of watercourses [7] and reservoirs [8, 9]. Using the example of sturgeons, it has been shown that in winter, even if they have access to large areas of unfragmented habitat, they concentrate on its individual areas, which make up <0.1% of the available habitat [10], that is, there is an aggregation of individuals in areas of the range that meet the specific requirements of the organism under certain environmental conditions.

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For fish, both accumulation and depletion of lipids is integral to successfully overcoming the decline in metabolic rate and activity level associated with cold winter periods, i.e. lipids in the body of fish are critical for their survival in winter. [1, 11], at the same time, for sturgeon juveniles, survival during the wintering period is noted at the level of 50-53% [12]. When winter sets in, some competing fish species may develop different behavioral responses, as a result of which interspecific food competition may decrease [13], while in other fish species, with the change of season, a change in the food spectrum is noted - from zooplankton to benthos [14]. In turn, as a result of research work, it was shown [15] that for fish of a temperate climate, the presence of a winter period is necessary for more successful replenishment of the population.

The study of the characteristics of winter habitats of animals, especially for species that form aggregations, while as a result of physiological adaptations have a slow metabolism, is important - since the search and discovery of such habitats allows, on the one hand, to ensure their protection at critical stages of the life cycle, on the other - to count their number [5, 10, 16, 17, 18, 19]. The winter period is a significant driving force of ecological processes with an impact on all levels of ecosystems, while it is noted [3, 4] a small number of scientific studies of trophic interactions of aquatic organisms in river ecosystems at this period of the year.

Thus, the goal of the work is to analyze our own research and systematize the available scientific information about fish species demonstrating behavioral and physiological adaptation - migration to deep and low-speed areas of water bodies and the formation of aggregations in winter in temperate and subpolar latitudes of the Northern Hemisphere.

2 Materials and methods

The species composition of fish was established as a result of control fishing with fixed multi-celled fishing gear (nets) in the winter period December (2011, 2012, 2015, 2017-2021). The presence of fish aggregations was determined using computerized hydroacoustic systems (LLC Promgidroakustika, Petrozavodsk) in the mode of vertical echometric sounding (50 and 200 kHz) of the water column in the winter refuge for fish located on the Irtysh River (Russian Federation) in geographic coordinates (WGS-84) 58.730795 N.L., 68.698336 E.L. Echometric sounding of the water column was carried out during the winter-spring period of 2017-2018, 2021-2022, to conduct surveys in the water area of the study area, moved in zigzags [20, 21]. The depth of the studied section of the river exceeds 40 m. Previously, a zigzag route was planned on a snowmobile over the ice cover, then holes were drilled every 30–40 m to immerse the hydroacoustic antenna on the boom and hydroacoustic surveys were performed (≥100 signals send-receives). The driver of the snowmobile moves along the laid route, stopping in such a way that the sled with the operator producing the hydroacoustic survey is located near the drilled holes during the stop. The hydroacoustic data files obtained in this way were processed using special computer applications in the laboratory.

3 Results

According to the results of hydroacoustic survey, it was found that in the water area of the winter refuge (pit), characterized by a significant difference in depth from 12 m along the riverbed to > 40 m in the deep part, the presence of vertical eddy structures (whirlpools) and multidirectional currents, there are aggregations of fish (density > 2100 ind./ha).

The ichthyofauna in the study area is represented by the species: family Cyprinidae genera *Rutilus, Leuciscus, Abramis, Carassius*, family Percidae genera *Gymnocephalus, Perca,* *Sander*, family Coregonidae genera *Coregonus, Stenodus*, family Esocidae genus *Esox*, family Lotidae genus *Lota*, family Acipenseridae genus *Acipenser*.

It has been established that the water column in the shelter area is not uniformly developed by fish, both in the horizontal aspect - in terms of the number of recorded fish registrations, and in the vertical aspect - in terms of the density of their distribution. The highest density of fish is observed mainly at depths up to 10 m, during the day - in the coastal area, at night - in the open part of the water area (on the current). Individuals from the Cyprinidae, Coregonidae and Esocidae families explore the entire water column of the deep part of the channel pit, but to varying degrees. Representatives of Percidae, Lotidae and Acipenseridae have been recorded only in the pelagic and near-bottom aquatic horizons of the pit (winter refuge). Despite the reduced physiological activity of fish, in the water area of winter refuge for them, there is a daily dynamics of vertical redistribution and horizontal explore of the water area, so the location of fish aggregations undergoes changes with a change in the light phase of the day-night. Changes in the taxonomic and size structure of fish aggregations are also observed.

Based on statistical analysis of variance, a significant effect of the influence of the time of day-night factor in the overall density of fish was revealed: a significant difference in density was established during the day and at night.

In addition, there is a negative moderate and high correlation in the analysis of the vertical distribution of a group of cyprinids with groups of predators - representatives of Esocidae, Coregonidae, Percidae and Lotidae families.

In the dynamics from December to April, under the conditions of the presence of ice cover, the density of fish decreases by 2-3 orders of magnitude. In numerical terms, representatives of the Cyprinidae и Percidae families dominate.

4 Discussion

According to the performed ichthyological studies in temperate and subpolar latitudes on the continents - North America (Canada, USA), Eurasia (England, France, Finland, Russia, China, Mongolia), it was found that the seasonal preference for deep water areas with low flow rates, hydraulic and hydrological features in the autumn and winter periods of the life cycle is used by various fish species, including Acipenseridae [5, 10, 18], Coregonidae [22], Cyprinidae [7], Percidae [8, 23]. These fish species become sedentary when the water temperature drops and move to deeper parts of water bodies. In the basin of the Irtysh River (Ob-Irtysh basin, Russia), it has been noted that in the water area of winter refuge (pit), are also accumulations of representatives of the ichthyofauna of various families (Cyprinidae, Percidae, Coregonidae, Acipenseridae) and their size groups. Their confinement to these areas is apparently due to the presence of low hydrodynamic section inside the watercourse [24]. The locations and list of fish families, which form aggregations in deep low-velocity areas in various water bodies in the autumn-winter period is presented at the Figure 1.

According to the researches of many authors, it has been noted that certain characteristics of the depth and near-bottom current velocities are fundamentally necessary conditions for the habitat of fish in the winter. [10, 29, 34]. Using the example of sturgeons, it was shown that [10] both depth and near-bottom flow velocity are important predictors of the choice of habitat for wintering fish. These factors dominate as the main prognostic variables of the environment in this unfavorable, severe season of the year [10]. This, in turn, supports the assumption that deep habitats provide shelter even for large fish, and low-velocity microbiotopes provide refuge that maximizes energy conservation at rest [10] by reducing lipid waste [35]. Lipid conservation is vital in winter as an increased metabolic rate has been shown to lead to lipid depletion [35, 36], which is one of the main causes of increased fish mortality during wintering, both for juveniles and for fish of older age groups [34, 37].

In addition to sturgeons, the preference for low-velocity microbiotopes in winter has also been established for salmonids [38, 39]. Such physiological-behavioral adaptation helps to minimize energy costs by avoiding adverse conditions in the form of high current velocities for various fish species of various families. [10, 38, 39]. In turn, it was found that in the absence of low-speed refuge for fish in the winter, when exposed to a stream, a manifestation of a stress reaction is noted in the form of increased ventilation of the operculum and a high level of cortisol in the plasma. [39].

It should be noted that in winter, fish aggregations in general in the areas of wintering riverbed depression are subject to certain dynamics to one degree or another: vertical diel migration, local redistribution (migration), dimensional, spatial rearrangement of certain species - that is, in the space of the winter refuge (pit), there is a dynamic of the size-species structure of fish aggregations [7, 32, 33].

Thus, the presence of refuges, both in the riverbed and in deep areas of water bodies, is especially important for the survival of fish in the winter period [4] - metabolic costs decrease due to rest [40].

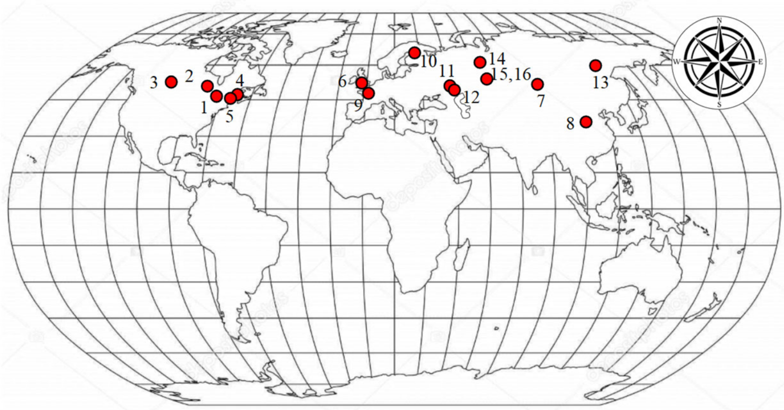

Fig. 1. Locations and list of fish families, which form aggregations in the autumn-winter period in deep and low-velocity sections of water bodies:1-3. Lake Erie Pic river, White river, South Saskatchewan River (family Acipenseridae genus *Acipenser*) [9, 10, 25]; 4, 5. Saint John River Penobscot River (family Acipenseridae genus *Acipenser*) [16,18]; 6. River Witham (family Cyprinidae genus *Abramis*) [26]; 7. Eroo River (family Salmonidae genus *Brachymystax*) [27]; 8. Huaihe River (family Cyprinidae genus *Parabramis*) [28]; 9. Bariousses Hydropower Reservoir (family Percidae genus *Perca*) [8]; 10. Pyhäkoski Reservoir (family Percidae genus *Sander*) [23]; 11. Volga River (family Siluridae genus *Silurus*, family Cyprinidae genus Cyprinus, family Percidae genus *Sander*) [29]; 12. Zheltaya River (family Cyprinidae genera *Abramis, Rutilus, Cyprinus,* family Siluridae genus *Silurus,* family Percidae *Sander*) [30]; 13. Naman River (family Thymallidae genus *Thymallus,* family Salmonidae genus *Brachymystax*) [31]; 14. Lyapin River (family Cyprinidae genera *Rutilus, Leuciscus, Abramis,* family Percidae genera *Gymnocephalus, Perca,* family Coregonidae genera *Coregonus, Stenodus,* family Esocidae genus *Esox,* family Lotidae genus *Lota*) [32]; 15, 16 Irtysh River (family Cyprinidae genera *Rutilus, Leuciscus, Abramis, Carassius,* family Percidae genera *Gymnocephalus, Perca, Sander,* family Coregonidae genera *Coregonus, Stenodus,* family Esocidae genus *Esox,* family Lotidae genus *Lota,* family Acipenseridae genus *Acipenser*) [7,33].

The importance of the presence of wintering sites and the risk of their loss is confirmed by studies, as a result of which it was established [41] that their loss (silting) can lead to reduction in the fish productivity of reservoirs and watercourses by an order of magnitude.

5 Conclusion

Analysis of their own research and ichthyological, hydrobiological studies of many scientists on the winter habitats of fish in the temperate and subarctic climatic zone, it was found that in winter, fish, as a result of evolutionarily developed behavioral and physiological adaptation, concentrate on wintering riverbeds depression - areas of reservoirs and streams with fundamental properties: depths and low current velocities. The use of these habitats makes it possible to reduce metabolic costs during an unfavorable period of the life cycle in order to maintain survival, i.e. allows fish to overcome thermal stress (from low temperatures) and starvation. Freshwater fish species concentrated in deep-water areas in the autumn-winter period include representatives of Cyprinidae, Percidae, Coregonidae, Thymallidae, Salmonidae, Lotidae, Esocidae, Siluridae, and Acipenseridae. These adaptations have been noted for fish in the Northern Hemisphere on the continents - North America and Eurasia.

Reference

1. D. Deslauriers, G. R. Yoon, M. L. Earhart, C. Long, C. N. Klassen, W. G. Anderson, Environmental Biology of Fishes **101(4)**, 623-637 (2018)
2. B. C. McMeans, K. S. McCann, M. Humphries, N. Rooney, A. T. Fisk, Trends in Ecology & Evolution **30(11)**, 662-672 (2015)
3. A. O. Sutton et al., Environmental Reviews **29(4)**, 431-442 (2021)
4. A. Thellman, K. J. Jankowski, B. Hayden, X. Yang, W. Dolan, A. P. Smits, A. M. O'Sullivan, Journal of Geophysical Research: Biogeosciences **126(9)**, e2021JG006275 (2021)
5. M. J. Moore, C. P. Paukert, T. L. Moore, Journal of Fisheries Management **41(4)**, 916-928 (2020)
6. I. Werner, H. Auel, Marine Ecology Progress Series **292**, 251-262 (2005)
7. A. D. Mochek, E. S. Borisenko, D. S. Pavlov, Journal of Ichthyology **59(3)**, 352-357 (2019)
8. S. Westrelin, R. Roy, L. Tissot-Rey, L. Bergès, C. Argillier, Hydrobiologia **809(1)**, 121-139 (2017)
9. J. L. Withers, H. Takade-Heumacher, L. Davis, R. Neuenhoff, S. E. Albeke, J. A. Sweka, Anim Biotelemetry **9,** 40 (2021)
10. D. Thayer, J. L. W. Ruppert, D. Watkinson, T. Clayton, M. S. Poesch, Global Ecology and Conservation **10**, 194-205 (2017)
11. T. Fernandes, B. C. McMeans, Ecography **42(12)**, 2037-2052 (2019)
12. M. J. Moore, C. P. Paukert, T. W. Bonnot, B. L. Brooke, T. L. Moore, River Research and Applications **38(4)**, 627-638 (2022)
13. B. C. McMeans et al., Ecology Letters **23(6)**, 922-938 (2020)
14. B. Hayden, C. Harrod, K. K. Kahilainen, Ecology of Freshwater Fish **22(2)**, 192-201 (2012)
15. T. M. Farmer, E. A. Marschall, K. Dabrowski, S. A. Ludsin, Nat Commun **6**, 7724 (2015)
16. K. A. Lachapelle, Wintering shortnose sturgeon (Acipenser brevirostrum) and their habitat in the Penobscot River, Maine (2013). Retrieved from: https://digitalcommons.library.umaine.edu/etd/1965

17. A. A. Chemagin, Vestnik of Astrakhan State Technical University. Series: Fishing industry **4**, 7-21 (2020)
18. S. N. Andrews, A. M. O'Sullivan, J. Helminen, D. F. Arluison, K. M. Samways, T. Linnansaari, R. A. Curry, Diversity **12(1)**, 23 (2020)
19. A. I. Kochetkova, E. S. Bryzgalina, Aquatic Bioresources & Environment **4(4)**, 7-13 (2021)
20. K. I. Yudanov, I. L. Kalikhman, V. D. Tesler, *Guidelines for hydroacoustic surveys* (Moscow: VNIRO, 1984), 1124
21. A. S. Aldokhin, A. A. Chemagin, Vestnik of Astrakhan State Technical University **2(66)**, 84-89 (2018)
22. M. V. Pigukova, Priroda **11**, 70-73 (2021)
23. T. Vehanen, M. Lahti, Ecology of Freshwater Fish **12(3)**, 203-215 (2003)
24. E. S. Borisenko, Hydro-acoustic investigations of fish distribution in floodplain-riverbed system of the lower Irtysh River system (2013). Retrieved from: https://www.sevin.ru/dissertations/gidrobiol/100.pdf
25. A. Ecclestone, T. J. Haxton, T. C. Pratt, C. C. Wilson, T. Whillans, Journal of Great Lakes Research **46(5)**, 1369-1381 (2020)
26. C. J. Gardner, D. C. Deeming, P. E. Eady, Fisheries Management and Ecology **20(4)**, 315-325 (2013)
27. A. Kaus, O. Büttner, D. Karthe, M. Schäffer, D. Borchardt, Ecology of Freshwater Fish **27(3)**, 752-766 (2017)
28. L. Wang, K. Mo, Q. Chen, J. Zhang, J. Xia, Y. Lin, Ecohydrology **12(5)**, e2098 (2019)
29. S. P. Chekhomov, V. V. Barabanov, L. M. Vasilieva, Fish Breeding and Fisheries **10(177)**, 18-25 (2020)
30. S. P. Chekhomov, V. V. Barabanov, S. V. Shipulin, Fisheries **5**, 28-33 (2018)
31. N. M. Solomonov, I. G. Sobakina, Vestnik of North-Eastern Federal University **2(70)**, 26-32 (2019)
32. V. D. Bogdanov, I. P. Mel'nichenko, Agrarian Vestnik of the Urals **7(86)**, 48-49 (2011)
33. A. A. Chemagin, Izvestia of the Samara Scientific Center of the Russian Academy of Sciences **20(85)**, 479-489 (2018)
34. R. S. Brown, W. A. Hubert, S. F. Daly, Fisheries **36(1)**, 8-26 (2011)
35. P. A. Biro, J. R. Post, C. Beckmann, Canadian Journal of Fisheries and Aquatic Sciences **78(6)**, 738-743 (2021)
36. P. A. Biro, A. E. Morton, J. R. Post, E. A. Parkinson, Canadian Journal of Fisheries and Aquatic Sciences **61(8)**, 1513-1519 (2004)
37. T. P. Hurst, Journal of Fish Biology **71(2)**, 315-345 (2007)
38. A. Huusko, L. Greenberg, M. Stickler, T. Linnansaari, M. Nykänen, T. Vehanen, S. Koljonen, P. Louhi, K. Alfredsen, River Research and Applications **23(5)**, 469-491 (2007)
39. J. Watz, Hydrobiologia **802(1)**, 131-140 (2012)
40. B. J. Shuter, A. G. Finstad, I. P. Helland, I. Zweimüller, F. Hölker, Aquatic Sciences **74(4)**, 637-657 (2012)
41. V. Sondak, O. Volkoshovetz, N. Kolesnik, M. Simon, Ribogospodars'ka Nauka Ukraïni **4(54)**, 5-21 (2020)