Distribution of fish in the subarctic lake

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Abstract. The paper studies fish population of an isolated lake in the subarctic zone. The study of the features of distribution of fish, the assessment of their abundance and size structure were carried out by the echometric method using hydroacoustic complexes and geoinformation systems. The research found out that the fish population is represented by 4 species of fish: roach, perch, pike and peled, with the absolute dominance of cyprinids. Their share of the total number of fish in the reservoir was >80%. Features of the horizontal distribution of fish are mainly due to trophic-defensive behavior (concentration of juveniles in the littoral), where it is possible to use macrophytes as shelters from visually oriented predators - perch and pike. In the horizons of the water column with depths <5 and >5 m, 72.4 and 27.6% of fish from their total abundance in the reservoir were recorded, the average density of fish at the considered horizons was 2149 and 398 ind. / ha. In the vertical aspect, the distribution of fish is determined by both trophic-defensive (concentration of juveniles in the littoral) and thermoregulatory behavior (concentration of peled on the drope of depth in the profundal zone).

1 Introduction

Currently, it is predicted that climate change will have a serious impact on the freshwater ecosystems of the Arctic due to changes in the abiotic model [1–3], for example, [4] the increased interaction of the catchment area with water bodies will also affect at biodiversity [3,5], the structure of communities [6] and food chains [7]. At the same time, there is no coordinated monitoring of Arctic fresh waters, which in turn does not allow to fully study and evaluate changes in the biodiversity of Arctic ecosystems [3]. Circumpolar assessments of phyto- and zooplankton, macrophytes, benthos, and fish provide monitoring of the impact of climate change and factors associated with it on the biodiversity of freshwater ecosystems [3], and will also allow tracking changes in the functioning of Arctic ecosystems [8]. It should be noted [3,5] that the lotic and limnic systems of the Arctic are increasingly affected by climate change. It is assumed [9, 10] that the ongoing climate warming can lead to a change in the network of watercourses, the connectivity of lakes, which in turn will have a significant impact on the distribution of fish in freshwater ecosystems.

In turn, it is shown that the acoustic method of studying the distribution of hydrobionts in various types of water bodies is widely used among researchers, for example, they study the

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behavioral features [11–13] of migrations and the distribution of fish [13–15], their spatial and temporal patterns of distribution and features ecology [16], including in lakes [11,12,17].

The hydroacoustic method is recognized [18] as one of the best methods for observing the spatial distribution of organisms in aquatic habitats, this method has proven itself well for real-time quantitative observation of fish populations with high spatiotemporal resolution [19], when used in conjunction with geoinformation systems (GIS); this creates an ideal opportunity for mapping and modeling the spatial distribution of fish [19], including small-sized individuals [16, 20].

In this regard, the aim of the work is to study the initial state of the fish population of a subarctic isolated lake - to determine the species diversity, abundance, size composition and features of distribution of fish.

2 Materials and methods

The studied lake Un-Novyinklor is of karst origin, has rounded shapes close to an ellipse, is part of the natural monument of district significance "The system of lakes Un-Novyinklor and Ai-Novyinklor", which is located on the territory of the West Siberian geographical country on the territory of the West Siberian Plain in the forest-bog zone in the western part of the municipality Beloyarsky district of the Khanty-Mansi Autonomous Okrug - Yugra, 5 km south, southeast of the city of Beloyarsky, on the second floodplain terrace on the left bank of the Kazym River [21]. The investigated reservoir is located at the coordinates 63.664768° N. L. and 66.802107° E. L. (Figure 1), its area is 316.2 ha. The work was completed in the period July-August 2020.

To carry out hydroacoustic surveys in the water area of the lake, we moved along a grid of tacks (zigzags) on a small vessel (an inflatable rubber boat) - SDP-420 with an outboard motor according to generally accepted methods [22]. Hydroacoustic surveys were carried out simultaneously in vertical (50 and 200 kHz) and horizontal (455 kHz) modes of echo sounding of the water column using Ascor and Pancor serial software and hardware systems (LLC Promhydroacoustics, Petrozavodsk), respectively. Acoustic antenna-receivers are installed in the body of the fairing installed in the bow of the boat (Figure 2).

The operation of the used computerized systems is based on the use of a Furuno LS 4100 serial echo sounder (Furuno Inc., Japan) with an additional GPS tracking function, as well as using an analog-to-digital converter of the signal received from the echo sounder. The launch, control, and shutdown of the hydroacoustic systems were carried out using field tablet computers Xplore 103,104i (USA).

The recorded hydroacoustic surveys were then processed in the laboratory using “AsCor”, “PanCor”, “Species AsCor” and “Species PanCor” software applications. The species recognition of fish at the family level is based on the shape of the reflected sound wave, which depends on the shape of the fish swim bladder [23-25].

This algorithm is built into these software applications. As a result, of this processing, all fish are divided into the appropriate groups: fish with a two-chamber swim bladder (Cyprinidae), fish with an asymmetric swim bladder (Percidae), fish with a symmetrical swim bladder (Coregonidae and Esocidae). The conditional division of the water column of the lake into the analyzed horizons <5 and >5 m is due to the peculiarities of ecology and the predominant biotopic distribution of pike and peled in these horizons, respectively.

To create a horizontal projection of the distribution of fish, isobath maps of the bottom relief, the coastline of the lakes was previously digitized in the MapViewer 7.0 application using satellite images from Google Earth Pro 7.3.2.

To create fish distribution areas and isobath lines, the Surfer 9.0 program was used with the exact interpolation method of the weighted average “Inverse distance to a power”, used by domestic [23,26,27] and foreign researchers [24,25]. Work with geographic coordinates

was carried out in the projection of the world system of geodetic parameters of the Earth (World Geodetic System 1984) - WGS -84.

To determine the species composition of fish, control gill nets of various meshes were used.

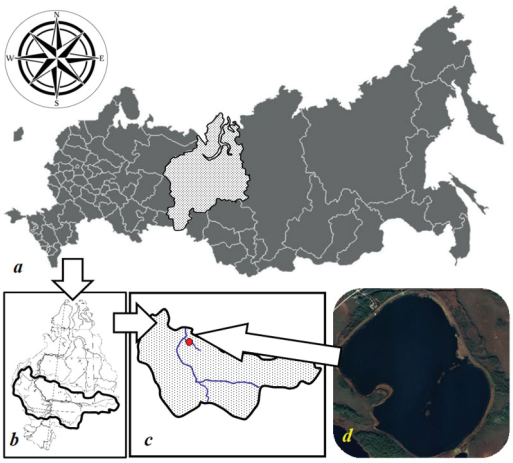

Fig. 1. Map of the location of Lake Un-Novyinklor: a. Russian Federation; b. Khanty-Mansi Autonomous Okrug; c. Schematic location of the lake on the territory of the Khanty-Mansiysk Autonomous Okrug; d. Satellite image of Lake Un-Novyinklor.

Fig. 2. Installation and location of the fairing (a-c) with hydroacoustic antennas-receivers (d) in the bow of the boat: 1. Fairing body; 2. Antenna-receiver for horizontal echo sounding; 3. Antenna-receiver for vertical echo sounding.

3 Results

According to the control catch, the fish population of Lake Un-Novyinklor is represented by the class Osteichthyes, 3 orders and 1 suborder Cypriniformes, Perciformes, Salmoniformes, Esocoidei, 4 families: Cyprinidae, Percidae, Coregonidae, Esocidae, 4 genera: Rutilus, Perca, Coregonus, Esox, 4 species: roach *Rutilus rutilus* L., perch *Perca fluviatilis* L., peled *Coregonus peled* Gmelin, pike *Esox lucius* L.

As a result of the analysis of hydroacoustic surveys in the water area of the lake, it was found that the dominant fish species in percentage and number are cyprinid fish. At depths less than 5 m, the share of cyprinid fish was 83.45, at depths >5 m - 70.26%, the number – 567.05 and 36.95 thousand individuals, respectively (Figure 3).

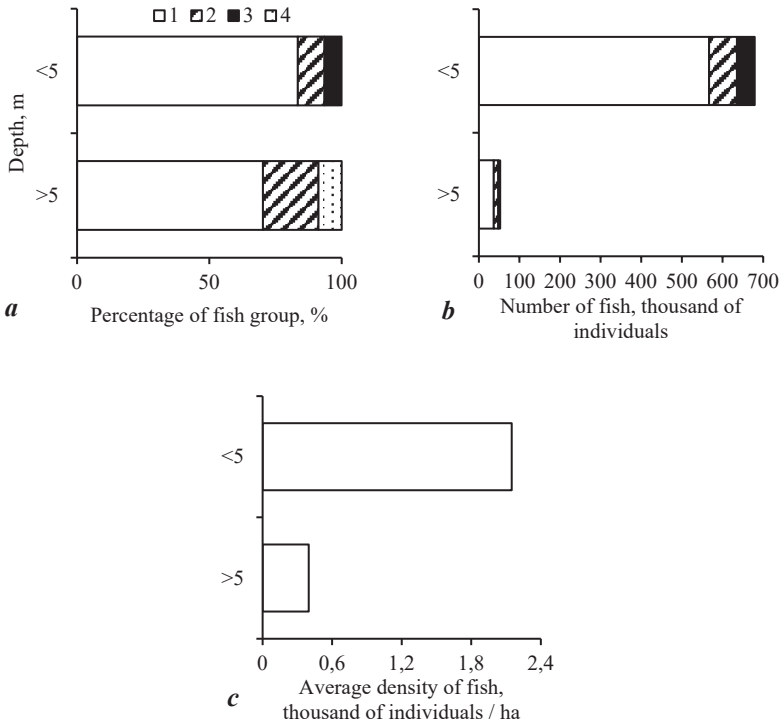

Fig. 3. Quantitative characteristics of the fish population: a. Percentage of taxonomic groups; b. Number of taxonomic groups; c. Average density; 1 - Cyprinidae; 2 - Percidae; 3 - Esociidae; 4 – Coregonidae.

The proportion of percids with increasing depth increased from 10.07 to 21.02%, and the number decreased – 68.43 and 11.06 thousand individuals, respectively. The proportion of pike at depths <5 m was 6.47% of the total number of fish in this horizon, and the number of registered fish was 43.97 thousand individuals. The proportion of peled at depths >5 m was 8.72%, and the number was 4.59 thousand individuals. The indicators of the average density of fish at depths <5 and >5 m were 2149 and 398 ind. /ha, respectively (Figure 3).

As a result of the analysis of hydroacoustic surveys, it was found that in almost all considered size groups of fish <5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, >35 cm, representatives of the Cyprinidae family dominated. Their proportions at depths <5 and >5 m were 31.00, 30.32, 11.49, 1.79, 1.22, 0.27, 0.65, 0.16 and 2.50, 37.74 , 16.08, 7.58, 3.57, 1.5, 0.50, 0.79%, respectively (Figure 4).

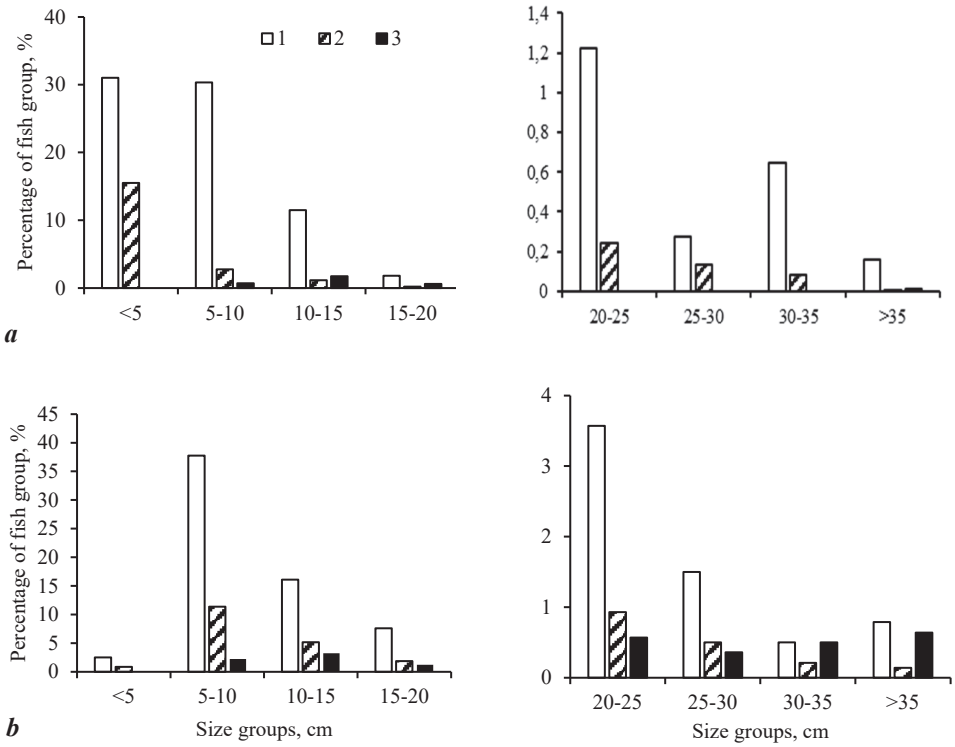

Fig. 4. The percentage of size groups according to hydroacoustic survey data, as a percentage of the total number of fish at depths <5 (a) and >5 m (b): a. 1 - Cyprinidae; 2 - Percidae; 3 - Esociidae; b. 1 - Cyprinidae; 2 - Percidae; 3 – Coregonidae.

Less significantly among the considered size ranges of fish is the percids group. The proportions of percids at depths <5 and >5 m among the size ranges <5, 5-10, 10-15, 15-20, 20-25, 25-30, >35 cm were: 15.50, 2.75, 1.15, 0.20, 0.25, 0.14, 0.08, 0.01 and 0.86, 11.37, 5.15, 1.86, 0.93, 0.50, 0.21, 0.14% respectively. Pike (<5 m) is represented as follows: fish size groups <5, 20-25, 25-30 cm were not registered, the proportions of size groups 5-10, 10-15, 15-20 and >35 cm were 0.69, 1.72, 0.60 and 0.01%, respectively. Peled (>5 m) is represented by all size groups of fish, except for the smallest (<5 cm). The proportions of size groups 5-10, 10-15, 15-20, 20-25, 25-30 and >35 cm were 2.22, 3.22, 1.22, 0.57, 0.36, 0.50 and 0.64%, respectively.

According to hydroacoustic survey data, in the deep parts of the lake, peled individuals are distributed mainly in the pelagial and profundal of the water column, forming aggregations (Figure 5).

As a result of constructing an isobath map (Figure 6) and a horizontal projection of the distribution of fish (Figure 7), it was found that the areas of maximum fish density are noted in the zones of conjugation of sections of the slope (difference) of depths and areas, overgrown areas of water areas:

- Along the southern and southwestern slope of the northeastern depression (pit), as well as in the "shoal" zone, dividing the lake into two pronounced basins.
- Along the southern and northeastern slopes of the southeastern basin.
- In the western shallow part of the lake, partially closed from wind and wave action by the features of the terrain and the location of the lake water area.

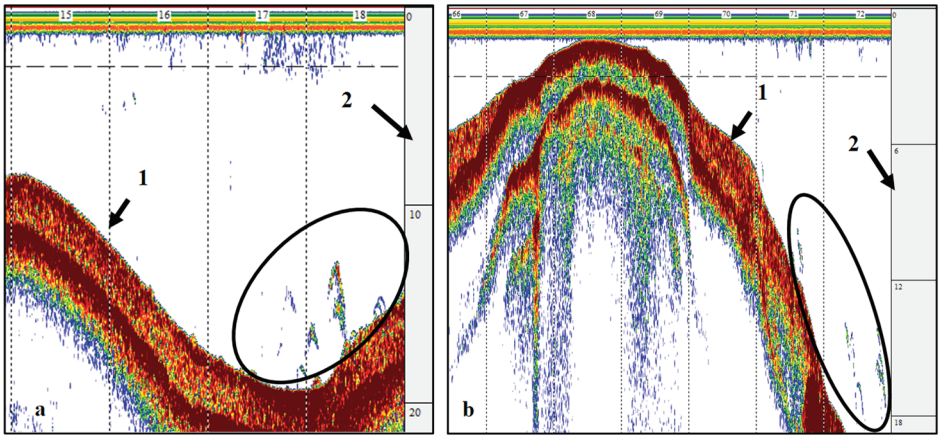

Fig. 5. Aggregations of peled (shown by ovals) a. Northern part of the lake; b. Southeast part of the lake; 1. Bottom profile; 2. Depth scale.

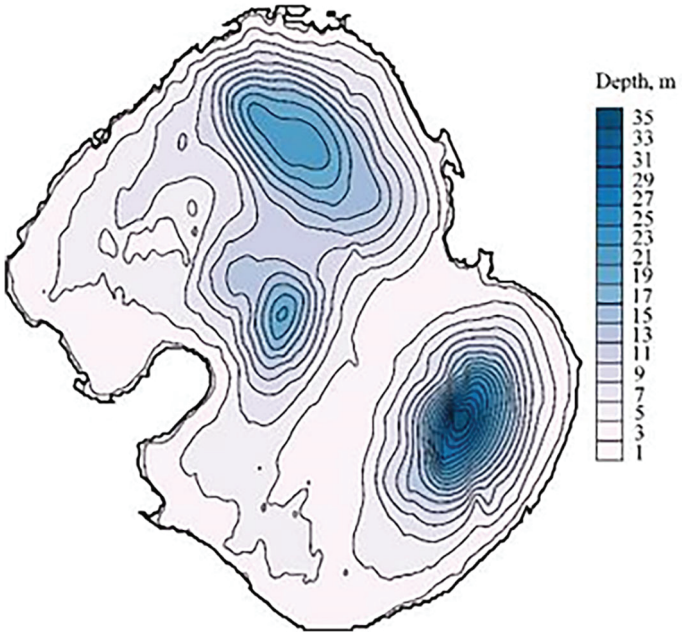

Fig. 6. Isobathic map of Lake Un-Novyinklor (steep bottom slope in the northern, central and southeastern parts).

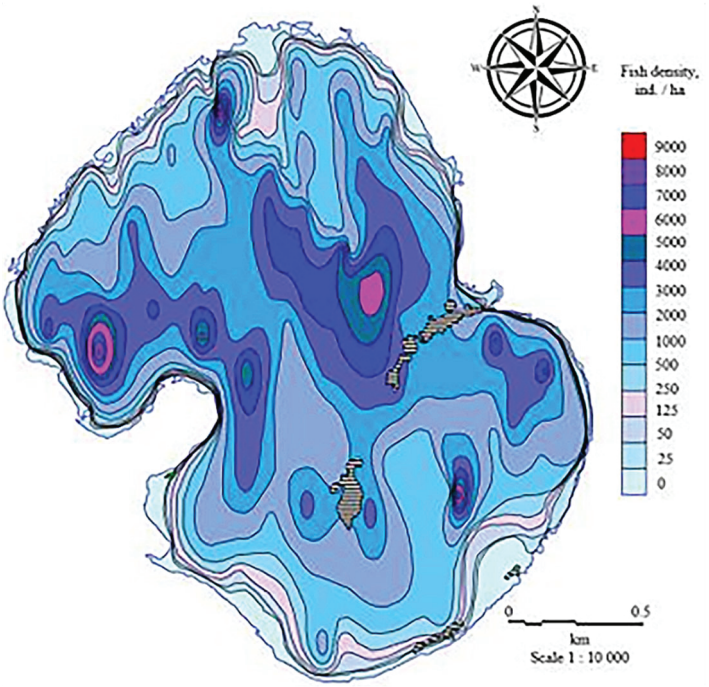

Fig. 7. Horizontal projection of the distribution of fish in the water area of Lake Un-Novyinklor (horizontal shading shows zones of developed macrophytes).

In the littoral part (in shallow water) of the lake, according to hydroacoustic survey data, many juveniles (>45%) with a body size of <5 cm in the size structure of the fish population were recorded, and 2/3 of them are juvenile cyprinids, the rest is represented by other fish species with perch dominance.

4 Discussion

The depth of distribution of peled is largely related to the seasonally changing vertical temperature gradient in the lake, since in deep lakes thermal stratification and the thermocline phenomenon [28] are observed - a sharp change in temperature at depths of 2 to 14 m or more, depending on the observation period. The peled, as a cold-water species, prefers cooler water columns (5–10 m or more), which correspond [28] to the optimal metabolic temperatures for coregonids. In this regard, the vertical segregation of peled is associated with metabolic advantages and thermoregulatory behavior of fish [28], since in this way cold-water fish species minimize the negative effect of exposure to elevated temperatures due to the possibility of thermoregulatory behavior in a deeper and, accordingly, cooler lake [29]. The patterns of vertical and horizontal distribution of fish in Lake Un-Novyinklor are primarily explained by the thermoregulatory and trophic-defensive behavior of fish, including juveniles, which prefer shallow warm areas with developed zones of macrophytes that form the structural complexity of the environment, which in turn has a fundamental effect on the interaction between fish and their prey [30].

Thus, due to the high transparency in the water area of Lake Un-Novyinklor, juveniles of cyprinids and percids, based on behavioral strategies, seek refuge in structurally complex habitats [31] and are distributed mainly in the littoral part of the lake (shallow) with

macrophyte zones which used as “shelter” from visually oriented predatory fish species (pike, predatory form of perch) [30].

In addition, it was shown [32, 33] that the distribution of juvenile fish also depends on atmospheric wind phenomena, which create the wave movement of water masses together with zooplankton [34], the food objects of juvenile fish and adult planktivorous fish (roach) as a result of surge wave action. In our study, during hydroacoustic surveys, waves were observed in the northwest direction, and the concentration of juvenile fish was noted in the northwestern littoral part of the lake, sheltered from the wind, i.e. in addition to the direct impact, wind phenomena can also have an indirect effect on the horizontal distribution of fish, since It has been established [35] that planktivorous fish concentrate in zones of increased density of zoo- and phytoplankton formed by wind phenomena, while [36] it becomes possible to feed more intensively and successfully with less bioenergy expenditure. Areas (zones) of aquatic vegetation are very important for small-sized eurytopic fish species, including perch, since abundant food resources are formed in such zones, and in addition, it becomes possible to use them as "refuge" [37].

5 Conclusion

The fish population of Lake Un-Novyinklor is represented by the class Osteichthyes, 3 orders and 1 suborder Cypriniformes, Perciformes, Salmoniformes, Esocoidei, 4 families: Cyprinidae, Percidae, Coregonidae, Esocidae, 4 genera: Rutilus, Perca, Coregonus, Esox, 4 species: roach *Rutilus rutilus* L., perch *Perca fluviatilis* L., peled *Coregonus peled* Gmelin, pike *Esox lucius* L.

The dominant species of fish in terms of numbers are representatives of the cyprinids. In decreasing order of abundance, fish species are arranged in the following order: roach > perch > pike > peled. The main part of the fish population (>70%) is concentrated in the littoral part of the lake.

The horizontal distribution of fish in the water area of the lake is characterized by accumulations of juveniles in the littoral part of the lake in the zone of macrophytes used as a refuge from visually oriented predatory fish species. The vertical distribution of fish is characterized by the accumulation of peled in the deep-water parts (slope of the depths) of the lake at depths >5 m, which in turn is due to the thermoregulatory behavior of cold-water fish species. Thus, the patterns of the distribution of fish in the water area of the lake are determined by their thermoregulatory and trophic-defensive behavior.

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References

1. T. Riis, K. S. Christoffersen, A. Baattrup-Pedersen, Freshwater Biology **59(8)**, 1622-1632 (2014)
2. J. R. Beaver, C. D. Arp, C. E. Tausz, B. M. Jones, M. S. Whitman, T. R. Renicker, E. E. Samples, D. M. Ordosch, K. C. Scotese, Arctic, Antarctic, and Alpine Research **51(1)**, 327-345 (2019)
3. J. M. Culp et al, Freshwater Biology **67(1)**, 1-13 (2021)
4. D. N. Thomas et al, *Arctic Ecology* (John Wiley & Sons Ltd, Oxford, 2021)
5. J. Lento et al, Freshwater Biology **67(1)**, 159-175 (2021)
6. P. M. Yurista, Freshwater Biology **42(1)**, 21-34 (1999)

7. M. Lindholm, R. Wolf, A. Finstad, D. O. Hessen, Freshwater Biology **61(3)**, 340-347 (2016)
8. S. M. Laske et al, Freshwater Biology **67(1)**, 176-193 (2019)
9. A. E. Hershey et al, Freshwater Biology **51(1)**, 39-55 (2006)
10. S. L. Klobucar, P. Budy, Oecologia **194(3)**, 491-504 (2020)
11. T. A. Dick, C. P. Gallagher, A. Yang, Ecology of Freshwater Fish **18(1)**, 117-125 (2009)
12. A. D. Spares, M. J. W. Stokesbury, R. K. O'Dor, T. A. Dick, Marine Biology **159(8)**, 1633-1646 (2012)
13. A. D. M. Wilson, T. A. Hayden, C. S. Vandergoot, R. T. Kraus, J. M. Dettmers, S. J. Cooke, C. C. Krueger, Ecology of Freshwater Fish **26(2)**, 292-300 (2016)
14. M. L. Acolas, E. Rochard, C. Le Pichon, E. Rouleau, Journal of Experimental Marine Biology and Ecology **430-431**, 68-77 (2012)
15. C. Wu, L. Chen, Y. Gao, W. Jiang, Fisheries Science **84(1)**, 71-78 (2017)
16. S. E. Walton-Rabideau, E. J. I. Lédée, J. P. Leblanc, P. Szekeres, J. D. Midwood, A. J. Gallagher, J. M. Farrell, S. J. Cooke, Ecology of Freshwater Fish **29(2)**, 346-363 (2019)
17. A. L. Bass, T. O. Haugen, L. A. Vøllestad, Ecology of Freshwater Fish **23(2)**, 149-160 (2013)
18. J. Simmonds, D. MacLennan (Eds.), *Fisheries Acoustics* (Blackwell Publishing Ltd, Oxford, 2005)
19. M. Muška, M. Tušer, J. Frouzová, T. Mrkvička, D. Ricard, J. Seďa, F. Morelli, J. Kubečka, Scientific Reports **8**, 5381 (2018)
20. C. Saraux, J-M. Fromentin, J-L. Bigot, J-H. Bourdeix, M. Morfin, D. Roos, E. Van Beveren, N. Bez, PLoS ONE **9(11)**, e111211 (2014)
21. E. L. Veryovkina, E. D. Lapshina, Bulletin of Nizhnevartovsk State University **3,** 26-35 (2018)
22. K. I. Yudanov, I. L. Kalihman, V. D. Tesler, *Hydroacoustic survey guidelines* (VNIRO, Moscow, 1984)
23. E. S. Borisenko, A. D. Mochek, D. S. Pavlov, A. I. Degtev, Journal of ichthyology **46(2)**, 227-234 (2006)
24. V. Rodríguez-Sánchez, L. Encina-Encina, A. Rodríguez-Ruiz, R. Sánchez-Carmona, Fisheries Research **164**, 214-222 (2015)
25. R. A. Pollom, G. A. Rose, Environmental Reviews **24(3)**, 333-347 (2016)
26. E. S. Borisenko, A. D. Mochek, D. S. Pavlov, A. A. Chemagin, Journal of Ichthyology **53(1)**, 16-27 (2013)
27. A. D. Mochek, E. S. Borisenko, S. V. Budaev, D. S. Pavlov, Journal of Ichthyology **55(3)**, 355-362 (2015)
28. T. Mehner, S. Busch, I. P. Helland, M. Emmrich, J. Freyhof, Ecology of Freshwater Fish **19(3)**, 408-419 (2010)
29. A. Murdoch, M. Power, Ecology of Freshwater Fish **22(3)**, 453-466 (2013)
30. N. Okun, T. Mehner, Ecology of Freshwater Fish **14(2)**, 150-160 (2005)
31. V. Huckstorf, W-C. Lewin, T. Mehner, C. Wolter, Behavioral Ecology and Sociobiology **63(12)**, 1735-1742 (2009)
32. A. Huusko, T. Sutela, Ecology of Freshwater Fish **7**, 69-77 (1998)

33. B. D. Turley, R. R. Rykaczewski, Canadian Journal of Fisheries and Aquatic Sciences **76(12)**, 2418-2432 (2019)
34. T. J. Marjomäki, Ecology of Freshwater Fish **13**, 46-60 (2004)
35. D. G. George, I. J. Winfield, Freshwater Biology **43(4)**, 557-570 (2000)
36. D. T. De Kerckhove, E. A. Blukacz-Richards, B. J. Shuter, L. Cruz-Font, P. A. Abrams, Canadian Journal of Fisheries and Aquatic Sciences **72(11)**, 1652-1662 (2015)
37. M. Grzybkowska, M. Dukowska, J. Leszczyńska, J. Lik, E. Szczerkowska-Majchrzak, M. Przybylski, Ecological Indicators **90**, 206-214 (2018)