# HABITAT PREFERENCES OF SMALL FISH SPECIES IN RIVERS AT THE EASTERN EDGE OF EUROPE

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## ABSTRACT

We studied the probability of occurrence, distribution and abundance of eight small fish species in 512 small rivers at the eastern edge of Europe in a region of high geographical and environmental heterogeneity. Stone loach, common minnow, and gudgeon were recorded in more than 50% of the study sites. Common minnow was the most abundant species, contributing 66% of all captures. Elevation, depth, and width of the river were the main environmental factors influencing the distribution of more than half of the studied fish species. Our research in the eastern edge of Europe shows that fish preferences in terms of probability of occurrence, abundance, and niche breadth for environmental factors can vary greatly, even among closely related species.

**ZUSAMMENFASSUNG**: Lebensraumpräferenzen von kleinen Fischarten in Flüssen in der Ostgrenze Europas.

Die Untersuchungsregion hat eine hohe geographische Heterogenität, wie auch die Umwelt. Bachschmerle, Erlitze und Gründling wurden in mehr als 50% der Untersuchungsgebieten gefunden. Außerdem hatte Erlitze die höchste Abundanz mit einem Anteil von 66% an den anderen ausgewählten Fischarten. Die Elevation, Tiefe und Breite des Flusses waren die Hauptumgebungsfaktoren, die Verteilung von mehr als Hälfte der ausgewählten Fischarten beeinflusste. Unsere Untersuchung in der Ostgrenze Europas zeigte, dass die Fischpräferenzen für Wahrscheinlichkeiten des Vorkommens, sowie der Abundanz und Nischenbreite für Umgebungsfaktoren sogar zwischen den engen verwandten Fischarten stark variieren können.

**REZUMAT**: Preferințele de habitat ale speciilor de pești mici în râurile de la limita de est a Europei.

Am studiat probabilitatea apariției, distribuției și abundenței a opt specii de pești mici în 512 râuri mici de la limita de est a Europei într-o regiune cu heterogenitate geografică și de mediu ridicată. Grindelul, boișteanul și porcușorul comun au fost înregistrați în mai mult de 50% din stațiile studiate. Boișteanul a fost cea mai abundentă specie, având o abundență de 66% din toate capturile. Altitudinea, adâncimea și lățimea râului au fost principalii factori de mediu care au influențat distribuția a mai mult de jumătate din speciile de pești studiate. Cercetările noastre de la limita de est a Europei arată că preferințele peștilor în ceea ce privește probabilitatea de apariție, abundența și lățimea de nișă pentru factorii de mediu pot varia foarte mult, chiar și în rândul speciilor strâns înrudite.

## INTRODUCTION

Small rivers are the most numerous water bodies within the Republics of Tatarstan and Bashkortostan. They make a significant contribution to biological diversity and are a refuge for many rare and endangered fish species. However, small rivers, due to their accumulative characteristics, are very fragile ecosystems (Pekárik et al., 2009; Biggs et al., 2017; Bănăduc et al., 2021a). The creation of large reservoirs, deforestation, pollution of water bodies with household waste, and grazing in the catchment area have had a strong detrimental effect on river ecosystems and have led to a change in the hydrological balance of small and medium rivers (Kuznetsov, 2005). The occurrence and abundance of many fish species, especially species of the rheophilic complex, have decreased greatly compared to their historical distribution in the Republic of Tatarstan (Askeyev et al., 2016). In addition to anthropogenic activity, the ichthyofauna of small rivers is currently negatively affected by climate warming (Buisson et al., 2013; Comte and Grenouillet, 2013; Bănăduc et al., 2021b). Tatarstan has warmed considerably over the past 30 years (Askeyev et al., 2018, 2020). If these trends continue, then many fish species of boreal origin may struggle to survive (Buisson et al., 2013; Comte and Grenouillet, 2013).

In the current study, we selected the following fish species: stone loach (*Barbatula barbatula* Linnaeus, 1758), common minnow (*Phoxinus phoxinus* Linnaeus, 1758), gudgeon (*Gobio gobio* Linnaeus, 1758), white-finned gudgeon (*Romanogobio albipinnatus* Lukasch, 1933), spined loach (*Cobitis taenia* Linnaeus, 1758), Siberian spined loach (*Cobitis melanoleuca* Nichols, 1925), ruffe (*Gymnocephalus cernua* Linnaeus, 1758) and European bullhead (*Cottus gobio* Linnaeus, 1758) (Red Book of the Republic of Tatarstan, 2016). These species are similar in morphological size, collectively contribute a large proportion of the total numbers of fish in the study region (Askeyev et al., 2015, 2017), and form the basis of the diet of predatory fish species (Askeyev et al., 2021). The study of a large region assures a wide range of environmental conditions, from small streams in upland areas to large flat rivers (Matthews, 2012). The species composition, distribution, occurrence, abundance, and ecology of fish depend largely on current environmental conditions (Matthews, 2012). The values of many environmental factors, such as height above sea level, current velocity, bottom substrate, width, depth and length of the river, affect the frequency and abundance of fish in watercourses. In this regard, it is interesting to know if there are differences between these fish species in preferences for environmental factors in the rivers of the east edge of Europe.

The main aim of the study was to reveal patterns of the distribution of eight fish species on environmental gradients in rivers in the east edge of Europe.

## MATERIALS AND METHODS

### Study area and fish assemblage data

The study area is located in the extreme east of Europe (in the eastern part of the Ponto-Caspian biogeographic region) (Fig. 1) and covers the Republic of Tatarstan and the mountainous part of the Republic of Bashkortostan. We focused on the fish assemblages of small rivers (length up to 500 km). We excluded rivers strongly impacted by large reservoirs. Fish sampling was conducted at 512 locations. Fieldwork was carried out from May to October in the years 2010-2021 during reduced summer flows. We used three different lengths of nets, depending on the width of the river. Three seining net were 5-15 m in length, 1.2-1.5 m high, 5x5 mm mesh in the wings, 3x3 mm in bags. Dip nets were of 50-70 cm diameter, with 4x4 mm mesh. Lengths of between 200 m (smaller rivers) and 400 m (larger rivers) of the river sites were sampled. For determining the length of the site, we followed the recommendations for catching fish by Fame Consortium (2004). Caught fish were placed in a plastic basin and identified, counted and measured at the end of each catch session, after which ≥ 90% of fish were returned to the water. Identification of fish was carried out according to Maitland and Linsell (2009) and Makeeva et al. (2011).

The following seven environmental variables were obtained for each site: elevation (altitude) above sea level (from 53 to 720 m, mean 239 m, standard deviation SD 184 m), mean width (from 0.5 to 55 m, mean 7.5 m, SD 15.6 m), mean depth (from 0.11 to 1.8 m, mean 0.63 m, SD 0.36 m), water velocity (from 0 to 1 m/s, mean 0.35 m/s, SD 0.16 m/s), tree/bush cover along banks (from 0 to 100%, mean 55%, SD 27.7%), dominant bottom substrate (1 – mud, 2 – clay or peat, 3 – sand, 4 – gravel, 5 – small pebbles, 6 – large stones up to 150 mm, 7 – large stones 150-300 mm, 8 – boulders > 300 mm) and human impact (as a seven point scale, 0 – no agriculture or forestry, 1 – light agricultural impact – hayfields, limited grazing and forestry at a distance of 0-250 m from the river bank, 2 – moderate agricultural impact – moderate grazing at a distance of 0-250 m from the river bank, the presence of a ford and a watering hole for livestock, 3 – strong agricultural impact – heavy grazing with visible cattle trails, arable land and housing for animals at a distance of 0-250 m from the river bank, 4 – moderate agriculture impact and oil pollution – average grazing and oil and gas extraction at a distance of 0-250 m from the river bank, 5 – urban impact – river site in town or large village, 6 – strong oil and chemical pollution is smelt and visible).

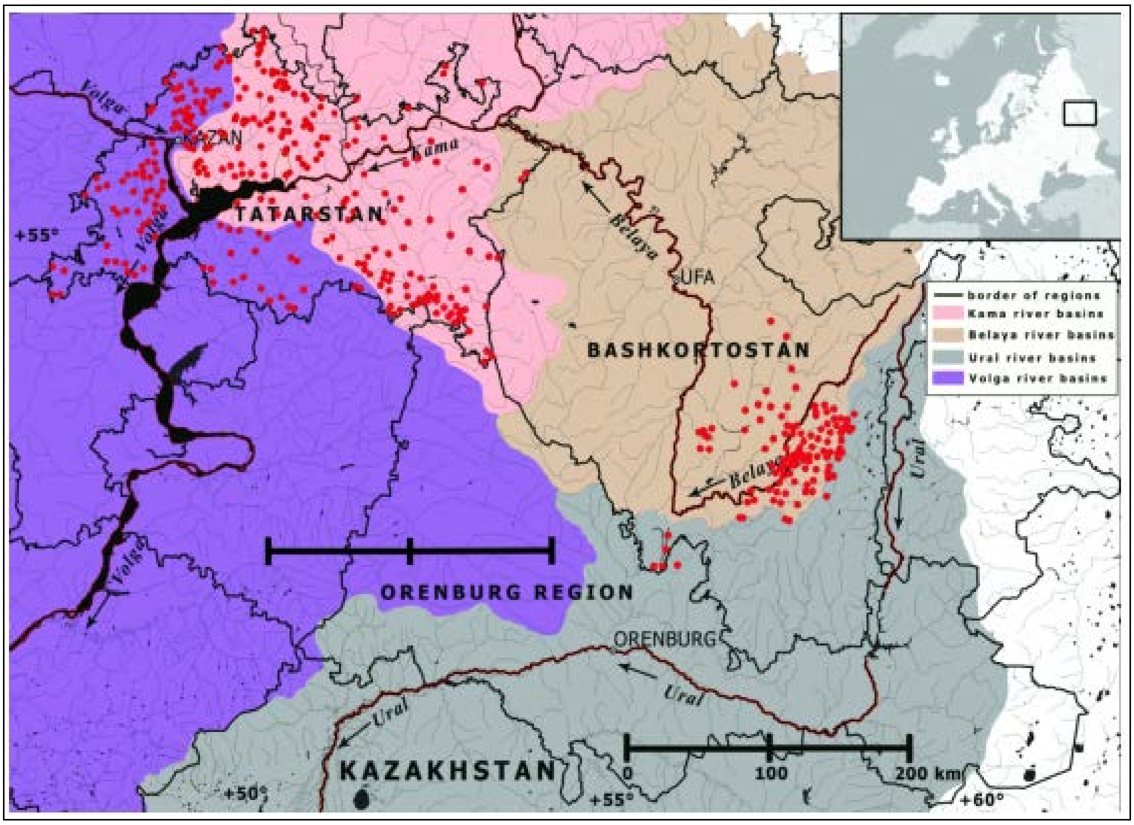

Figure 1: Distribution of the sampling sites
(inset shows location within Europe).

### Data analysis

Relationship between fish species and environmental variables

For each of the eight fish species the nature and strength of relationships with the seven environmental parameters was examined using binary logistic regression with the environmental variables as predictors. Only statistically significant variables were retained in these regressions. In order to assess the accuracy of the final models, we used the area under the ROC curve (AUC), which indicates the predictive performance expressed as an index ranging from 0.5 to 1. The accuracy of the model was interpreted after Swets (1988) as follows: 0.90-1.00 excellent; 0.80-0.90 good; 0.70-0.80 fair; 0.60-0.70 poor; and 0.50-0.60 fail.

Species optimums and niche breadth

Species optima in terms of fish numbers for each environmental variable were calculated in order to rank species by habitat preferences. This model fits Gaussian response models to species abundances along an environmental gradient. The fitted parameters are optimum (i.e. average) and niche breadth/tolerance (i.e. standard deviation). The algorithm is based on weighted averaging (ter Braak and van Dam, 1989).

Calculation and visualization were done in PAST version 4.04 and XLSTAT 2021.

## RESULTS AND DISCUSSION

### Occurrence and abundance of the fish species

Only stone loach, gudgeon, and common minnow were found in more than half of our studied sites (Tab. 1). Stone loach was the most widespread of the studied fish species (Tab. 1); it occurred at 76% of sites, much higher than in the rivers of Western Europe. For example, it occurred in 66% of French rivers (Maire et al., 2016), 43% of river basins in southwestern France (Santoul et al., 2005), 41% in northeastern Germany (Fieseler and Wolter, 2006), 32% of Czech rivers (Lusk and Pivnicka, 2009), and as juveniles in only 15% of rivers in Lithuania (Stakenas, 2002). The occurrence of gudgeon and common minnow varies strongly in different parts of Europe. For example, common minnow occurred in 64% of rivers in southwestern France (Santoul et al., 2005) and rivers in Latvia (Birzaks, 2012) but was completely absent in the potamal rivers of northeastern Germany (Fieseler and Wolter, 2006). For gudgeon, occurrence ranged from 72% in the Treene River catchment (North Germany) (Radinger et al., 2015) to 43% in France (Maire et al., 2016). These three species are quite common in Romania (Bănărescu, 1964). Common minnow had the highest abundance among the fish species in the current study (Tab. 1); it contributed 66% of the captured individuals. It is also the most abundant species in Great Britain (Pretty et al., 2003).

Table 1: Occurrence and abundance of the studied species. Species arranged in decreasing order of occurrence; mean = mean number of individuals of this species per one study site.

| Species | Occurrence % of rivers | Total number caught | Mean ± SD |
|---|---|---|---|
| Stone loach | 75.9 | 9034 | 17.7 ± 39.2 |
| Gudgeon | 67.2 | 10658 | 20.9 ± 51.8 |
| Common minnow | 59.7 | 42105 | 82.6 ± 185.5 |
| Siberian spined loach | 24.9 | 907 | 1.8 ± 7.3 |
| Spined loach | 11.0 | 226 | 0.44 ± 1.81 |
| European bullhead | 10.6 | 183 | 0.36 ± 1.72 |
| Ruffe | 6.1 | 172 | 0.34 ± 2.43 |
| White-finned gudgeon | 5.9 | 558 | 1.1 ± 12.3 |

### Environmental factors influencing the distribution of the eight fish species

The presence/absence of each fish species had statistically significant relationships with two or more of the environmental variables (Tab. 2). Seven species were associated with elevation, six with depth and width of the river, four with bottom substrate, three with tree and bush cover, two with human impact and one species with water velocity. All final models had satisfactory (fair to excellent) predictive power (AUC) varying from 0.78 to 0.94 (Tab. 2). For the most abundant and frequently occurring fish species the most influential environmental factors, such as elevation and river morphology, were similar to those in the less environmentally diverse sub area of Tatarstan (Askeyev et al., 2015). Thus, we can say with confidence that these factors are of integral importance for fish species at the eastern edge of Europe.

Models of stone loach and common minnow in relation to environmental factors were quite similar; both species were found mainly in rivers that are small in terms of width and depth (Fig. 2), at a relatively high elevation and with relatively hard bottom substrates (Tab. 2, Fig. 3). Similar results have been reported in many regions of Europe (Bănărescu, 1964; Mastrorillo et al., 1996; Lusk and Pivnicka, 2009; Maire et al., 2016). However, the common minnow in our study, in contrast to the stone loach, had preferences for clear river sites without human impact; a similar relationship with human impact was described in Bănărescu (1964). The negative impact of anthropogenic pressure on common minnow has been described in Finland (Sutela and Vehanen, 2010) and Romania (Bănărescu, 1964). For gudgeon, in contrast to stone loach and common minnow, we observed contrasting preferences for environmental factors. In our study, gudgeon occurred more often in wide and deep rivers (Fig. 2); similar preferences were found in Hungary, Czech Republic, Latvia, and France (Takács et al., 2008; Lusk and Pivnicka, 2009; Birzaks, 2012; Maire et al., 2016). We noted that gudgeon avoided sections of rivers with “hard” substrates that are not suitable for them as food and spawning substrates; similar preferences for this species are described in Lamouroux and Souchon (2002). Another factor (negatively) influencing the occurrence of gudgeon was tree/bush cover. A similar relationship was described in Hungary and France (Takács et al., 2008; Maire et al., 2016). Another possible reason for the gudgeon avoiding high tree/bush cover is a negative relationship with burbot (*Lota lota*, Linnaeus, 1758), which is a predator of gudgeon and prefers shaded areas of rivers (Askeyev et al., 2021). Such strong differences in environmental preferences among the most common and numerous fish species in our study region emphasize the need for a wide variety of environmental conditions by living organisms. The European bullhead is a typical rheophilic species that prefers rhythral conditions in rivers (Fig. 3), mainly in mountainous areas, avoiding slow moving rivers. The preference of the European bullheads for fast sections of rivers has been previously noted (Blanck et al., 2007; Cismaş et al., 2017). In our study, European bullhead avoided areas with soft substrates such as silt or clay, since they cannot serve as a substrate for reproduction and do not provide a safe refuge from predatory species (Gosselin et al., 2010). The European bullhead can be an indicator of the clarity of watercourses; this species does not occur in areas with a high anthropogenic impact and, moreover, a chemical pressure. A similar reaction of the European bullhead to pollution was noted in Finland and Romania (Sutela and Vehanen, 2010; Curtean-Bănăduc et al., 2017). Unlike the European bullhead, the white-finned gudgeon, and ruffe are potamal species, they occur more often in deep and wide rivers at low elevation (Tab. 2, Fig. 3). The preference of these species for large rivers was noted in the Czech Republic (Lusk and Pivnicka, 2009). The two closely related *Cobitis* species (spined loach, Siberian spined loach) have similar altitude preferences, inhabiting the lower part of the gradient, but the Siberian spined loach prefers deeper water and less tree/bush cover than the spined loach.

Table 2: Coefficients and model summary summarising the relationship between presence/absence of fish and environmental variables. Species arranged in decreasing order of occurrence.

| Species | Constant | Elevation | Width | Depth | Velocity | Tree/bush cover | Substrate | Human impact | AUC |
|---|---|---|---|---|---|---|---|---|---|
| Stone loach | 1.64 | 4.09 | –6.25 | –0.47 | | | 0.34 | | 0.781 |
| Gudgeon | –1.58 | | 0.19 | 1.56 | | –0.22 | –0.39 | | 0.811 |
| Common minnow | –0.92 | 2.37 | –5.75 | –0.51 | | | 0.59 | –0.31 | 0.801 |
| Siberian spined loach | –0.49 | –2.10 | | 0.95 | | –1.60 | | | 0.778 |
| Spined loach | –1.55 | –3.78 | 1.83 | | | | | | 0.763 |
| European bullhead | –5.04 | 4.39 | | | 1.27 | | 0.47 | –0.32 | 0.856 |
| Ruffe | –3.90 | –0.21 | 5.14 | 2.79 | | | | | 0.931 |
| White-finned Gudgeon | 0.57 | –5.15 | 3.61 | 2.11 | | –1.54 | | | 0.941 |

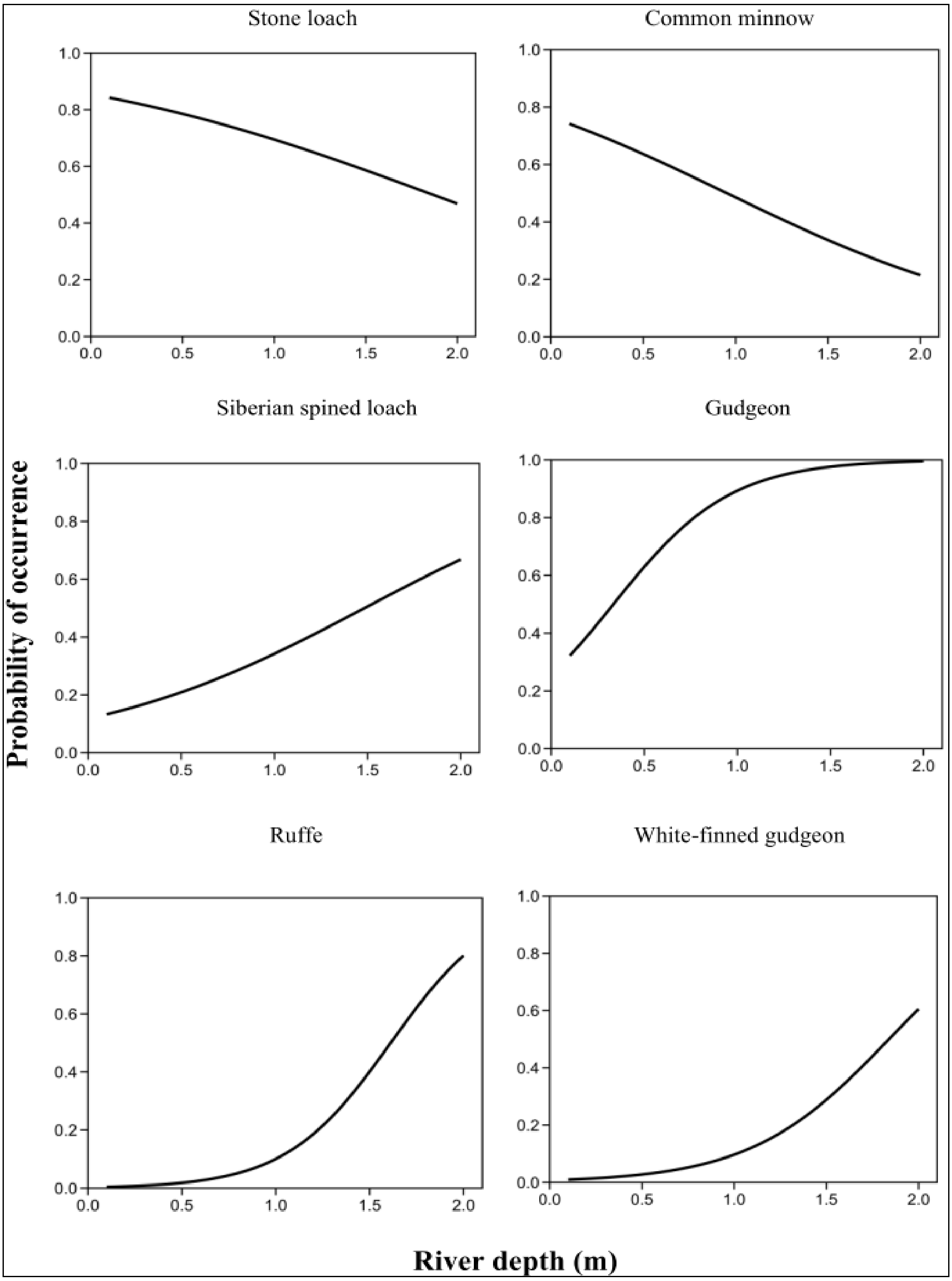

Figure 2: Relationship between the probability of occurrence of fish and depth for six species for which depth was a significant influence. Species arranged in order of increasing depth.

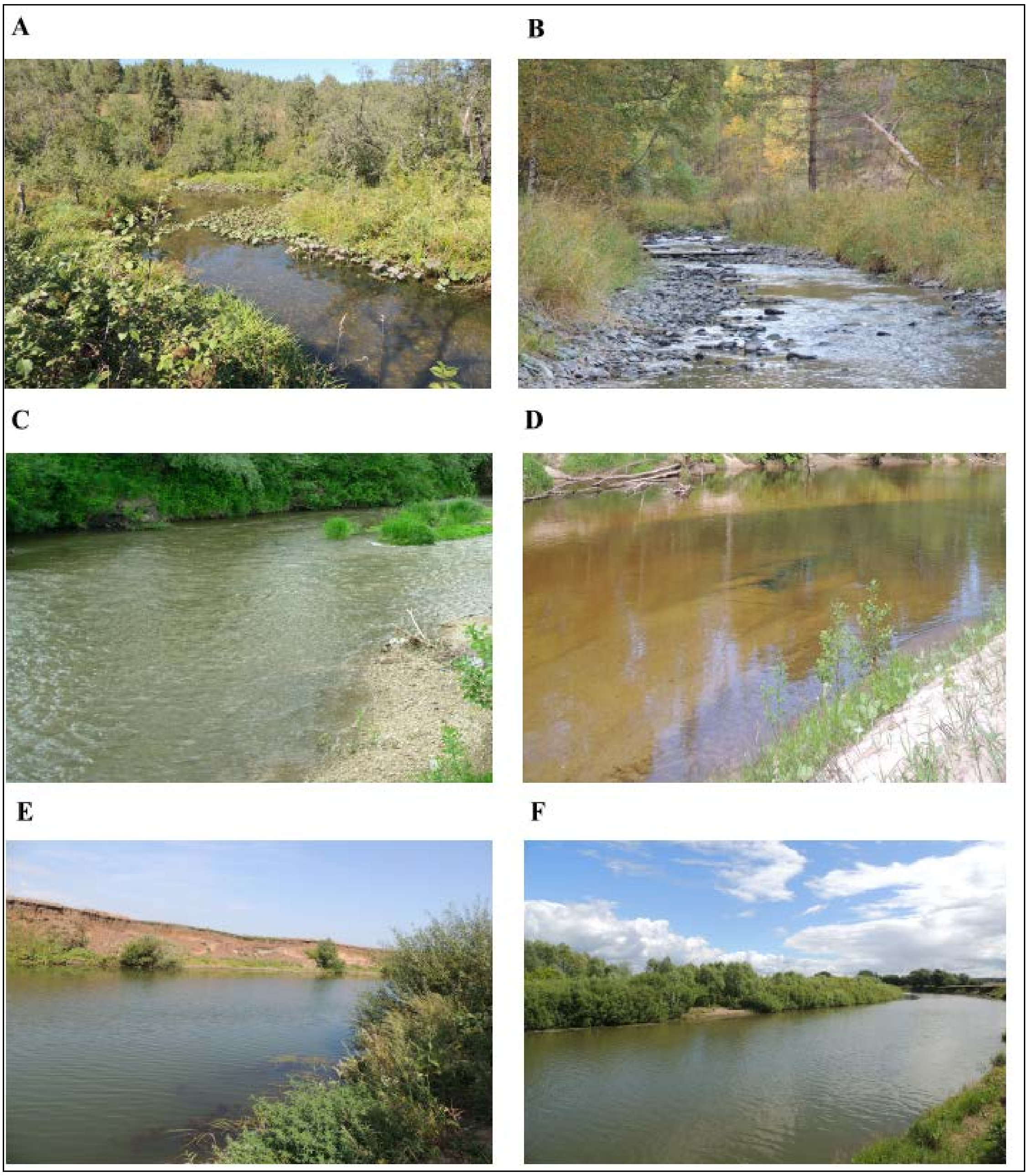

Figure 3: Typical habitats for common minnow and stone loach (A), for European bullhead (B), for spined loach (C), for gudgeon (D), for Siberian spined loach (E) for ruffe and white-finned gudgeon (F).

**Species optimum and niche breadth**

Table 3 shows the optimal points and breadths on four continuous environmental variables; those for elevation have been presented elsewhere (Askeyev et al., 2017). The optimal values varied greatly between fish species for some factors. For example, the difference in optimal river width between the narrowest (stone loach and common minnow) and the widest (ruffe) was 37 m. Ruffe is the only species in our current study that had an optimal depth value of more than one m, while in the common minnow it was < 0.5 m. The white-finned gudgeon had the smallest optimal for tree/bush cover but the highest for velocity. Niche breadth also varied greatly between species, and within the same species to different environmental factors. For example, the ruffe had the widest niche for river width but the narrowest for tree/bush cover. The difference in the niche breadth for river width was more than 24 m. But the niche breadths of all environmental factors did not all differ greatly, for example, the niche breadth for velocity in our study was relatively similar for all fish species. The narrow niche of stone loach for river width and depth was one of the reasons why this species, despite being the most widespread, was not the most abundant species of small rivers at the eastern edge of Europe.

Table 3: Optimum values and tolerance (niche breadth) of the studied fish species against four environmental variables (based on abundance data). Species arranged in decreasing order of occurrence.

| Fish species | Width (m) | Depth (m) | Velocity (m/s) | Tree/bush cover (%) |
|---|---|---|---|---|
| Optimum values | | | | |
| Stone loach | 5.8 | 0.66 | 0.35 | 52.2 |
| Gudgeon | 10.6 | 0.72 | 0.30 | 45.3 |
| Common minnow | 5.4 | 0.48 | 0.39 | 62.5 |
| Siberian spined loach | 9.9 | 0.79 | 0.33 | 35.3 |
| Spined loach | 11.3 | 0.73 | 0.33 | 51.6 |
| European Bullhead | 8.2 | 0.53 | 0.45 | 65.9 |
| Ruffe | 43.3 | 1.35 | 0.44 | 42.3 |
| White-finned gudgeon | 27.2 | 0.93 | 0.45 | 34.8 |
| Tolerance (niche breadth) | | | | |
| Stone loach | 5.1 | 0.26 | 0.15 | 26.4 |
| Gudgeon | 11.1 | 0.28 | 0.14 | 27.7 |
| Common minnow | 15.1 | 0.47 | 0.16 | 22.9 |
| Siberian spined loach | 14.8 | 0.36 | 0.16 | 22.5 |
| Spined loach | 11.6 | 0.32 | 0.14 | 25.9 |
| European bullhead | 9.5 | 0.29 | 0.15 | 20.2 |
| Ruffe | 29.7 | 0.42 | 0.15 | 14.9 |
| White-finned gudgeon | 11.4 | 0.29 | 0.13 | 15.6 |

## CONCLUSIONS

For rational protection in the era of global climate change, it is important to understand the responses of specific animal species to environmental factors in large and varied landscapes. Our research at the eastern edge of Europe shows that fish preferences for environmental factors can vary greatly, even among closely related species. Thus, we see that the distribution of fish, as well as their protection, can only be satisfactorily explained when using a combination of all the environmental factors involved. Based on the results of our work, the Rychkovskaya Lesostep protected natural area has been created, which includes rivers characterized by a high abundance of the European bullhead which is currently on Tatarstan's Red List.

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