AQUATIC RESEARCH

AQUATIC RESEARCH
E-ISSN 2618-6365

Aquatic Research 7(4), 189-198 (2024) • https://doi.org/10.3153/AR24017 Research Article

Spatial and temporal dynamics of fish-habitat interactions in Yuvarlakçay stream (Muğla, Türkiye)

Nildeniz KARAKUŞ

Cite this article as:
Karakuş, N. (2024). Spatial and temporal dynamics of fish-habitat interactions in Yuvarlakçay stream (Muğla, Türkiye). *Aquatic Research*, 7(4), 189-198. https://doi.org/10.3153/AR24017

Muğla Sıtkı Koçman University, Faculty of Fisheries, 48000, Muğla, Türkiye

ORCID IDs of the author(s):

N.K. 0000-0001-8490-6261

Submitted: 18.03.2024
Revision requested: 06.05.2024
Last revision received: 12.05.2024
Accepted: 13.05.2024
Published online: 29.08.2024

Correspondence:
Nildeniz KARAKUŞ
E-mail: nildeniz@mu.edu.tr

ABSTRACT

Human activities significantly impact freshwater ecosystems, and the dynamic nature of fluvial ecosystems makes resident species more vulnerable. The ecological importance of freshwater organisms is often overlooked in conservation concepts. The Yuvarlakçay Stream in Muğla, Türkiye, hosts endemic species but lacks conservation plans despite various threats. Freshwater habitat quality significantly affects fish survival, emphasising the need to establish fish-habitat relationships. This study aims to reveal habitat use and temporal/spatial interactions of fish in the ecosystem. In this context, Constrained Quadratic Ordination (CQO) and Point Abundance Sampling (PAS) with electrofishing are employed to understand fish-habitat relationships in the Yuvarlakçay Stream. The results revealed insignificant spatial variations over seasons within the fish populations. The endemic Aegean chub *Squalius fellowesii*, barbel *Barbus xanthos*, and spined loach *Cobitis fahireae* emerged as the most prevalent species in the study. Their presence was consistent across seasons, and their habitat relations exhibited overlaps. Water abstraction for agricultural and aquacultural purposes is defined as the major threat in the area, compounded by climate change-induced reductions in rainfall.

Keywords: *Anguilla anguilla, Rhodeus amarus*, Constrained Quadratic Ordination, *Knipowitshcia caunosi, Oncorhynchus mykiss*

Introduction

Globally, freshwater ecosystems encounter several threats and stressors, such as habitat degradation, pathway blockages, pollution, introduction of non-native species, overfishing and the impacts of climate change (Malmqvist & Rundle, 2002; Dudgeon et al., 2006). Paradoxically, despite the ecological significance of freshwater ecosystems (Carpenter et al., 1992), they often receive insufficient attention (Dudgeon et al., 2006; Butchart et al., 2010; Barbarossa et al., 2021). The dynamic nature of fluvial ecosystems further compounds the challenge, making resident species vulnerable in space and time (Angeler et al., 2014). The quality of freshwater habitats significantly influences fish survival within ecosystems (Carpenter et al., 2011). Changes in habitat availability can pose a threat to species persistence. In conservation, it is essential first to establish fish-habitat relationships and overall fish community structures (Yamazaki et al., 2006). For instance, significant gaps in knowledge and data availability among habitat requirements are discovered for many Italian species (Negro et al., 2021). Thus, species that depend on specific habitats can be at risk of extinction, and reduced water availability may lead to increased cohabitation and competition between species. Therefore, the habitat requirements that play a critical role for species should be determined within the ecosystems (Doll et al., 2021). Constrained Quadratic Ordination (CQO) is commonly employed to determine fish-habitat relations (Vilizzi et al., 2012). This technique focuses on species-specific habitat profiles and unveils how different species interact and coexist (Klaar et al., 2004; Vilizzi et al., 2012; Top et al., 2016, 2019). On the other hand, Point Abundance Sampling (PAS) using electrofishing (Persat & Copp, 1989) has proven to be a valuable approach for habitat utilisation studies, offering simplicity and a non-lethal method. With the help of these environment-friendly methods, we aimed in the present study to understand the overall structure of the fish community and significant threats in a small stream in Aegean Region-Türkiye. Environmental variables significantly influence fish habitat preferences and community structure, including substrate type, water velocity, and vegetation cover. (Vieira et al., 2020). Due to anthropogenic pressures and natural ecosystem dynamics, these habitat characteristics dictate endemic species' spatial and temporal distribution, affecting biodiversity and ecosystem resilience. Therefore, the particular focus of the study was to reveal (i) the habitat use of the resident species and (ii) temporal and spatial interactions of fish assemblages in the Yuvarlakçay stream, Muğla (SW, Türkiye).

Materials and Methods

Sampling Locations

The Yuvarlakçay stream is 15 km in length and feeds an important lake (Köyceğiz Lake) in south-west Türkiye (Figure 1). We determined five sampling sites based on elevation (Table 1, Figure 2) along the stream as representatives of ecologic zones (Simonović et al., 2017). The headwater section (S0, crenon) was not wadable or sampled due to possible insecure fieldwork. Therefore, the first locality was a wadable uppermost part of the stream (S1). The general habitat structure was mostly shallow (~0,5m), including high velocity along stones, and was poor in submerged vegetation. Sites 2, 3 and 4 were determined on the areas of the rhithron section of the stream (Figure 1, Table 1). Finally, the last sampling site of the study (S5) was the connection section to the lake of the stream along the potamon zone.

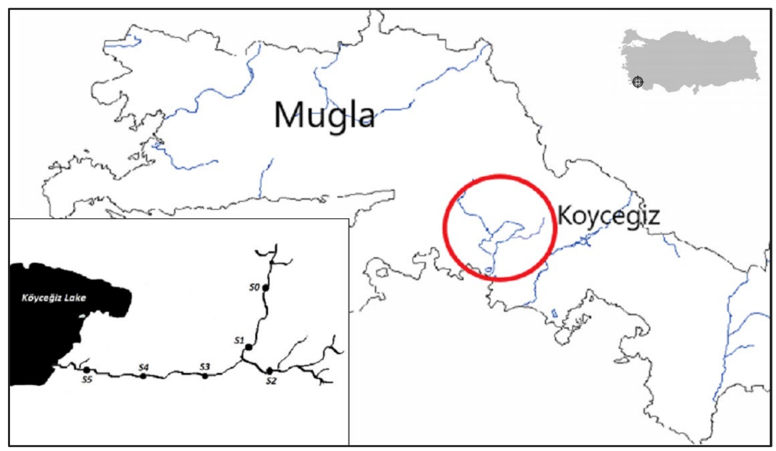

Figure 1. Map of the Yuvarlakçay stream and sampling locations

Point abundance sampling was applied via electrofishing from down to up direction following a zigzag manner (Tomanova et al., 2013). Fifty points were sampled on each site during a season. S4 was dried up in summer due to a common anthropogenic pressure (water abstraction), and no data was available. Therefore, 950 points were electrified along the stream (Table 1). On each randomly selected point, we recorded the physical variables, and these included depth, dominant substrate types, distance from the bank, submersed vegetation, submersed woody structure (roots, riparian), plant cover, velocity, light condition and turbidity (Vilizzi et al., 2012). These variables were measured as follows: Depth and Distance from the bank, with a one-meter-long pole labelled each 10 cm. Substrate types were classified based on particle size, measured in millimetres (mm), according to a modified Wentworth scale: mud (<0.062 mm), pebbles (4 mm to 64 mm), stones (64 mm to 256 mm), big stones (256 mm to 1024 mm), and rocks (>1024 mm). Submersed structures and plant cover were quantified as percentages within a 2m² surveyed area (Beyer et al., 2007). Water velocity was determined semi-quantitatively as described in Beyer et al. (2007) using the pole; upon immersion of the pole, (1) absent: no ripple effect around the pole was noted as zero water velocity; (2) weak: a gentle ripple effect (broken water) around the pole (>0 but <5cms-1); (3) moderate: an elevated ripple effect around the pole (5–10 cm s-1). The light condition was noted, including whether the discrete sampling point was in the sun or shaded. Turbidity: visually determined as clear, turbid and very turbid. For data analysis, nominal variables such as 'sunny'/'shady' were coded (e.g., sunny = 1, shady = 2). Water temperature was measured on each side with a temperature probe (YSI ProDSS) and represented in Table 2. The same person applied measurements on each season/site to sustain consistency.

Table 1. Geographical locations and total sampling points by each site and season

Sites	Elevation (m)	Lat-Lon	Winter	Spring	Summer	Autumn
S0	209	36.945-28.808	-	-	-	-
S1	108	36.918-28.796	50	50	50	50
S2	107	36.907-28.808	50	50	50	50
S3	58.4	36.906-28.771	50	50	50	50
S4	28.9	36.906-28.740	50	50	-	50
S5	6.9	36.907-28.711	50	50	50	50
Total			250	250	200	250

Figure 2. Habitat examples of Yuvarlakçay stream

Fish Metrics and Community Analysis

The fish survey was employed using binary data (presence/absence) on each described point by each pulse. A matrix bubble plot was used to illustrate the abundance of fish populations across sites and seasons. For this purpose, fish survey data were used to find the cumulative sum of each site species. Using the cumulative sum, the matrix bubble plot was generated using R-4.2.3 (R Core Team, 2022) with the library "tidyverse" to visually display each taxon amount.

The Shannon Diversity Index H determined the taxonomic diversity of fish at each sampling site (Welcomme, 1979). It considers both the richness (the number of different species present) and the evenness (EH, the relative abundance of those species). This index measures the uncertainty or entropy associated with species diversity in the ecosystem. A higher Shannon Diversity Index indicates greater diversity. It is calculated using the expression:

$H' = -\Sigma pi \times \ln(pi)$

$EH = H' / \ln(Si)$

In this formula, H': the Shannon Diversity Index, pi represents the proportion of individuals of the i-th species relative to the total number of individuals. Si is the number of species on site/season.

One-way ANOVA was used independently to analyse the effects of sites (spatial) and seasons (temporal) on fish species richness (Park et al., 2020).

CQO evaluated the degree of overlap and sharing of microhabitat preferences between species following the instructions of Vilizzi et al. (2012). With generalized linear models, this technique has been found suitable for shaping fish-environment relationships (Yee 2004, 2006). CQO is brief; a sample × species data matrix is related to a sample microhabitat variables data matrix, and the output is an ordination diagram. In this diagram, the x-axis represents the 'latent variable', which in the present case is a combination of physical descriptors (Table 3, note: Light and turbidity were not considered in the analysis due to the inconsistent records of light and indifference of turbidity among sites) whereas the y- axis plots the n scores (i.e. abundance or presence/absence). CQO estimates an optimal linear combination of the environmental variables and regresses the species data upon the latent variable using quadratic curves fitted across the species scores. Each response curve in an ordination diagram represents the distributional range of a certain fish species across the microhabitat gradient so that the relative position of the curve indicates the use/preference of a certain fish species for certain values (Table 4). Models were run in R-4.2.3 (R Core Team, 2022) using library VGAM v0.9-7 using following scripts: cqo (formula = cbind (Sp1, Sp2) ~ scale(habitat1) + scale(habitat2) +, family = binomialff (multiple.responses = TRUE), Rank = 1, df1.nl = 3 , Bestof = 100, Crow1positive = FALSE, I.tolerances = FALSE, data = Season).

Results and Discussion

Three hundred ninety-six specimens across 11 taxa were identified in the Yuvarlakçay Stream. The matrix bubble plots showed spatial variations over seasons within the fish population (see Figure 3). Notably, the statistical analysis revealed that there were no significant site-related impacts on overall diversity (F=1.287, $P > 0.05$), and the seasonal variations did not exert any influence on the community distribution ($F = 0.014$, $P > 0.05$) (Table 2). The uppermost sampling location -Site 1- has the lowest species number (Table 3, Figure 3). The potamon section of the Yuvarlakçay stream, i.e., Site 5, has the highest species diversity, hosting 10 species (Table 3). The Evenness Index (EH) exhibited a consistent pattern, with similar values observed across all sampling sites (Table 2).

The most prevalent fish species identified in the study included the endemic Aegean chub *Squalius fellowesii* (Günther, 1868), barbel *Barbus xanthos* (Güçlü et al., 2020) and the spined loach *Cobitis fahireae* (Linnaeus, 1758) (Table 3). In contrast, the European eel *Anguilla anguilla* (Linnaeus, 1758) and the endemic scraper *Capoeta aydinensis* (Turan et al., 2017) were found in smaller numbers. Mullet *Mugil cephalus* and the non-native rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792), which had escaped from aquaculture facilities, were relatively rare, accounting for less than 2% of the total count in the study. Endemic Anatolian gizani *Ladigesocypris irideus* (Ladiges, 1960) and dwarf goby *Knipowitschia byblisia* (Balık et al., 2005; Ahnelt, 2011) were observed in limited numbers, while bitterling *Rhodeus amarus* (Bloch, 1782) was documented for the first time in the Yuvarlakçay Stream, with just one specimen recorded during the study.

Seasonal CQO results are presented in Figure 4. Table 4 displays the species scores for each component on the latent variable (Figure 4) and provides the scores for the descriptors. As shown in Figure 3, the response profiles or bell-shaped curves overlapped in most cases for Cyprinid species but exhibited variations in occurrence. These species were consistently discovered in areas with coarser substrates, near riparian trees with vegetation, and the stream bank. The spined loach, *Cobitis fahireae*, avoids deep waters and woody structures (such as those found along the stream bank). Instead, it primarily inhabits vegetated, finer substrates in shallow waters, particularly during summer. *Anguilla anguilla* was observed in significant numbers during the autumn season. Although they exhibited considerable overlap with other species in winter and spring, a shift in their distribution was noted during autumn and summer. For the ordination diagram, we included the most abundant fish species. The less abundant ones led to a confusing representation on the diagram, as they did not exhibit bell-shaped curves (Figure 4); however, these less abundant species were discussed separately.

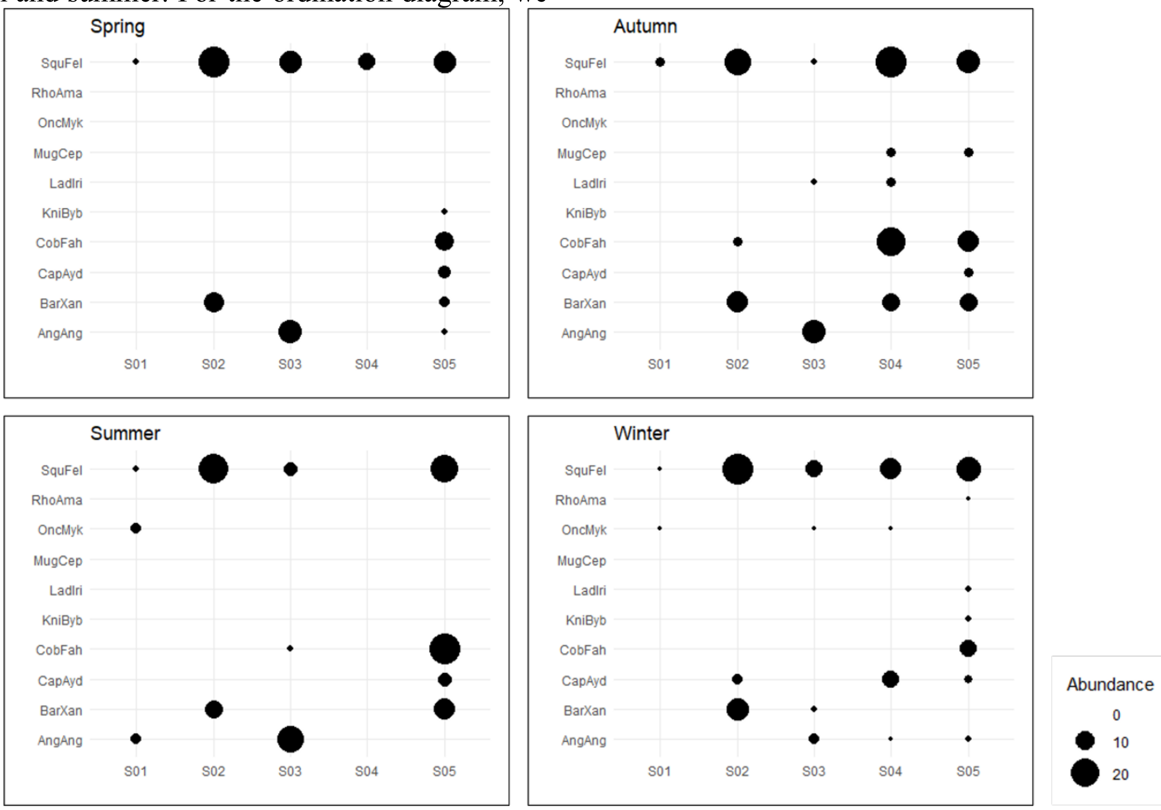

Figure 3. Species abundance bubble plot for the Yuvarlakçay Stream over sites and seasons. SquFel: *Squalius fellowesii*, RhoAma: *Rhodeus amarus*, OncMyk: *Oncorhynchus mykiss*, MugCep: *Mugil cephalus*, LadIri: *Ladigesocypris irideus*, KniByb: *Knipowitschia byblisia*, CobFah: *Cobitis fahireae*, CapAyd: *Capoeta aydinensis*, BarXan: *Barbus xanthos*, AngAng: *Anguilla anguilla*.

Table 2. Summary of data, sites, Shannon Diversity Index (H^i), Evenness (EH), Seasons, Sampling date and Temp (water temperature)

Sites	H^i	EH	Seasons	Sampling date	H^i	EH	Temp(°C)
S1	1.01	0.94	Winter	18.02.2022	1.60	0.77	6.6
S2	0.99	0.55	Spring	19.05.2022	1.66	0.75	17.8
S3	1.03	0.57	Summer	24.08.2022	1.57	0.81	24.8
S4	1.66	0.76	Autumn	29.10.2022	1.52	0.66	11.3
S5	1.80	0.72					

Table 3. Number of fish species sampled from each site during the study

Taxon/Sites	S1	S2	S3	S4	S5	Total (n)
Anguilla anguilla	2	-	33	1	3	39
Barbus xantos	-	36	2	6	15	59
Capoeta aydinensis	-	4	-	9	11	24
Cobitis fahireae	-	2	1	14	38	55
Knipowitschia byblisia	-	-	-	-	3	3
Ladigesocyrpris irideus	-	-	1	2	2	5
Mugil cephalus	-	-	-	2	2	4
Oncorhynchus mykiss	3	-	1	1	-	5
Rhodeus amarus	-	-	-	-	1	1
Squalius fellowesii	5	70	21	36	48	180
Larvae	-	2	-	14	5	21
Total number of species	3	5	6	9	10	11

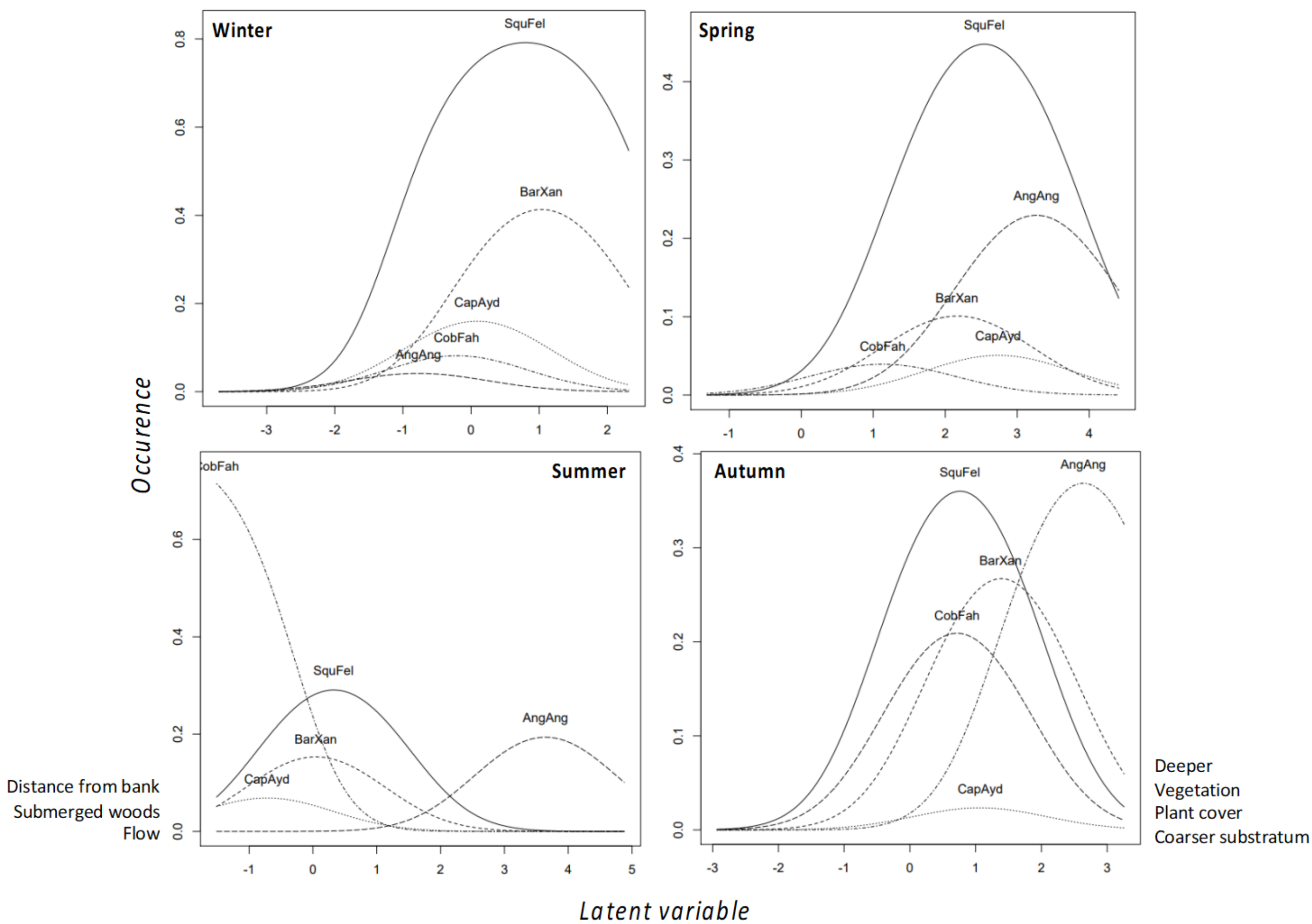

Figure 4. CQO ordination plots for species of the Yuvarlakçay Stream over seasons. A summary of the main microhabitat features (i.e., Table 4) is provided on each side of the latent variable. (SquFel: *Squalius fellowesii*, BarXan: *Barbus xanthos*, CapAyd: *Capoeta aydinensis*, AngAng: *Anguilla anguilla*, CobFah: *Cobitis fahireae*)

Species Diversity and Distribution

Identified species provide a foundational understanding of the fish community within the Yuvarlakçay Stream. Notably, the species diversity exhibited spatial variability (Table 3). While the uppermost sections of the stream (Site 1 & 2) displayed the lowest diversity, the potamon section of the stream (Site 5) hosted a remarkable total of 10 species. This section of the stream is a transition area between the river and the lake. This refers to the increased diversity and density of plant and animal species that typically occurs in these transition zones. This variation in species richness among sites highlights the importance of considering spatial factors in managing and conserving aquatic ecosystems.

Matrix bubble plots depicted the dynamic nature of the fish community (Figure 3), with changes occurring over the year. Despite these fluctuations, statistical analysis indicated that overall diversity remained stable across sites and seasons. The consistent pattern observed in the Evenness Index (EH) further emphasises the resilience and stability of the fish community in the face of environmental variations.

Species-Specific Insights

Insights into the habitat preferences of certain species provide valuable information for conservation efforts. *Squalius fellowesii, B. xanthos*, and *C. fahireae* emerged as the most prevalent species in the study. Their presence was consistent across seasons, and their distribution profiles exhibited overlaps. However, *A. anguilla* and *C. aydinensis* were encountered in smaller numbers, suggesting potential vulnerabilities or habitat preferences that warrant further investigation.

Anguilla anguilla was particularly abundant during the autumn season and mostly occurred on Site 3. They generally prefer being distant from the riverbank, found in a coarser substratum in the middle of the stream section with high flow. In autumn, they prefer hiding among riparian trees (i.e., woody structures). However, in spring, they avoid velocity, submersed woods and vegetation. The observation that *A. anguilla* was particularly abundant during different seasons could suggest that this altered presence is linked to their migratory behaviour or other ecological factors affecting their distribution. For instance, current velocities, inclination pitches, bottom materials and carrying capacities are potential factors in different habitat use and migration behaviours of eels (Glova et al., 1998). On the other hand, seasonal changes in food items/prey populations could also influence eel abundance, with eels possibly taking advantage of increased prey availability (Arai, 2022). The European eel has been listed as Critically Endangered in the latest International Union for Conservation of Nature (IUCN) Red List assessment (Pike et al., 2020). Thus, the data on local population structures have a critical role in the overall population trend (ICES, 2020; Ertürk et al., 2023), and their repartition in the Yuvarlakçay Stream during particular seasons emphasises the importance of considering temporal dynamics in ecological studies.

Capoeta aydinensis is notably abundant in a nearby stream, the Tersakan stream, as reported by Akbaş et al. (2019). These fish are predominantly found in muddy shelters along the stream bank in that stream. Interestingly, Akbaş et al. (2019) highlighted that they tend to inhabit turbid waters. However, it is worth noting that turbidity was not a significant factor in the present study. Consequently, the lower catches of *C. aydinensis* observed in our study may be attributed to the absence of turbidity, which could have acted as a stressor for this species.

Cobitis fahireae preferred highly vegetated flowing waters, particularly during the summer. As small-sized fish, they use small stones as shelters/shields and a large number of the specimens were caught from both submerged plants and filamentous algae. This behavioural adaptation aligns with its avoidance of deep waters and woody structures. These bottom-dwelling species are very sensitive to any disturbance of benthic structure, which is vulnerable to getting easily altered by human activities (Erkakan & Ekmekçi, 2000). The final photograph in Figure 2 is crucial as it clearly shows the stream structure characteristic of the Cobitis species' environment, and its destruction must be prohibited immediately.

The Yuvarlakçay Stream hosts several endemic species; however, the present study revealed that one of them, *Ladigesocypris irideus*, was rarely encountered, accounting for less than 2% of the total samples collected from the entire stream. Previous research by Top and Tarkan (2009) indicated that the Anatolian gizani prefers stagnant, deep, and ponded sections of streams, often among small pebbles. Despite its tolerance to high temperatures and low oxygen levels (Özdemir et al., 2015), the population trend of this small endemic species is declining (Yılmaz et al., 2015). Notably, *L. irideus* is classified as "Near Threatened" on the Red List (Yılmaz et al., 2015).

Knipowitschia spp. Inhabit various aquatic environments, including marine, freshwater, and brackish waters (IUCN, 2022). The present study discovered them at the nearest site to the lake, Site 5. This observation aligns with the expectation that they primarily inhabit Köyceğiz Lake (Balık et al., 2005; Ahnelt, 2011). Köyceğiz Lake is distinguished by its brackish water composition (Akın et al. (2005). This unique environmental condition would have provided a favourable habitat for a euryhaline population of *Knipowitschia byblisia* (Ahnelt, 2011).

The mullets, occasional residents in the area, were primarily captured at sites near the lake, specifically at Sites 4 and 5. Notably, mullets constitute the most numerous fish species within Köyceğiz Lake, demonstrating a remarkable tolerance to fluctuating environmental conditions (Akın et al., 2005).

Among the fish species observed in the entire stream, the aquaculture escapee *Oncorhynchus mykiss* stood out as the only non-native fish species, with only a few individuals recorded. The presence of escapees can potentially act as a stressor if they establish themselves in the ecosystem. However, it is important to note that the habitat suitability for rainbow trout in the Muğla region is limited, and there have been no officially confirmed established populations of this species (Yoğurtçuoğlu et al., 2021).

Conclusion

The comprehensive seasonal sampling effort conducted at various sites within the Yuvarlakçay stream revealed valuable insights into the fish populations and their ecological dynamics.

The results presented in this study provide knowledge of several key aspects of the stream's fish community and its response to seasonal and spatial variations.

The stability of overall diversity, species-specific patterns, and habitat preferences offer valuable insights for conserving and managing this unique aquatic ecosystem. Protecting the unique habitats in the Yuvarlakçay stream from environmental destructions such as water abstraction, pollution, artificial hydraulic barriers, trout farms, etc., is essential.

Further research, especially focusing on the less common species and their specific ecological requirements, will contribute to a more comprehensive understanding of the stream's biodiversity and its responses to environmental changes. As the vulnerability of endemic species continues to trend upward, this study becomes a crucial source of knowledge for prioritising protection plans.

Further, it is essential to recognise that water abstraction for agricultural and aquacultural purposes stands out as the major threat in the area, compounded by climate change-induced reductions in rainfall (Cai & Cowan, 2013), economic development, and the expanding human population (Squires, 2014). Additionally, the thriving tourism industry in the region places significant demands on freshwater resources, further increasing the strain on water sources, which are often polluted.

Compliance with Ethical Standards

Conflict of interest: The authors declare no actual, potential, or perceived conflict of interest for this article.

Ethics committee approval: This study was conducted by approval (2021/13-2) of Muğla Sıtkı Koçman University-Local Ethics Committee for Aquatic Animal Experimentation.

Data availability: Data will be made available on request.

Funding disclosure: This study was supported by the Scientific & Technological Research Council of Türkiye (TUBITAK, Project No: 1919B012101484).

Acknowledgements: I sincerely thank Uğur Karakuş and Gizem Demircan, who helped with the sampling in the Yuvarlakçay Stream.

Disclosure: -

References

Ahnelt, H. (2011). Two new sympatric Knipowitschia species (Telesotei: Gobiidae) from an Eastern Mediterranean coastal examples of different dispersal patterns? *Zootaxa,* 3114, 22–30. https://doi.org/10.11646/zootaxa.3114.1.2.

Akbaş, F., Tarkan, A. S., Top, N. Karakuş, U. (2019). Endemik tatlısu balığı *Capoeta aydinensis* (Turan, Küçük, Kaya, Güçlü & Bektaş, 2017)'in Tersakan Deresi (Muğla)'ndeki bazı biyolojik özellikleri, habitat gereksinimleri ve korunması için öneriler. *Turkish Journal of Bioscience and Collections,* 3(2), 43-52. https://doi.org/10.26650/tjbc.20190009.

Akın, S., Buhan, E., Winemiller, K.O. Yilmaz, H. (2005). Fish assemblage structure of Koycegiz Lagoon-Estuary, Turkey: Spatial and temporal distribution patterns in relation to environmental variation. *Estuarine Coastal and Shelf Science,* 64, 671–684. https://doi.org/10.1016/j.ecss.2005.03.019

Angeler, D. G., Allen, C. R., Birgé, H. E. et al. (2014). Assessing and managing freshwater ecosystems vulnerable to environmental change. *AMBIO*, 43, 113–125. https://doi.org/10.1007/s13280-014-0566-z

Arai, T. (2022). Migration ecology in the freshwater eels of the genus *Anguilla* Schrank, 1798. *Tropical Ecology,* 63, 155–170. https://doi.org/10.1007/s42965-021-00217-7

Balık, S., Ruşen, M., Sarı, H.M., İlhan, A. Topkara, E.T. (2005). The fish fauna of Yuvarlakçay (Köyceğiz, Muğla).

Ege University Journal of Fisheries & Aquatic Sciences, 22, 221–223.

Barbarossa, V., Bosmans, J., Wanders, N., King, H., Bierkens, M. F. P., Huijbregts, M. A. J., Schipper, A. M. (2021). Threats of global warming to the world's freshwater fishes, *Nature Communications,* 12(1), 1701. https://doi.org/10.1038/s41467-021-21655-w

Beyer, K., Copp, G.H. & Gozlan, R.E. (2007). Microhabitat use and interspecific associations of introduced topmouth gudgeon *Pseudorasbora parva* and native fishes in a small stream. *Journal of Fish Biology,* 71: 224-238. https://doi.org/10.1111/j.1095-8649.2007.01677.x

Butchart, S. H. M. et al. (2010). Global Biodiversity: Indicators of Recent Declines. *Science*, 328, 1164–1168.

Cai, W & Cowan, T. (2013). Southeast Australia autumn rainfall reduction: a climate-change-induced poleward shift of ocean–atmosphere circulation. *Journal of Climate*, 26(1), 189-205. https://doi.org/10.1175/JCLI-D-12-00035.1

Carpenter, S. R., Fisher, S. G., Grimm, N. B., Kitchell, J. F. (1992). Global change and freshwater ecosystems. *Annual Review of Ecology, Evolution, and Systematics,* 23,119-39.

Carpenter, S. R., Stanley, Emily H & Vander Zanden, M. J. (2011). State of the World's Freshwater Ecosystems: Physical, Chemical, and Biological Changes. *Annual Review of Environment and Resources*, 36(1), 75-99.

Doll, P. C., Munday, P. L, Bonin, M.C., Jones, G.P. (2021). Habitat specialisation and overlap in coral reef gobies of the genus *Eviota* (Teleostei: Gobiidae)". *Marine Ecology Progress Series*, 677, 81-94. https://doi.org/10.3354/meps13863

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A.H., Soto, D., Stiassny, M.L., & Sullivan, C.A. (2006). Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Revisions*, 81, 163.

Erkakan, F. & Ekmekçi, F.G. (2000). Habitats of *Cobitis fahireae, Cobitis puncticulata*, and *Cobitis levantina* (Teleostei: Cobitidae) in Turkey. *Folia Zoologica*, 49,193–98.

Ertürk, S.G., Mestav, B. and Yalçin-Özdilek, Ş. (2023). Evaluation of the role of enzyme activities in the silvering process of European Eels (*Anguilla anguilla*). *Ichthyological Research*, 70(1), 132–41. https://doi.org/10.1007/s10228-022-00870-5.

Glova, G.J., Jellyman, D. J. Bonnett, M. L. (1998). Factors associated with the distribution and habitat of eels (*Anguilla spp.)* in three New Zealand lowland streams. *New Zealand Journal of Marine and Freshwater Research,* 32(2), 255-269. https://doi.org/10.1080/00288330.1998.9516824

ICES (2020). Joint EIFAAC/ICES/GFCM Working Group on eels (WGEEL). *ICES Scientific Reports*, 2(85). ICES, Copenhagen.

IUCN 2022. The IUCN Red List of Threatened Species. Version 2022-2. https://www.iucnredlist.org. (accessed 27.03.2023).

Klaar, M., Copp, G. & Horsfield, R. (2004). Autumnal habitat use of non-native pumpkinseed *Lepomis gibbosus* and associations with native fish species in small English streams. *Folia Zoologica,* 53, 189-202.

Malmqvist, B. & Rundle, S. (2002). Threats to the running water ecosystems of the world. *Environmental Conservation*, 9(2), 134-153.

Negro, G., Stefano, F., Emanuele, Q., Claudio, C., Isabella, G & Paolo V. (2022). Habitat Preferences of Italian Freshwater Fish: A Systematic Review of Data Availability for Applications of the MesoHABSIM Model. *Frontiers in Environmental Science*, 9, 634737. https://doi.org/10.3389/fenvs.2021.634737

Özdemir, N., Tarkan, A.S., Agdamar, S., Top, N., Karakuş, U. (2015). Ecological Requirements and Distribution of Native and Introduced Freshwater Fishes in a Mediterranean-Type Basin (Mugla, SW Turkey). *Fresenius Environmental Bulletin*, 24(1).

Park, J.M., Riedel, R., Ju, H. H., Choi, H.C. (2020). Fish assemblage structure comparison between freshwater and estuarine habitats in the lower Nakdong River, South Korea. *Journal of Marine Science and Engineering*, 8(7),496. https://doi.org/10.3390/jmse8070496

Persat, H. & Copp, G.H. (1989). Electrofishing and point abundance sampling for the ichthyology of large rivers. In Developments in Electrofishing; Cowx, I. Ed.; Fishing News Books, Oxford, pp 203–215.

Pike, C., Crook, V. Gollock, M. (2020). *Anguilla anguilla.* The IUCN Red List of Threatened Species, e.T60344A152845178.
https://dx.doi.org/10.2305/IUCN.UK.2020.

R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Simonović, P., Piria, M., Zuliani, T., Ilić, M., Marinković, N., Kračun-Kolarević, M & Paunović, M. (2017). Characterization of sections of the Sava River based on fish community structure. *Science of the Total Environment,* 574, 264–71.
https://doi.org/10.1016/j.scitotenv.2016.09.072.

Squires, D. (2013). Biodiversity Conservation in Asia. *Asia & the Pacific Policy Studies*. 1, 144–159.
https://doi.org/10.1002/app5.13

Tomanova, S., Tedesco, P.A., Roset, N., Berrebi dit Thomas, R. & Belliard, J. (2013). Systematic point sampling of fish communities in medium- and large-sized rivers: sampling procedure and effort. *Fisheries Management and Ecology*, 20, 533-543.
https://doi.org/10.1111/fme.12045

Top, N. & Tarkan, A.S. (2009). Endemik bir tatlısu balığının (*Ladigesocypris ghiigi*, Gianferrari, 1927) habitat tercihleri." IX. National Ecology and Environment Congress.

Top, N., Karakuş, U., Tepeköy, E.G., Britton, J.R. and Tarkan, A.S. (2019). Plasticity in habitat use of two native Ponto-Caspian gobies, *Proterorhinus semilunaris* and *Neogobius fluviatilis*: implications for invasive populations. *Knowledge and Management of Aquatic Ecosystems*, 420, 40.
https://doi.org/10.1051/kmae/2019031.

Top, N., Tarkan, A.S., Vilizzi, L. and Karakuş, U. (2016). Microhabitat interactions of non-native pumpkinseed *Lepomis gibbosus* in a mediterranean-type stream suggest no evidence for impact on endemic fishes. *Knowledge and Management of Aquatic Ecosystems*, 417, 36.
https://doi.org/10.1051/kmae/2016023.

Vieira, T. B., Tejerina-Garro, F. L. (2020). Relationships Between Environmental Conditions and Fish Assemblages in Tropical Savanna Headwater Streams. *Scientific Reports*, 10, 2174.
https://doi.org/10.1038/s41598-020-59207-9

Vilizzi, L., Stakenas, S. and Copp, G.H. (2012). Use of constrained additive and quadratic ordination in fish habitat studies: an application to introduced pumpkinseed (*Lepomis gibbosus*) and native Brown Trout (*Salmo trutta*) in an English stream. *Fundamental and Applied Limnology*, 180(1), 69–75.
https://doi.org/10.1127/1863-9135/2012/0277.

Welcomme, R.L. (1979). Fisheries ecology of floodplain rivers. Longman, New York.

Yamazaki, Y., Haramoto, S. & Takeshi, F. (2006). Habitat uses of freshwater fishes on the scale of reach system provided in small streams. *Environmental Biology of Fisheries,* 75, 333-341.

Yee, T.W. (2004). A new technique for maximum-likelihood canonical Gaussian ordination. *Ecological Monographs,* 74, 685–701.

Yee, T.W. (2006). VGAM Family functions for reduced-rank regression and constrained ordination. Beta version 0.6-5.

Yılmaz, F., Yorulmaz, B. and Giannett, D. (2015). Threatened fishes of the world: *Ladigesocypris irideus* (Ladiges, 1960) (Cyprinidae). *Ribartsvo, Croatian Journal of Fisheries*, 177–80.
https://doi.org/10.14798/73.3.830

Yoğurtçuoğlu, B., Bucak, T., Ekmekçi, F.G., Kaya, C. Tarkan, A.S. (2021). Mapping the establishment and invasiveness potential of rainbow trout (*Oncorhynchus mykiss*) in Turkey: with special emphasis on the conservation of native salmonids. *Frontiers in Ecology and Evolution*, 8, 599881.
https://doi.org/10.3389/fevo.2020.599881