Nature Conservation

Nature Conservation 65: 49–63 (2026)
DOI: 10.3897/natureconservation.65.190429

Research Article

Changes in the distribution of the European mudminnow (*Umbra krameri* Walbaum, 1792) in Hungary over the last 50 years

Zoltán Sallai[1], István Lehoczky[2], Ákos Harka[3], Péter Takács[4]

1 *Vaskos Csabak Ltd, Békésszentandrás, Hungary*
2 *National Centre for Biodiversity and Gene Conservation, Gödöllő, Hungary*
3 *Hungarian Ichthyological Society, Tiszafüred, Hungary*
4 *HUN-REN Balaton Limnological Research Institute, Tihany, Hungary*

Corresponding author: Péter Takács (takacs.peter@blki.hu)

Abstract

The European mudminnow (*Umbra krameri* Walbaum, 1792) is a relict wetland fish endemic to the Danube Basin, with Hungary representing the core of its historical distribution. We compiled published faunistic records, grey literature and standardised field-survey data from 1975–2025 to quantify long-term distribution changes across 12 Hungarian geographic regions and 200 documented localities. Confirmed persistent populations occur at 45.5% of historical localities (91 sites), including 17 “large” and 74 “small” populations. An additional 15 sites (7.5%) show only occasional recent records, whereas the European mudminnow has disappeared from 44% of its historically known localities. Most extant populations remain small and spatially fragmented. The Danube–Tisza Interfluve historically contained the highest number of localities (n = 57) and exhibited the greatest absolute loss (33 disappeared sites), primarily associated with hydrological degradation. In contrast, the Fertő–Hanság–Szigetköz Region currently represents the most important north-western refuge (21 persistent populations, including three large populations), whereas the Zámoly Basin is regionally extinct.

Across all localities, invasion by the Amur sleeper (*Perccottus glenii* Dybowski, 1877) (35% of sites) and documented desiccation (30.5%) were the two most frequently recorded threat categories. GLM applied to sites with known status (n = 194) showed substantially lower predicted persistence probabilities at sites affected by desiccation. At the national scale, desiccation emerged as the only clear independent predictor of reduced persistence, whereas the effects of other pressures appeared regionally heterogeneous and context-dependent. Surviving populations increasingly occur in artificial canal systems, indicating a marked shift from natural floodplain habitats towards secondary refugia. Integrated hydrological restoration, invasive-species control and genetically informed conservation management, including eDNA-based monitoring, are urgently required to prevent further contraction of this approximately 60-million-year-old Danubian endemic lineage.

Key words: Artificial canal refugia, Carpathian Basin, Danube Basin, fragmentation, groundwater decline, hydrological degradation, invasive species, *Perccottus glenii*, regional extinction, wetland conservation

OPEN ACCESS

Academic editor: Lukáš Kalous
Received: 4 March 2026
Accepted: 21 May 2026
Published: 9 October 2026

ZooBank: https://zoobank.org/AAF78945-D207-4148-83C5-4E3EC106A04F

Citation: Sallai Z, Lehoczky I, Harka Á, Takács P (2026) Changes in the distribution of the European mudminnow (*Umbra krameri* Walbaum, 1792) in Hungary over the last 50 years. In: Wanzenböck J, Šmejkal M, Kalous L, Klefoth T, Geist J, Takacs P (Eds) Biology and conservation of wetland fishes in Europe. Nature Conservation 65: 49–63. https://doi.org/10.3897/natureconservation.65.190429

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Introduction

The European mudminnow (*Umbra krameri* Walbaum, 1792) is a small, esociform fish endemic to the Middle- and Lower Danube River Basin. As a characteristic inhabitant of shallow, vegetated wetlands and oxbow lakes, the species is often considered an indicator of intact floodplain wetland habitats. More broadly, *U. krameri* belongs to a wider group of native European wetland fishes whose persistence is increasingly constrained by the combined effects of wetland degradation and invasive non-native species (Aarts et al. 2004; Wanzenböck 2004; Arthington 2012; Xu et al. 2019; Tickner et al. 2020). Recent syntheses have emphasised that habitat loss, hydrological alteration and biological invasions may jointly contribute to local extirpation risk across European wetland systems (Didham et al. 2007; Šmejkal et al. 2025). In Hungary, the species has been documented since the mid-19th century (Heckel 1847; Heckel and Kner 1858; Herman 1882, 1887), when it was reported as abundant across extensive floodplain wetlands of the Tisza, Körös and Danube and Dráva rivers and around Lake Balaton. Historical accounts describe mudminnows being captured in large numbers – sometimes filling entire traps – and used as livestock feed rather than for human consumption, highlighting their former dominance in wetland fish assemblages (Károli 1879, 1882; Lakatos 1907).

Since the late 19th and especially the 20th century, however, Hungary's wetland landscapes have undergone profound transformation. Large-scale drainage, river regulation and agricultural expansion across the Carpathian Basin resulted in the loss of approximately 90% of natural wetland habitats (Nagy 2013; Lieskovský et al. 2018). Although interventions were carried out throughout the entire Carpathian lowland river system, the largest works were implemented during the regulation of the Tisza drainage. This floodplain alone was dramatically altered: permanently inundated areas declined from roughly 4400 km^2 following river engineering works between 1846 and the 1930s, while channel shortening (from 1419 km to 966 km) and the construction of more than 4200 km of levees further reduced floodplain connectivity (Botár and Károlyi 1971). Channel incision and hydrological regulation lowered groundwater tables (Szanyi et al. 2026) and weakened lateral river–floodplain linkages, diminishing the resilience of remnant wetlands (Varga et al. 2013; Decsi et al. 2020). These historical transformations are consistent with broader European trends, where extensive floodplain loss, canalisation and land conversion have reduced the area and ecological integrity of wetland habitats required by stagnophilic fish species (Bunn and Arthington 2002; Aarts et al. 2004; Schindler et al. 2014; Grizzetti et al. 2017; Hayes et al. 2018).

Agricultural intensification during the 20th century introduced large-scale fertiliser and pesticide inputs, contributing to eutrophication and water-quality degradation in the remaining habitats (Racoviceanu et al. 2023). The recreational use (e.g. angling) of the remaining wetlands has caused additional degradation. Chinese herbivorous carps (silver, bighead and grass carps) and common carp overstocking reduced macrophyte cover and increased water turbidity, creating conditions fundamentally unsuitable for wetland specialists. These pressures have been compounded by increasing drought frequency since the late 20th century (Jánosi et al. 2023). Together, land-use change, hydrological alteration, pollution and climate variability have fragmented formerly continuous wetland networks

into small, isolated habitat patches with reduced ecological function (Dóka 2015; Dóka et al. 2019). Such landscape-scale transformations had profound consequences for wetland-dependent species, including the European mudminnow. By disrupting dispersal pathways and gene flow, habitat fragmentation promotes population isolation and increased inbreeding, while also preventing natural recolonisation after local extinctions. For specialised wetland fishes, this process is especially severe because many surviving populations persist in small, environmentally unstable habitats that are highly sensitive to drying, connectivity loss and management disturbance (Wanzenböck 2004; Roni 2019; Šmejkal et al. 2025).

Beyond habitat degradation, biotic interactions have also contributed to population declines. Mudminnow populations are increasingly threatened by the expansion of ecologically similar invasive competitors, most notably the Amur sleeper (*Perccottus glenii* Dybowski, 1877) (Somogyi et al. 2023). Although this species appeared in Hungary only in the late 20th century, it has rapidly colonised floodplain wetlands and oxbow habitats and several studies report substantial negative effects on mudminnow populations, particularly along the Tisza River and in the Kis-Balaton Region (Harka 1998; Harka et al. 2003; Sallai 2005; Erős et al. 2008). Importantly, invasion processes interact with hydrological instability, habitat fragmentation and management-related pressures, creating spatially heterogeneous, multi-driver patterns of decline (Didham et al. 2007; Gallardo et al. 2016). This interpretation is also consistent with recent European-scale syntheses, which identify wetland degradation and invasive non-native fishes as the two dominant, often interacting pressures affecting native wetland fish species, including *U. krameri* (Blackburn et al. 2011; Grabowska et al. 2019; Bănăduc et al. 2022; Šmejkal et al. 2025). However, the relative strength of these pressures is unlikely to be spatially uniform: invasion intensity itself may be regionally heterogeneous and its effects may depend on hydrological context, habitat fragmentation and the persistence of suitable refuge habitats.

Despite the species' conservation importance and listing in Annex II of the European Union's Habitats Directive, comprehensive long-term faunistic assessments have remained limited. In particular, the relative contribution of multiple documented threat categories to local population persistence has not been quantitatively evaluated at the national scale. This gap is important because broad conceptual studies now suggest that native wetland fish decline across Europe is driven by interacting, context-dependent pressures, yet locality-based national syntheses capable of separating hydrological, invasion-related and other anthropogenic effects remain scarce. Hungary, which represents the historical core area of *U. krameri*, provides an especially informative system for such an assessment because it encompasses both major refugial regions and some of the most heavily transformed lowland wetland landscapes within the species' range.

Therefore, this study aims to provide a comprehensive national assessment of the distribution and conservation status of the European mudminnow in Hungary. Specifically, we: 1) reconstruct historical and current distribution patterns across the country's major geographic regions; 2) compile locality-level conservation status for 200 documented sites; 3) identify regional patterns of persistence and decline, based on field surveys and literature data; 4) evaluate the relative contribution of major documented threat factors using binomial GLM modelling and 5) discuss conservation implications and management priorities in the broader context of European wetland-fish decline and secondary refugia conservation.

Materials and methods

Data compilation and database construction

Data on the occurrence and status of *Umbra krameri* in Hungary were compiled from multiple sources, including published scientific literature, grey literature (e.g. reports, faunistic surveys) and original field observations conducted by the authors between 1975 and 2025. Historical records, dating back to the late 19th century, were also included where locality information was sufficiently precise. All records were standardised and integrated into a unified database, ensuring consistency in locality identification, temporal information and status classification. When multiple records were available for the same locality, the most recent reliable observation was used to define current status, while earlier records were retained for historical context.

Localities were georeferenced, based on available descriptions, maps and field knowledge. In total, 200 localities with confirmed historical or recent occurrence of *U. krameri* were included in the analysis. For the naming of waterbodies, we followed the official geographical names listed in the Hungarian Gazetteer of Geographical Names (Földi 1982).

Classification of locality status

Each locality was assigned to one of four status categories, based on the most recent available information: Large population – stable, well-established population with regular detection and relatively high abundance, Small population – persistent, but low-abundance population, Occasional occurrence – irregular or uncertain presence, often based on sporadic observations, Disappeared – no recent records despite targeted surveys or historically documented presence. For the purposes of statistical analysis, these categories were aggregated into a binary response variable: “persistent” (large + small populations) and “non-persistent” (occasional + disappeared). This classification reflects differences in long-term population viability rather than short-term detection probability.

Environmental pressures and threat variables

To evaluate the potential drivers of population persistence and decline, major anthropogenic and ecological pressures were compiled for each locality, based on field observations and literature sources. The analysed threat categories included desiccation (evidence of periodic or permanent drying), presence of invasive species, particulary the Amur sleeper, intensive angling activity, water-management impacts, habitat alteration (e.g. canalisation, dredging, vegetation removal) and water pollution.

All variables were coded as binary predictors (presence/absence), indicating whether a given pressure had been documented at a locality. This approach was selected because the available historical and recent information was heterogeneous and often semi-quantitative in nature. Since several predictors represent related aspects of habitat degradation, they are not fully independent in ecological terms. Therefore, the analysis was intended to identify broad-scale patterns of association rather than strictly independent causal

relationships. To avoid unstable parameter estimation caused by extremely rare predictors, only threat categories recorded at more than five localities were included in the GLM analysis.

Statistical analyses

To evaluate the relative importance of major environmental threats on the persistence of *Umbra krameri* populations, we fitted a generalised linear model (GLM) with binomial error distribution and logit link function using the binary persistence classification and threat variables described above. Localities with insufficient information were excluded from the analysis. To facilitate interpretation of model outcomes, fitted probabilities of population persistence and corresponding 95% confidence intervals were estimated on the response scale for each predictor category (presence vs. absence of the given threat). Predicted probabilities were visualised as model-based estimates with associated confidence intervals. Model coefficients were expressed both on the logit scale and as odds ratios (OR) with 95% confidence intervals. Model performance was evaluated using McFadden's pseudo-R^2 and the area under the receiver operating characteristic curve (AUC). All statistical analyses were performed in R (version 4.3.2; R Core Team (2025)), while Python was used for data processing and visualisation.

Results

Distribution and conservation status

A total of 200 localities with historical or recent records of *Umbra krameri* were identified across Hungary (Table 1, Fig. 1). Of these, 106 localities (53%) had records within the last decade, while 94 localities (47%) were classified as disappeared (Fig. 2). Amongst the recently recorded localities, 15 were classified as occasional occurrences, indicating uncertain or irregular presence. Consequently, only 91 localities (45.5% of all recorded sites) were considered to support persistent (large or small) populations.

Persistent populations were unevenly distributed across biogeographic regions. The highest number of recent records was observed in the Fertő–Hanság–Szigetköz Region (22 localities), followed by the Bihari floodplain (14 localities) and the Takta–Hejő Region (10 localities). In contrast, complete regional disappearance was observed in the Zámoly Basin, while strong declines were recorded in the Danube–Tisza Interfluve, Bodrogköz and the Hortobágy–Middle Tisza Regions. These results indicate a pronounced spatial heterogeneity in persistence patterns, with western and some eastern floodplain systems functioning as refugial areas, while large parts of the central lowlands show extensive local extirpation.

Patterns of decline and regional differences

The proportion of disappeared localities varied markedly amongst regions. The Danube–Tisza Interfluve exhibited the highest absolute number of lost populations (38 localities), despite historically supporting the largest number of sites. In contrast, regions with relatively intact hydrological conditions, such

Table 1. The number of sites, recent data, population presences and sizes, threats and the estimated recent status of the studied 12 Hungarian regions. For the full dataset, see Suppl. material 1: table S1.

Region	No. of sites	Estimated population size					Threats*							Estimated recent status
		Persistent		Non-persistent		No information	Desiccation	Invasion	Angling	Water mgmt	Hab. alt.	Pollution	Unthreatened	
		Large pop.	Small pop.	Occas.	Disapp.									
1. Szatmár–Bereg floodplain	10	0	4	0	6	0	4	9	0	0	1	1	0	Severe decline, invasion-dominated, small fragmented remnants
2. Bodrogköz Region	12	0	2	2	8	0	3	9	0	1	0	0	2	Almost total collapse, fragmented remnants under strong invasion pressure
3. Takta–Hejő River System	17	1	9	0	7	0	0	17	0	0	0	0	0	Relatively stable but invasion-dominated remnant system
4. Hortobágy and Middle Tisa floodplain	10	0	2	2	6	0	3	8	0	0	0	0	1	Mostly disappeared, few invasion-affected remnants
5. Bihari floodplain, Kis-Sárrét Region	16	4	9	1	2	0	9	11	1	0	1	0	1	Important eastern refuge with multiple large populations. but high invasion pressure
6. Tápió–Hajta River System	4	0	0	0	4	0	3	2	0	0	0	0	0	Nearly extinct region
7. Danube–Tisza Interfluve, Danube floodplain	57	4	15	0	33	5	30	7	3	1	2	0	16	Strong hydrological decline with fragmented, but locally persistent canal populations
8 Zámoly Basin	3	0	0	0	3	0	3	0	0	0	0	0	0	Regionally extinct
9. Fertő–Hanság and Szigetköz Region	31	3	18	3	7	0	2	0	0	2	0	0	27	Currently the most important north-western refuge area with low invasion pressure
10. Rába Valley	2	0	1	0	1	0	0	0	0	0	1	0	1	Marginal survival, single remnant population
11. Lake Balaton and Kis-Balaton River System	26	3	8	4	10	1	1	7	0	3	0	0	15	Mixed and unstable system with moderate invasion and water-management pressure
12. Dráva–Mura River System	12	2	6	3	1	0	3	0	2	0	0	1	7	Important southern refuge, moderately fragmented with local angling pressure
Σ	**200**	**17**	**74**	**15**	**88**	**6**	**61**	**70**	**6**	**7**	**5**	**2**	**70**	

* Note: Individual sites may be affected by multiple threat categories; therefore, threat totals may exceed the number of sites per region. (Abbreviations: Occas: Occasionally, Disapp.: Disappeared, Hab. alt.: Habitat alteration).

as the Fertő–Hanság–Szigetköz system, retained a higher proportion of small, but persistent populations. These patterns suggest that regional differences in hydrological stability and habitat connectivity play a key role in determining long-term population persistence.

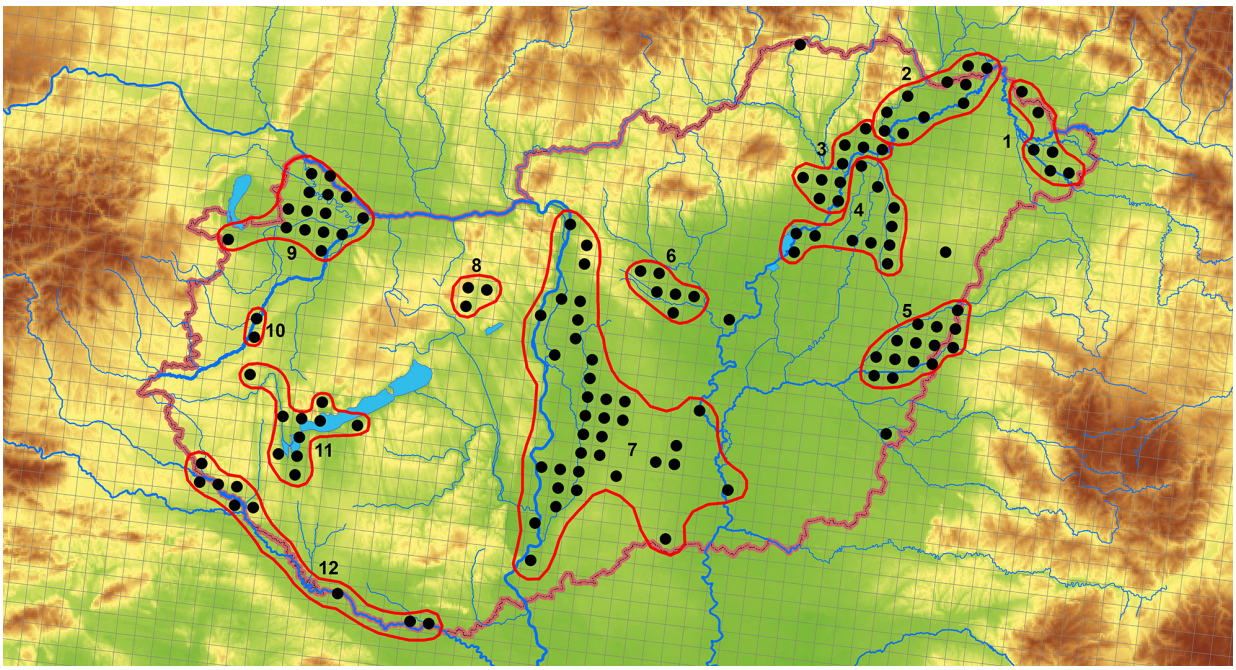

Figure 1. Distribution patterns of *Umbra krameri* in Hungary in the past 50 years. Black dots show the occurrences within the certain 10 × 10 km ETRS rectangle. Red lines show the borders of the 12 geographic regions. Region names: 1. Szatmár-Bereg-floodplain, 2. Bodrogköz Region, 3. Takta–Hejő River System, 4. Hortobágy and Middle Tisza floodplain, 5. Bihari floodplain, Kis-Sárrét region, 6. Tápió–Hajta River System, 7. Danube–Tisza Interfluve, Danube floodplain, 8. Zámoly Basin, 9. Fertő–Hanság and Szigetköz Region, 10. Rába Valley, 11. Lake Balaton and Kis-Balaton River System, 12. Dráva–Mura River System.

Effects of environmental pressures and spatial patterns

The GLM identified desiccation as the strongest negative predictor of population persistence (Table 2, Fig. 3). Sites affected by desiccation showed substantially lower predicted persistence probabilities than sites without documented desiccation. The estimated odds ratio for desiccation was 0.33 (95% CI: 0.17–0.64; p = 0.001), indicating markedly reduced persistence probability in affected localities.

In contrast, invasion (mostly caused by the Amur sleeper) did not show a significant independent effect at the national scale (OR = 1.33, p = 0.372). Similarly, angling pressure, habitat alteration and water-management impacts were not statistically significant predictors in the model, although water management showed a tendency towards lower persistence probabilities (Table 2).

Table 2. Full coefficient table of the multi-predictor binomial logistic regression model evaluating the effects of major threat categories on the persistence of *Umbra krameri* populations across Hungary (n = 194 sites). Coefficients are shown on the logit scale together with odds ratios (OR), 95% confidence intervals and p-values.

Predictor	β (logit)	(OR)	95% CI lower	95% CI upper	p-value
Intercept	0.197	1.220	0.77	1.930	0.402
Desiccation	−1.116	0.328	0.167	0.643	0.001
Invasion	0.287	1.333	0.709	2.505	0.372
Intensive angling activity	−0.679	0.507	0.084	3.077	0.460
Inadequate water management	−1.813	0.163	0.019	1.422	0.101
Habitat alteration	−0.989	0.372	0.033	4.241	0.426

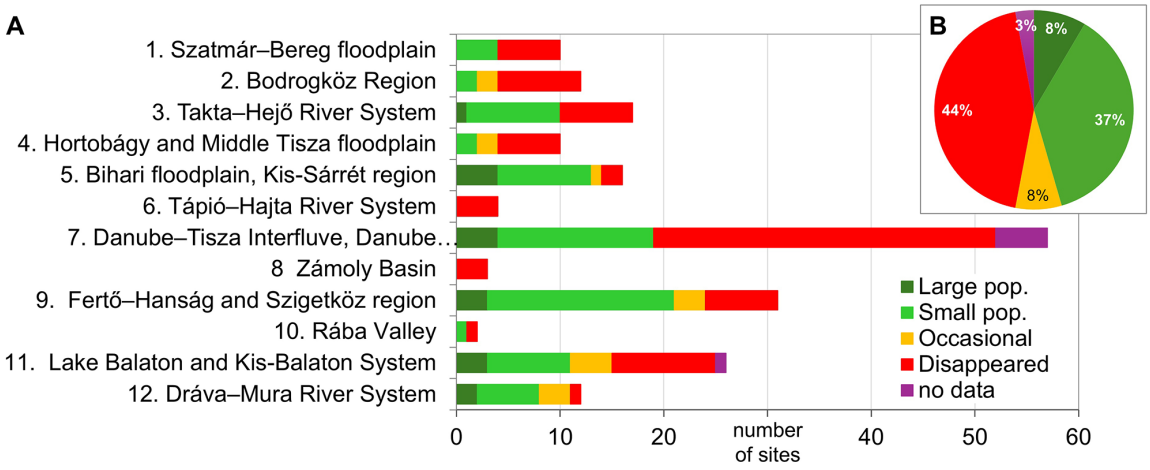

Figure 2. The regional (**A**) and overall (**B**) status of European mudminnow in Hungarian waters. Population status categories are indicated by different colours. dark green: large population (permanent population, with more than 20 individuals per survey); light green: small population (permanent population with 1–19 individuals per survey); orange: Occasional occurrence (at least one faunistic data in the last 10 years, but not appearing in all samples); red: disappeared (dried habitat and/or no literature notes from the last 10 years and/or despite several attempts, the European mudminnow did not appear in the catch); purple: no relevant information about the given site.

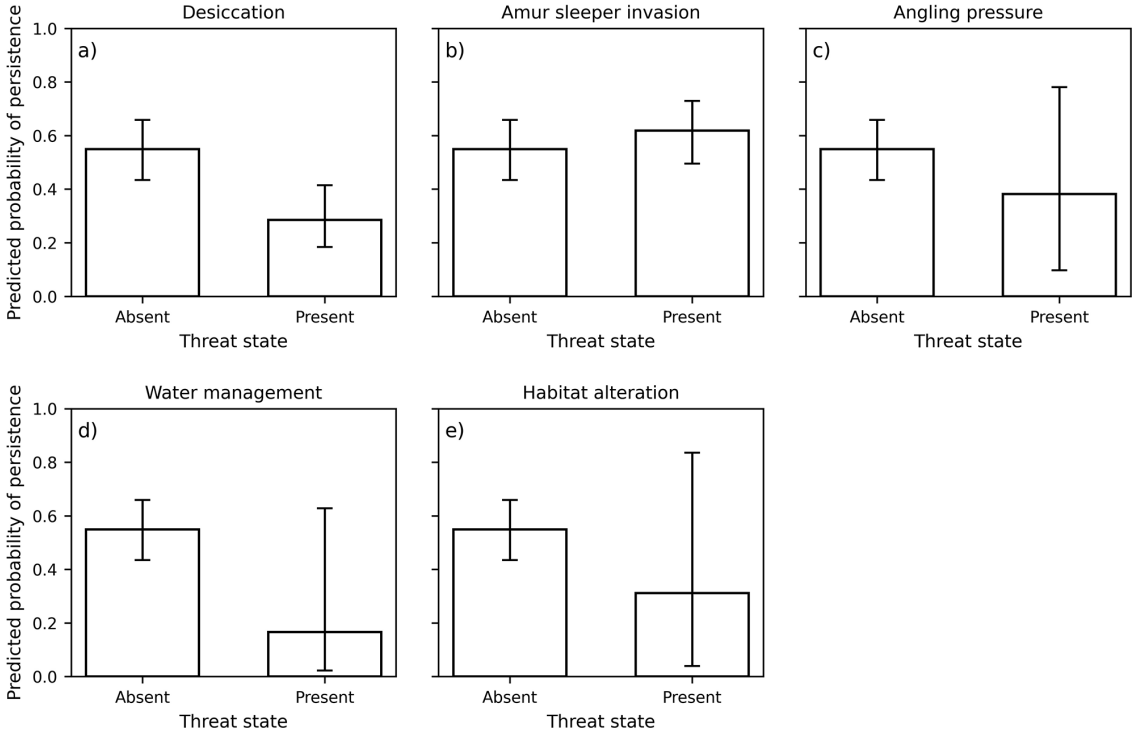

Figure 3. Predicted probabilities of persistence of *Umbra krameri* populations in relation to major threat factors, based on the binomial generalised linear model (GLM). Bars show fitted probabilities and vertical bars indicate 95% confidence intervals.

The distribution of major threat factors showed clear spatial structuring. Desiccation was most frequently recorded in the central lowland regions, particularly in the Danube–Tisza Interfluve, where groundwater decline and habitat loss are widespread. In contrast, invasive species were more frequently documented in eastern floodplain systems, especially along the Tisza River and its tributaries. Model performance metrics indicated moderate explanatory power (McFadden's pseudo-R^2 = 0.067) and moderate classification ability (AUC = 0.649).

Discussion

Large-scale patterns of decline

Our countrywide synthesis demonstrates that *Umbra krameri* has undergone a substantial contraction in Hungary over the past decades. Although recent records are still available from approximately half of the historically known localities, the majority of these populations are small, fragmented and likely demographically vulnerable. This discrepancy between apparent presence and actual population stability highlights the importance of distinguishing between occurrence and persistence, particularly for wetland specialists inhabiting highly dynamic and disturbance-prone environments.

The observed spatial patterns indicate that population persistence is not uniformly distributed across the country. Instead, surviving populations are concentrated in specific regions, while large areas—particularly in the central lowlands—have experienced extensive local extirpation. These spatial patterns are also consistent with the results of the GLM analysis.

Hydrological degradation as a primary driver

The statistical analysis identified desiccation as the only significant predictor of population persistence at the national scale and this effect was also clearly reflected in the model-based predicted probabilities. Sites affected by desiccation showed markedly reduced persistence probabilities compared to those without documented threats, indicating that hydrological degradation is the primary large-scale factor associated with reduced persistence of *U. krameri* populations.

From a mechanistic perspective, desiccation likely affects populations through multiple pathways, including direct habitat loss, reduction of water permanence, disruption of connectivity amongst habitats and increased vulnerability to stochastic events. These processes may lead to local extinction even in the absence of strong biotic interactions. This interpretation is consistent with previous studies highlighting the critical role of hydrological stability for wetland-dependent fish species (Bunn and Arthington 2002; Roni 2019).

More broadly, our results align with growing evidence that hydrological degradation represents one of the major drivers of freshwater biodiversity loss across European floodplain systems (Tickner et al. 2020; Šmejkal et al. 2025). Similar patterns of fragmentation, habitat isolation and refuge-dependent persistence have also been reported from other parts of the Danube Basin, including Austria and Romania (Wanzenböck 2004; Bănăduc et al. 2022). Together, these findings suggest that the processes identified in Hungary likely reflect broader regional trends affecting wetland-specialist fishes throughout the Carpathian Basin and adjacent lowland river systems.

Regional heterogeneity in invasion impacts

In contrast to desiccation, the presence of invasive species did not show a significant independent effect in the national-scale model. At first glance, this result may appear to contradict previous studies demonstrating negative impacts of *Perccottus glenii* on *U. krameri* populations (Harka et al. 2003; Somogyi et al.

2023). However, the spatial distribution of the two major threat categories provides important additional context. Desiccation was most frequently recorded in the central lowland regions, particularly in the Danube–Tisza Interfluve, where groundwater decline and habitat loss are widespread. In contrast, invasive species were more frequently documented in eastern floodplain systems, especially along the Tisza River and its tributaries. This spatial heterogeneity likely contributes to the contrasting statistical patterns observed in the GLM analysis.

Relatively high persistence probabilities were observed under invasion-only conditions, but this pattern should not be interpreted as a positive effect of invasive species. Instead, it likely reflects the spatial association of invasion records with more permanent waterbodies, where *U. krameri* populations may still persist. Consequently, invasion pressure appears to be regionally structured and context-dependent rather than a uniform national-scale determinant of persistence.

Recent European-scale studies have emphasised that the decline of native wetland fish species is often driven by the combined and potentially synergistic effects of habitat degradation, hydrological alteration and biological invasions (Gallardo et al. 2016; Tickner et al. 2020; Šmejkal et al. 2025). Our results support this broader framework, while also suggesting that the relative importance of individual drivers depends strongly on local ecological conditions. In highly degraded or hydrologically unstable habitats, desiccation alone may substantially contribute to population collapse, whereas in more stable systems, biotic interactions, such as competition and predation, may become more important.

The relatively low explanatory power of the model likely reflects the coarse resolution of historical threat data, the absence of explicit spatial structure and interaction terms and the inherently multi-driver nature of wetland fish decline, rather than the absence of underlying ecological mechanisms.

Secondary refugia and the role of artificial habitats

An important finding of this study is the increasing importance of artificial waterbodies, particularly canal systems, as refugia for *U. krameri*. Historically associated with natural floodplain habitats, the species is now frequently found in anthropogenically modified environments that provide relatively stable hydrological conditions. These systems may function as secondary refugia, allowing populations to persist in landscapes where natural wetlands have largely disappeared.

This observation is consistent with previous studies identifying artificial canal systems and secondary waterbodies as important refuge habitats for *U. krameri* (Pekárik et al. 2014; Takács et al. 2015). More broadly, recent studies suggest that small or artificial waterbodies can play an important role in the conservation of wetland-specialist fish species under conditions of widespread habitat loss (Oertli and Parris 2019; Šmejkal et al. 2025; Thomas et al. 2025). However, these habitats also present risks, as they are often subject to intensive management (e.g. dredging, water-level regulation) and may facilitate the spread of invasive species.

Management implications

Our results highlight several priorities for the conservation of the European mudminnow in Hungary. Most importantly, the strong negative association between desiccation and population persistence indicates that hydrological

restoration and groundwater stabilisation should represent central elements of long-term conservation planning.

First, hydrological restoration and groundwater stabilisation are essential, particularly in the Danube–Tisza Interfluve and other drought-affected regions. Landscape-scale water retention, restoration of natural hydrological regimes and the reconnection of floodplain habitats are critical for maintaining groundwater-fed wetlands that support mudminnow populations. Given the strong association between desiccation and reduced persistence identified in our analysis, improving hydrological stability should represent a central priority of long-term conservation planning.

Second, artificial canal systems require ecologically coordinated management. Maintenance and dredging operations should be temporally and spatially adjusted to minimise impacts during sensitive periods, including spawning and overwintering and residual water levels should be maintained during drought periods wherever possible. Without such measures, canal habitats may function as ecological traps rather than secure refugia. At the same time, these systems represent important secondary refugia within highly modified landscapes and should, therefore, be explicitly incorporated into conservation planning rather than treated solely as degraded habitats. The increasing conservation importance of artificial or highly modified waterbodies may also represent a broader emerging pattern in fragmented European wetland landscapes (Oertli and Parris 2019; Thomas et al. 2025).

Third, monitoring and early detection of invasive species should be strengthened. Environmental DNA (eDNA) surveillance has proven highly effective in detecting the expansion of the Amur sleeper (Czeglédi et al. 2024), particularly in structurally complex wetlands where traditional sampling methods often fail. Given the regionally heterogeneous nature of invasion pressure identified in this study, monitoring efforts should be spatially prioritised, focusing on areas where hydrological conditions allow both species persistence and invasion impact.

Finally, ex situ safeguarding measures should be considered for populations threatened by desiccation, pollution or invasive species. Emergency translocations, controlled propagation and gamete cryopreservation have already demonstrated feasibility (Tatár et al. 2017; Gazsi et al. 2021). In the longer term, a coordinated national—ideally basin-wide—living and DNA gene bank should be established to preserve rapidly eroding genetic diversity.

Conclusions and synthesis

The European mudminnow, an endemic species of the Danube Basin, faces a critical conservation situation in Hungary, which represents the core of its distribution. Although nearly half of historically known sites still have recent records, most populations are small, fragmented, and hydrologically unstable, indicating a far more vulnerable status than occurrence data alone suggest.

Our results identify hydrological degradation—particularly desiccation—as the primary large-scale factor associated with population decline in *Umbra krameri*, while the effects of invasive species appear to be regionally important and context-dependent. This pattern suggests that broad-scale habitat constraints largely determine population persistence, whereas biotic interactions

may primarily influence local outcomes under suitable hydrological conditions. More broadly, these findings are consistent with increasing evidence that hydrological alteration and habitat fragmentation represent key drivers of wetland-fish decline across human-modified European floodplain systems.

Ensuring long-term persistence requires integrated conservation action, including hydrological restoration, invasive-species management and genetically informed strategies embedded within landscape-scale water governance.

Overall, this study provides the first countrywide baseline assessment of the species' status in Hungary and highlights the urgent need for coordinated, system-level conservation across the Carpathian Basin. The patterns, identified here, likely extend beyond Hungary and reflect broader conservation challenges affecting wetland-specialist fishes throughout the Middle Danube Region.

Acknowledgements

We acknowledge the critical role of National Park Directorates (Balaton-felvidéki, Duna-Dráva, Fertő-Hanság, Hortobágyi, Kiskunsági) in mudminnow conservation and research. This study builds upon decades of field surveys and research by Hungarian ichthyologists and conservation biologists. We thank all field assistants and collaborators who contributed to data collection over the 50-year survey period.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Artificial Intelligence (AI) use

Regarding the use of AI in the preparation of this manuscript, the authors declare the following:
linguistic corrections, suggestions for the structure of the manuscript.

Funding

No funding was reported.

Author contributions

SZ: data collection, manuscript writing, visualisation. LI: manuscript writing, data collection. HÁ: data collection. TP: data curation, statistical analyses, manuscript writing.

Author ORCIDs

Z. Sallai https://orcid.org/0009-0006-9997-9213
I. Lehoczky https://orcid.org/0000-0001-9834-823X
P. Takács https://orcid.org/0000-0001-5247-7597

Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

Supplementary material 1

Umbra krameri distribution data and results of regression analyses

Authors: Péter Takács
Data type: xlsx
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Link: https://doi.org/10.3897/natureconservation.65.190429.suppl1