UNIVERSITATEA OVIDIUS DIN CONSTANȚA

ȘCOALA DOCTORALĂ DE ȘTIINȚE APLICATE

DOMENIUL DE DOCTORAT BIOLOGIE

SUMMARY OF THE DOCTORAL THESIS

MANAGING ALIEN FISH SPECIES IN MOUNTAIN LAKES

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INTRODUCTION

Alien species represent a major threat to biodiversity and ecosystem stability, being spread through human activities such as international trade, transportation, land-use changes, and pollution (Simberloff et al., 2013; Essl et al., 2020; Pyšek et al., 2020). Globalization has accelerated accidental introductions, while climate change expands suitable ranges, promoting their establishment and competition with native species (Seebens et al., 2018; Cuthbert et al., 2021; Gallardo et al., 2016; Russell et al., 2017). Their global economic impact exceeds USD 423 billion annually, affecting agriculture, fisheries, health, and infrastructure (IPBES, 2023; Haubrock et al., 2021). Effective measures rely on early detection and prevention, and the invasion curve highlights that interventions become increasingly costly and less effective as species spread (Burnett et al., 2006; Fletcher et al., 2015; Epanchin-Niell & Hastings, 2010; Green & Grosholz, 2021). Tools such as eDNA support detection, but implementation of measures remains challenging (Liu et al., 2024; IPBES, 2023).

Freshwater ecosystems are particularly vulnerable, being affected by alien species through trophic network alterations, water quality degradation, and pathogen introduction (Strayer, 2010; Yang et al., 2025; Champneys et al., 2024; Rochat et al., 2025). Human activities such as aquaculture and the ornamental fish trade facilitate introductions, and climate change increases establishment risk (Kettunen et al., 2009; Baso et al., 2024). These species also alter habitats and trophic cycles, and the global economic costs from freshwater ecosystems are estimated at approximately USD 39 billion annually (Cuthbert et al., 2021; Haubrock et al., 2022; Marchand & Schoefs, 2025).

Climate change contributes to the spread of invasive fish species by warming waters and intensifying extreme events, which negatively impact native species and create favorable conditions for more tolerant ones (Adeniran-Obey & Osagie, 2024; Arimoro et al., 2024; Canonico et al., 2005). Altered hydrological cycles, such as frequent floods and flow variability, facilitate the dispersal and establishment of these species in new habitats (Xie et al., 2023; Kim et al., 2024). These alien fish species severely impact trophic networks and water quality, reduce biodiversity, and trigger ecosystem changes (Çinar et al., 2014; Natugonza, 2024; Costantini et al., 2023). Species such as Cyprinus carpio and Hypophthalmichthys molitrix disturb sediments and reduce water clarity, while excessive zooplankton consumption by Asian carp species disrupts food webs (Nico et al., 2025; Leonardos et al., 2008; Yu et al., 2016). They also impact commercial and subsistence fishing by reducing catches, damaging fishing gear, and increasing operational costs (Haubrock et al., 2022; Meyerson & Reaser, 2003; de Carvalho-Souza et al., 2024).

At the health level, alien fish such as Tilapia can transmit pathogens like *Streptococcus iniae*, which causes severe infections in humans (Zin Eldin et al., 2023; Wodajo, 2020; Torres Corral, 2022). They also promote toxic algal blooms through nutrient resuspension, posing risks to public health and food security (Backer & Miller, 2016; Ash & Patterson, 2022; Keswani et al., 2016). Bioaccumulation of heavy metals and persistent organic pollutants occurs in invasive predatory species, with neurotoxic and carcinogenic effects on consumers (Weber et al., 2023; Meng et al., 2024; Yadav et al., 2024; Wahiduzzaman et al., 2022). The impact on tourism and recreation arises from the degradation of aquatic landscapes and the replacement of recreationally valuable species (Cambray, 2003; Kettunen et al., 2009). These alien fish species also generate socio-cultural conflicts, affecting local communities that depend on aquatic resources and triggering debates between economic sectors and conservation efforts (Gómez et al., 2021; Marques et al., 2014; Reid et al., 2019).

In the European Union, the legal framework for invasive alien species is based on Regulation 1143/2014, which mandates prevention, early detection, and control measures for species on the Union List (European Commission, 2024). Romania transposed these regulations through Emergency Ordinance 57/2007 and Order 979/2009 (Haubrock et al., 2022). The national IAS project (2018–2022), with a budget of 29.5 million RON, aimed to prioritize species, identify introduction pathways, and improve management measures in Natura 2000 sites. However, challenges persist regarding illegal trade, unregulated aquaculture, and accidental introductions via transport and commerce (Kettunen et al., 2009; Tsiamis et al., 2019). Future priorities include strengthening law enforcement, increasing financial resources, and enhancing transboundary scientific cooperation (European Commission, 2024).

STUDY AIM

This doctoral thesis aims to develop an integrated understanding of the distribution, spread, ecological interactions, and socio-economic dimensions associated with alien fish species in Romania's freshwater ecosystems. The study employs a multidisciplinary framework combining spatial analyses, ecological field investigations, behavioral ecology experiments, and assessments of public perception.

The thesis has four specific objectives:

1. To document the current distribution and introduction pathways of alien fish species in Romanian freshwater systems, identify hotspots, and assess the main anthropogenic vectors.
2. To investigate the persistence and spread of accidentally introduced minnow (Phoxinus sp.) populations in the alpine lakes of Retezat National Park, following historical trout stocking.
3. To evaluate the behavioral responses of native amphibians to the presence of minnows through a mesocosm experiment, focusing on tadpole activity levels and predator avoidance behaviors.
4. To analyze public perception and the economic implications of alien fish removal strategies in protected alpine areas, using field questionnaires and travel cost analysis to understand social support for conservation interventions and the economic trade-offs involved in managing alien fish.

The thesis contributes to advancing scientific knowledge on freshwater biological invasions, to supporting effective management strategies, and to developing conservation policies that are both ecologically sound and socially acceptable in the Romanian context.

CHAPTER I
Invasive fish species in Romanian freshwater

This chapter is based on the following article published in *NeoBiota*:
• Drăgan O, Rozylowicz L, Ureche D, Falka I and Cogălniceanu D (2024) Invasive fish species in Romanian freshwater. A review of over 100 years of occurrence reports. *NeoBiota*, 94, 15–30.

Introduction

Biological invasions are one of the main drivers of biodiversity decline globally, alongside land-use changes, overexploitation, climate change, and pollution (IPBES 2023; Roy et al. 2024). The number of invasive species is continuously increasing, with no evidence that the rate of new species establishment is slowing down (Mormul et al. 2022; Pyšek et al. 2020). Invasive fish species pose a significant threat to freshwater ecosystems (Katsanevakis et al. 2013; Nunes et al. 2015). In Europe, alien fish introductions were mainly carried out through stocking and aquaculture, with accidental or commercial introductions increasing from the 1960s onward (Gherardi et al. 2009; Zieritz et al. 2016). In Romania, data on alien fish presence are limited, with initial spread occurring naturally or, after 1956, being facilitated by national stocking programs (Decei 1981; Popa 2002). The objectives of this study were: (i) to update the inventory of alien fish species in Romanian freshwater and identify those considered invasive; (ii) to map their distribution and identify high-density areas ("hotspots") and major pathways of spread.

Materials and Methods

Data collection

Data on species presence were compiled from scientific literature, social media, public databases (e.g., GBIF), online questionnaires, and original field data (2019–2022). Literature searches used keywords and geographical terms relevant to Romania and neighboring countries. Collected data included species, source, year, coordinates, and habitat, with a focus on invasive species due to the limited number of records for other alien species.

Data analysis

Presence records were georeferenced using a 10 km × 10 km UTM grid, overlaid on the 11 water management basins of Romanian Waters. Hotspot areas were identified using Kernel Density Estimation in QGIS, with a kernel radius of 10 km. Alien fish were classified following the methodology of Blackburn et al. (2011), categorizing species as casual, naturalized, invasive, unknown, or failed. The main analysis focused only on invasive species.

Results

Between 1910 and 2022, a total of 52 alien fish species were reported in Romania. Of these, 11

met the criteria for invasiveness (Fig. 1):
• *Ameiurus melas*
• *Ameiurus nebulosus*
• *Carassius gibelio*
• *Ctenopharyngodon idella*
• *Hypophthalmichthys molitrix*
• *Hypophthalmichthys nobilis*
• *Lepomis gibbosus*
• *Oncorhynchus mykiss*
• *Perccottus glenii*
• *Pseudorasbora parva*
• *Salvelinus fontinalis*

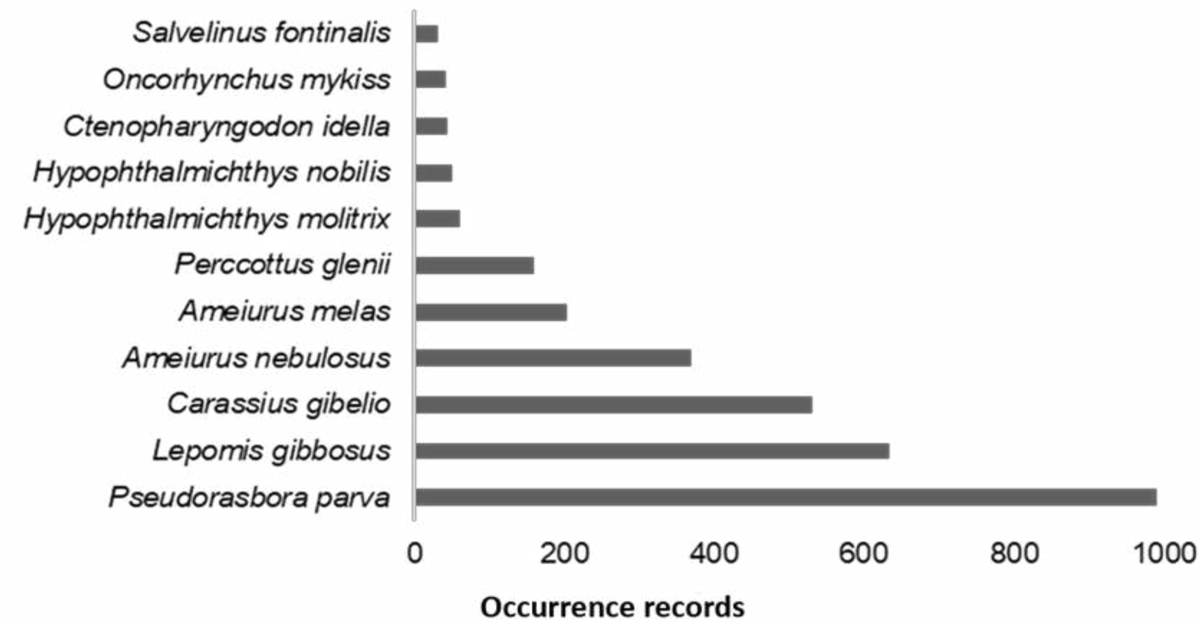

Fig. 1. Total number of presence records for the 11 invasive alien fish species in Romania.

Most records were concentrated after 1990, with a peak in the 2000–2010 decade. The main data sources were **published literature** (2372 records), **field data** (588), **GBIF** (78), **social media** (22), and **online questionnaires** (47).

The **spatial distribution was uneven**, with most occurrences reported in the **Mureș, Crișuri, and Siret river basins** (Fig. 2). The identified **hotspot areas** (Fig. 3) coincided with the main entry and spread points, especially in **western, central, and eastern Romania** (Mureș, Crișuri, and Siret basins).

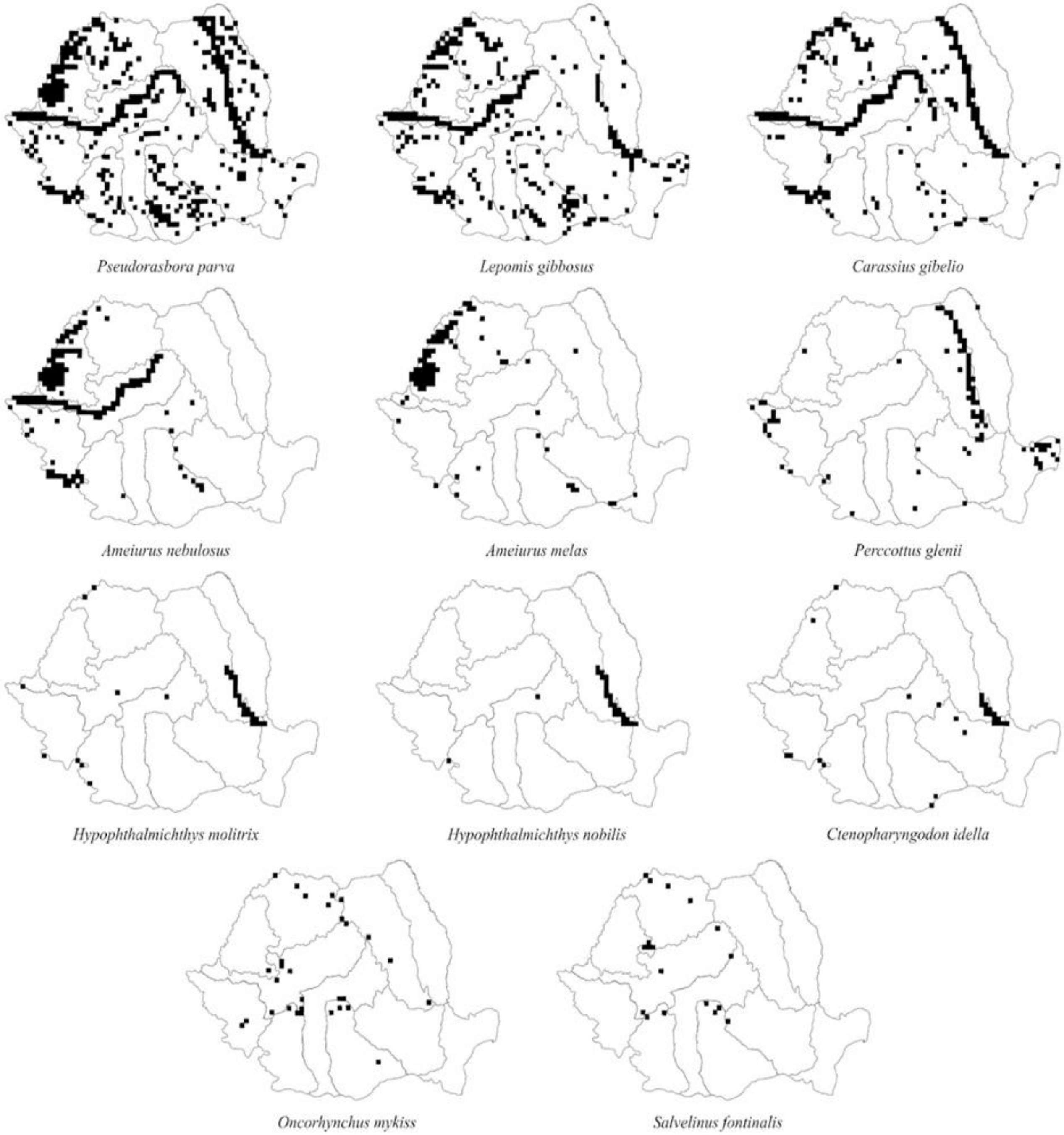

Fig. 2. Records of invasive alien fish species presence in Romanian freshwater, by river basin units, using 10×10 km UTM grid cells.

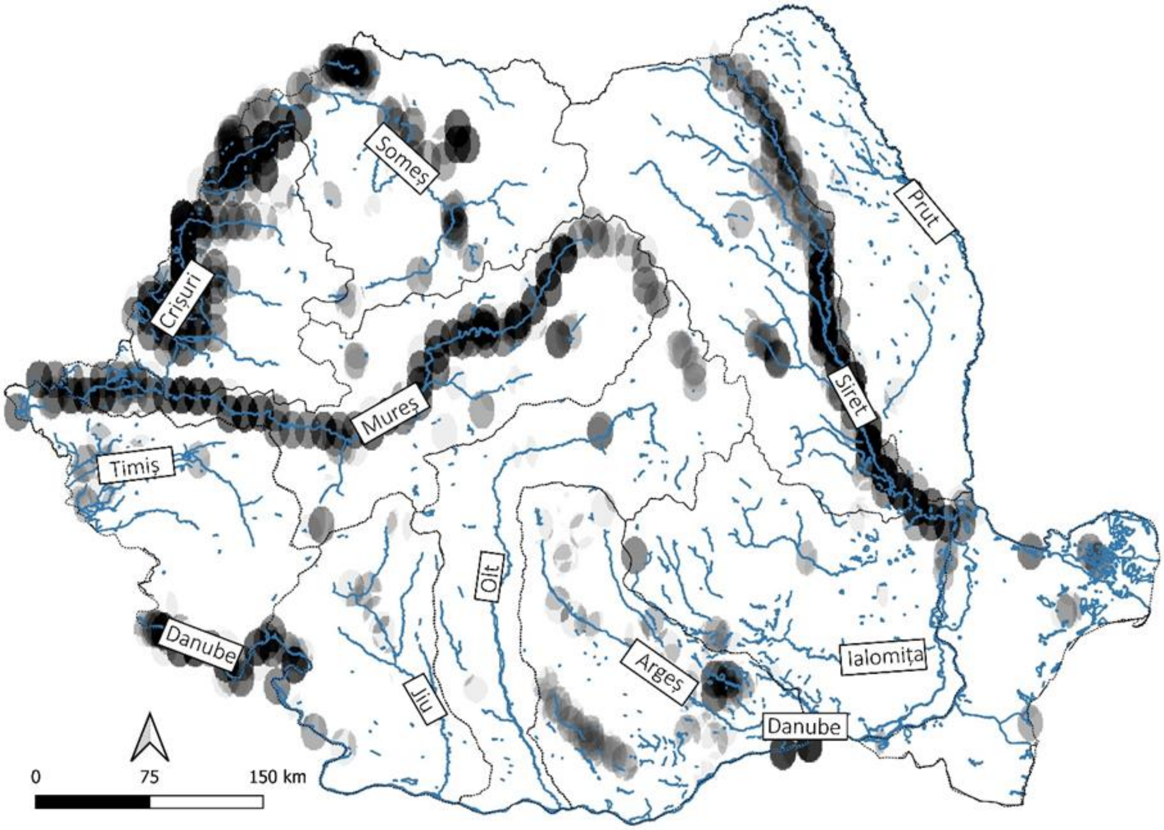

Fig. 3. The hotspot map illustrates the distribution of invasive alien fish species along Romania's main rivers. The visualization uses a grayscale gradient, with values ranging from 1 (light) to 60 (dark), representing the density of records within a 10 km radius.

Discussions

The study identified 11 invasive fish species out of 52 alien fish species reported in Romania between 1910 and 2022. Their spatial distribution is uneven, with most occurrences in the northwest and in transboundary rivers, reflecting unassisted entry routes. The high number of records may also reflect areas with the most sampling, not only actual abundance. Hotspot areas often coincide with vulnerable protected areas, such as the Iron Gates Natural Park and the Danube Delta Biosphere Reserve. As a result of high connectivity of aquatic systems and climate change, a continuous expansion of invasive species is expected, highlighting the need for proactive measures and cross-border collaboration to manage them.

CHAPTER II
Accidental introduction of fish as live bait following trout stocking in Retezat National Park

This chapter is based on the following manuscript submitted for publication:

• Drăgan O, Danău C and Cogălniceanu D (2025) Unforeseen consequences of trout stocking in alpine lakes – The introduction and spread of bait fish in Retezat National Park, Romania.

Introduction

Alpine lakes in the Northern Hemisphere were naturally fishless due to natural barriers (Knapp et al., 2001), but trout introduction has been widespread in Europe (Fausch, 2007; Stanković et al., 2015; Rasmussen et al., 2019), North America (Adams et al., 2001), and parts of South America (Arismendi et al., 2019), starting in the 19th century for recreational fishing (Bahls, 1992). These introductions have had cascading effects, altering food webs and threatening local biodiversity, mainly through predation and direct competition with native species (Sequeiros et al., 2018; Miró et al., 2018; Lucati et al., 2020; Knapp et al., 2007; Pope et al., 2009; Tiberti et al., 2019). A growingly documented side effect of these stockings is the accidental introduction of bait fish by anglers, with severe ecological impacts (Miró & Ventura, 2015; Gacia et al., 2018; Osorio et al., 2022; Tiberti et al., 2022a). These fish, such as *Phoxinus* sp., are highly adaptable and reproduce rapidly, quickly occupying ecological niches and affecting not only native trout but also invertebrate fauna and amphibians (Miró & Ventura, 2015; Gacia et al., 2018; Schabetsberger et al., 2023). In other regions, their dominance has led to decreased trout densities (Ventura et al., 2017; Tiberti et al., 2022a), disruptions of nutrient cycles, and the introduction of parasites that further threaten native populations (Eby et al., 2006; Parker et al., 2001).

Materials and Methods

The study was conducted in Retezat National Park. Of the 58 permanent glacial lakes, most were originally fishless (Pișota, 1971) (Fig. 4). Between 1960 and 1980, repeated stocking was carried out with native and non-native trout species, as well as coregonids, for recreational fishing (Decei, 1981). Between 2022 and 2024, 25 lakes were investigated using: visual shore observations (Tiberti et al., 2022b), umbrella traps, underwater drones for deep zones (*Gladius Mini S*), and aerial drones for surface imaging (Harris et al., 2019; Suska, 2024). These data were supplemented with historical stocking records and morphometric data from published sources (Pișota, 1971; Vespremeanu-Stroe et al., 2008; Necsoiu et al., 2016).

Results

Out of the 25 lakes investigated, specimens of the genus *Phoxinus* were observed in 12 lakes, including both lakes with native fish populations and historically stocked lakes. In 2023, the presence of *Barbatula barbatula* was reported for the first time in Zănoaga Lake, where it was likely also introduced as live bait, given that the steep spillway excludes natural colonization. The trout stockings failed in all investigated lakes; only native trout persisted in a few lakes hydrologically connected to mountain streams, where natural reproduction is possible. In lakes without such connections, stocked populations did not survive, while *Phoxinus* sp., being well adapted and prolific, persisted and spread.

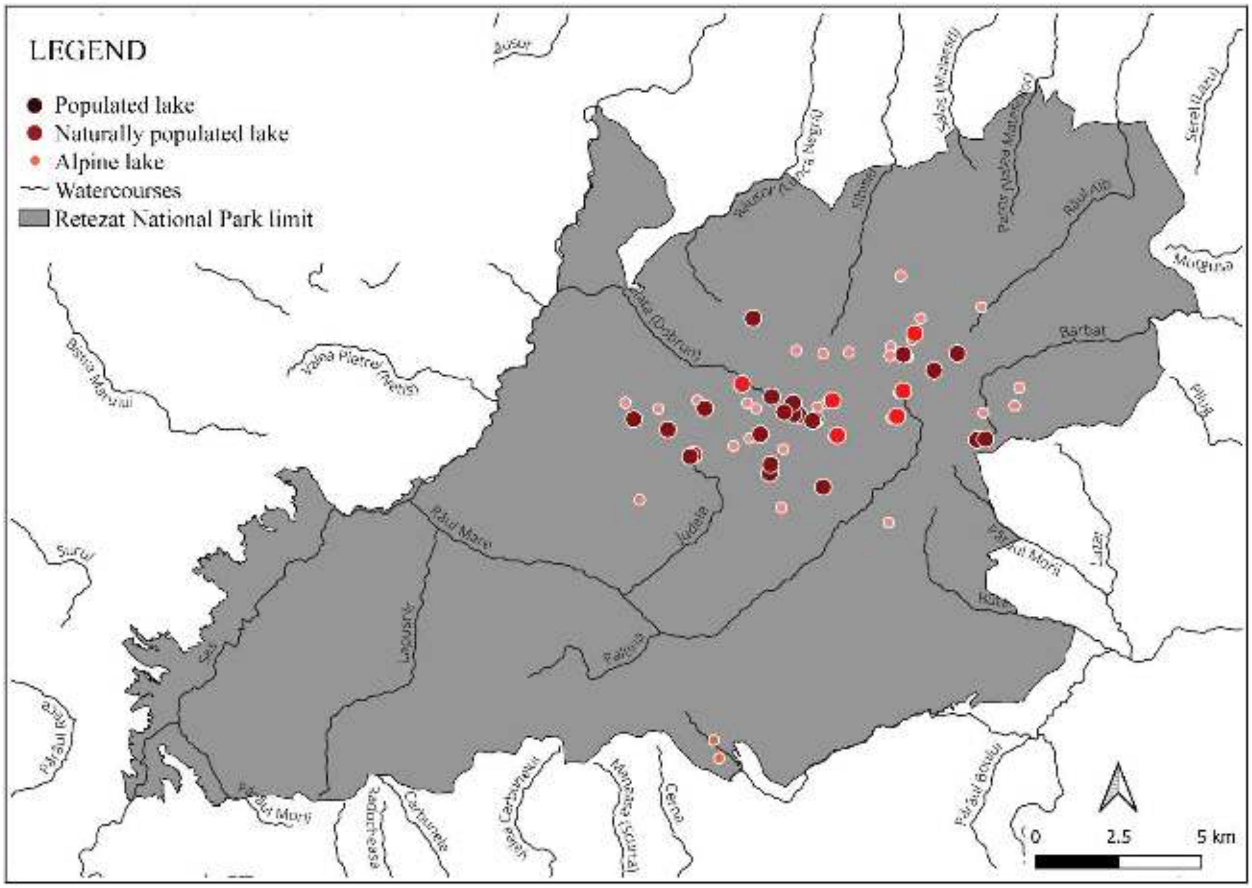

Fig. 4. Introduction and presence of native and alien trout species in the alpine lakes of Retezat National Park.

Discussions

The presence of these small fish used as live bait was detected only in lakes where trout populations existed at some point or are still present, suggesting accidental introduction by anglers (Miró & Ventura, 2015). The dominance of *Phoxinus* sp. populations in lakes leads to the decline of native trout, either through resource competition or predation on eggs and larvae (Museth et al., 2007; Osorio et al., 2022). Attempts to eliminate them have proven costly and ineffective, as shown by cases in Austria where *Phoxinus* populations persisted even after the removal of introduced fish (Schabetsberger et al., 2023). The presence of anostracan crustaceans (fairy shrimp) only in fishless alpine lakes in Retezat demonstrates the negative impact of introductions on rare and specialized invertebrates (Bohonak & Whiteman, 1999; Demeter & Mori, 2004).

Future conservation efforts should focus on preventing further introductions, managing already established invasive populations, and educating anglers about the risks associated with using live bait (Osorio et al., 2022).

CHAPTER III

Assessing the influence of minnows on tadpole development dynamics

This chapter is based on the following manuscript prepared for publication:

• Drăgan, O., Stănescu, F., Drăgan, A.-M., Fănaru, G., & Cogălniceanu, D. *The minnow and the common frog: A story of smooth cohabitation?*

Introduction

Amphibian populations in alpine lakes have undergone significant declines, particularly due to the introduction of predatory fish and habitat alterations (Blaustein, 1994; Pechmann & Wilbur, 1994; Tiberti & von Hardenberg, 2012). These lakes were historically fishless, creating favorable conditions for amphibian reproduction. Artificial stockings with trout species have transformed these ecosystems (Schilling et al., 2009; Ventura et al., 2017), with effects including predation, competition, and the exclusion of amphibians from optimal habitats (Orizaola & Braña, 2006; Miró & Ventura, 2015).

A frequently overlooked but significant consequence is the accidental introduction of minnows (Phoxinus sp.) by anglers as live bait (Miró & Ventura, 2015; Miró et al., 2018). This species adapts quickly, becomes abundant, and increases ecological pressure on invertebrates and amphibians (Tiberti et al., 2021; Schabetsberger et al., 2023). These fish can even contribute to local trout extinctions (Gacia et al., 2018; Osorio et al., 2022).

Materials and Methods

Studied species

The experiment focused on two species: the minnow (Phoxinus sp.), a small freshwater fish with a wide distribution in Europe and northern Asia, adapted to cold, well-oxygenated waters; and the common frog (Rana temporaria), one of the most widespread amphibian species in Europe, characterized by high ecological tolerance and the ability to inhabit diverse environments, including high-altitude habitats.

Study area and organism collection

The research was conducted in Retezat National Park (Fig. 5). On June 14, 2023, ten fresh egg clutches of Rana temporaria were collected from Lake Bucurelu, a fishless alpine lake at 2070 m elevation.

Minnows were captured from Lake Ostrov (460 m elevation, near the village of Ostrovel). Out of 60 specimens collected, 40 individuals of similar size (mean length 50.01 ± 0.53 mm, range 42.33–56.85 mm) were selected to ensure experimental consistency; the rest were kept as reserves.

The organisms were carefully transported to the Gura Zlata research station (800 m elevation), where the experimental infrastructure had been prepared.

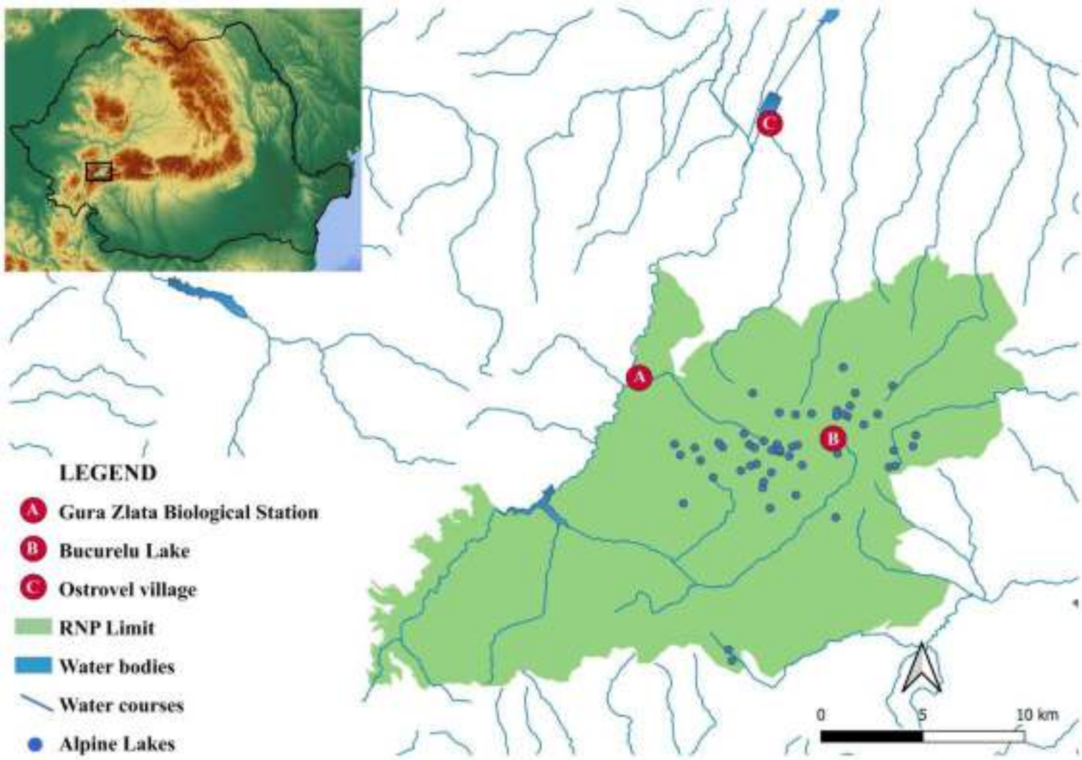

Fig. 5. Study area and collection sites

Experimental setup

Experimental procedure

The experimental system consisted of 16 cylindrical plastic tanks (each 500 L, diameter 104.5 cm), filled with 400 L of water from a nearby stream. A 2 cm layer of leaf litter from the surrounding forest was added to simulate the natural environment. The tanks were divided equally: 8 for the control group (no fish) and 8 for the minnow treatment (5 fish/tank). Tanks were filled in advance to allow water parameters to stabilize.

Water quality was monitored at five time points using portable instruments for temperature, pH, conductivity, and dissolved oxygen (Hanna HI98129, Oakton DO 450). Measurements were taken before stocking and then at regular intervals (May 30, June 13, June 19, June 30, and July 16).

Morphological measurements and growth analysis

In each tank, 20 tadpoles were randomly selected for measurement. Measurements were taken at the beginning (July 1 – initial evaluation) and end of the exposure period (July 16 – post-exposure evaluation). Snout–vent length (SVL) and total length (TL) were determined from photographs with millimeter paper, and measurements were performed using ImageJ v1.54p. In some cases, the number of individuals measured after exposure was reduced due to mortality. Mean growth was calculated as the difference between initial and final values.

Behavioral analysis

To assess baseline behavior before treatment, a pre-exposure behavioral evaluation was conducted on day one: 20 tadpoles were placed individually in white circular dishes with shallow water (1 cm depth). After 5 minutes of acclimatization, each individual was recorded for 15 minutes with an overhead HD camera (1980×1080, 30 fps). The second behavioral assessment (post-exposure) took place after 16 days of exposure, when the tadpoles reached Gosner stages 40–41, using the same filming conditions.

Video footage was analyzed with EthoVision XT 17, focusing on four key parameters: mean velocity, maximum velocity, total distance traveled, and percent time active. Statistical analysis included testing data normality with the Shapiro–Wilk test and comparing groups using the Mann–Whitney U test, suitable for small and independent samples. All statistical analyses were conducted using IBM SPSS Statistics v29.

Results

At the beginning of the experiment, tadpoles (n=320) had a mean SVL of 8.05 mm ± 0.58 SD and a TL of 20.86 mm ± 1.64 SD.

1. **Morphological changes**:
   - After 16 days, SVL did not differ significantly between treatments ($U = 2973.0$, $p = 0.1523$):
     - Control: 15.50 mm ± 1.20 SD
     - Treatment: 15.72 mm ± 1.35 SD
   - In contrast, TL was significantly greater in tadpoles exposed to minnows ($U = 1816.5$, $p < 0.0001$):
     - Control: 40.34 mm ± 3.53 SD
     - Treatment: 43.25 mm ± 5.45 SD

   This difference is attributed to tail elongation—a plastic response induced by the presence of fish.
2. **Locomotor activity and behavior** (Fig. 6):
   - Total distance traveled:
     - Control: 8,943 mm ± 1,953
     - Treatment: 18,160 mm ± 4,408 ($U = 0.0$, $p < 0.0001$)
   - Mean velocity:
     - Control: 10.07 mm/s ± 2.27
     - Treatment: 20.53 mm/s ± 5.01 ($U = 0.0$, $p < 0.0001$)
   - Maximum velocity:
     - Control: 205.02 mm/s ± 41.81
     - Treatment: 282.54 mm/s ± 71.24 ($U = 0.0$, $p < 0.0001$)
   - Percent time active:

• Control: 17% ± 8
• Treatment: 31% ± 11 (U = 0.0, $p < 0.0001$)

All these parameters indicated a significant increase in activity among tadpoles exposed to minnows compared to the control group.

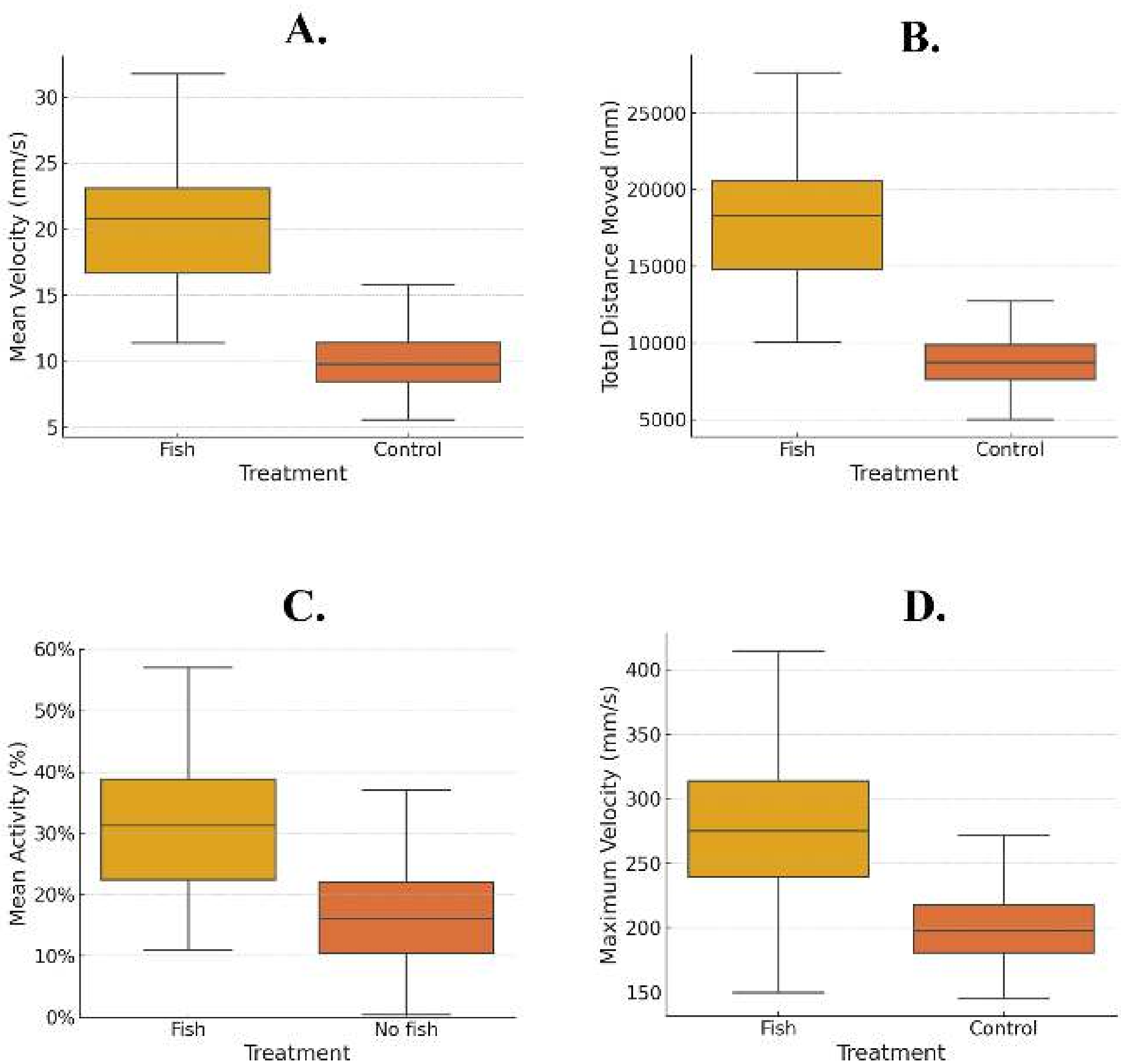

Fig. 6. Behavioral responses of tadpoles by treatment group.
A – mean velocity; B – total distance traveled; C – mean activity percentage; D – maximum velocity.

Discussions

Exposure to minnows triggered tail elongation in tadpoles—a plastic response that may enhance swimming performance and maneuverability in the presence of potential predators (Relyea, 2001). All behavioral parameters (velocity, distance, active time) increased significantly in the minnow treatment, indicating a proactive antipredator strategy (Fraker, 2008). These persistent responses may carry energetic costs, potentially affecting later development and post-metamorphic success (Relyea, 2002).

Although minnows are not typically predators of amphibian larvae (Museth et al., 2007; Osorio et al., 2022), their presence led to major behavioral changes. Non-consumptive effects, where prey respond merely to perceived risk, can alter community structure (Preisser et al., 2005; Ferrari et al., 2010). The persistence of minnows delays amphibian recovery after trout removal and highlights the need for strict management strategies (Miró & Ventura, 2015; Tiberti et al., 2019; Ventura et al., 2017).

CHAPTER IV

Public perceptions of fish eradication efforts in alpine lake ecosystems

This chapter is based on the following manuscript currently under review at *Oryx – The International Journal of Conservation*:

• Ferreira-Rodríguez N, Drăgan O, Vlad S, Drăgan AM, Băncilă R, Cogălniceanu D and Stănescu F (2025) *Social perception of fish removal in alpine lakes*.

Introduction

The introduction of alien fish species, as well as the translocation of native species into various aquatic ecosystems—including naturally fishless alpine lakes—has been widespread globally, typically driven by economic or social motivations (Xu et al., 2006; Roy et al., 2024). Such interventions have had unexpected ecological consequences, becoming one of the main threats to native biodiversity (Mollot et al., 2017; Roy et al., 2024). In Europe, recent policies emphasize nature restoration, including through the removal of alien species (*EU Biodiversity Strategy 2030*; *Regulation (EU) 2024/1991*).

Alpine lakes, isolated and low in biodiversity, were subject to fish stocking, particularly for recreational purposes (Pister, 2001; Ventura et al., 2017). These introductions significantly altered ecosystem structure and the ecosystem services provided by alpine lakes (Knapp et al., 2001; Tiberti et al., 2014). Additionally, the accidental release of bait species such as the minnow (*Phoxinus* sp.) led to competition for resources with initially introduced species (Osorio et al., 2022).

Until the late 20th century, the main method of eradicating alien fish was the use of rotenone, a substance toxic to other native species as well (Knapp & Matthews, 1998). More recent, selective methods involve netting or electrofishing, but these require considerable costs and effort (Tiberti et al., 2021; Knapp & Matthews, 1998). At the same time, introduced fish have acquired recreational and cultural value among anglers (Chiapella et al., 2018), complicating social acceptance of eradication measures and potentially generating stakeholder conflict (Tiberti & Cardarelli, 2021).

Most studies have focused on ecological recovery after eradication, not on public perceptions or socio-economic implications (Miró et al., 2020; Toro et al., 2020; Schabetsberger et al., 2009; Parker et al., 2001).

This study aimed to evaluate public perception of the value and removal of alien fish from the alpine lakes of Retezat National Park (RNP), Romania, and to compare the economic value of fishing to other recreational activities, in the context of ecosystem restoration under the European Nature Restoration Law.

Materials and Methods

Study area

Retezat National Park is the oldest national park in Romania, with 58 permanent glacial lakes at altitudes ranging from 1,700 to 2,300 m (Pișotă, 1971). Fishing is legally prohibited in alpine lakes and allowed only in a few lower areas (Gura Apelor reservoir and certain river segments). In recent years, the park has attracted approximately 35,000 visitors annually (ANANP, 2024), most of whom are engaged in various recreational activities.

Data collection

A total of 203 face-to-face interviews were conducted with visitors and locals in August 2023, at three of the most frequently visited camping zones (Gura Apelor, Poiana Pelegii, Bucura). Convenience sampling was used (Newing, 2011), targeting individuals over 18 years old. The structured questionnaire included both open and closed questions to gather qualitative and quantitative data. Each interview lasted around 5 minutes, and responses were noted in real time and later digitized for statistical analysis. All ethical standards were followed (informed consent, anonymity, voluntary participation).

Economic evaluation

To assess economic impact, the Individual Travel Cost Method (ITCM; Fleming & Cook, 2008) was used. Data were collected on visit frequency, participant origin, primary motivation for visiting (fishing or other activities), total travel cost per visitor, and opportunity cost (OC), based on European and national standards (Commission Decision C (2023) 4928; *Distanțe rutiere*, 2025; INS, 2023). OC was calculated as one-third of the wage rate for the time spent traveling.

Statistical analysis

Data were analyzed using R v. 4.3.2 (R Core Team, 2024). The methods included: descriptive statistics, Shapiro–Wilk test for normality, ordinal logistic regression to identify predictors of support for fish removal (factors: visit frequency, origin, activity type, education, gender, age, status), Welch's two-sample t-test, Mann–Whitney U test for non-parametric differences, proportion test, and chi-square test for economic contribution comparisons between anglers and other visitors.

Results

A total of 203 participants were interviewed: 18 at Gura Apelor, 163 at Poiana Pelegii, and 22 at Bucura. Gender distribution was 64.04% male and 35.96% female. Age categories were: 18–39 years (56.65%), 40–59 years (35.47%), and over 60 (7.88%). Education level was predominantly higher education (73.40%), followed by secondary education (24.63%). Most respondents were visitors (87.68%), the rest were locals, and nearly all were Romanian citizens (92.12%).

Preferred activities (*Fig. 7*): The most popular activity was nature exploration (hiking, camping, photography, relaxation), followed by mountain sports. Extractive activities (fishing, hunting) and services (guiding, mountain rescue) were mostly associated with frequent visitors.

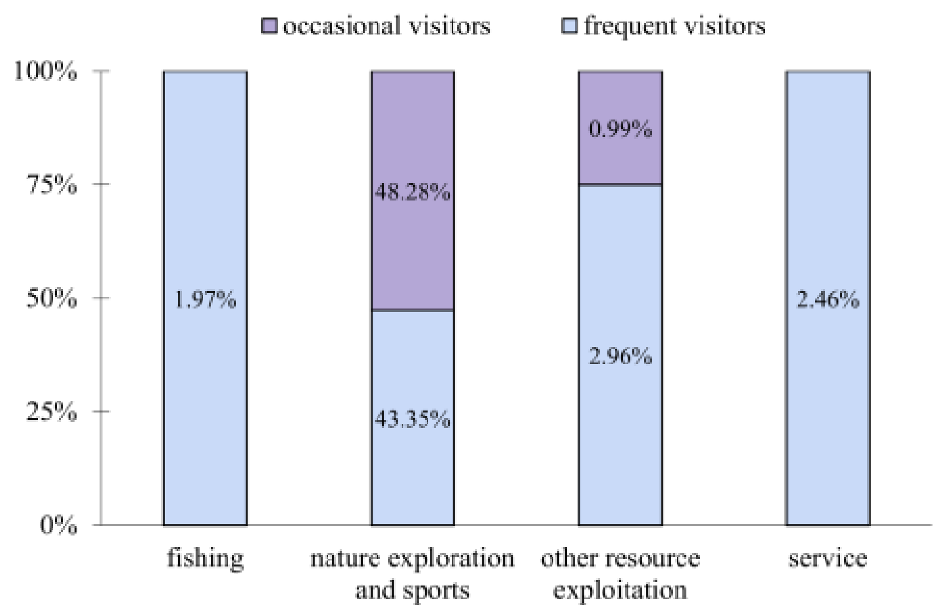

Fig. 7. Types of preferred activities during mountain trips, based on participants' responses

Perceptions of fish: 91.63% considered fish to be important in alpine lakes. Reasons given included intrinsic value (54.3%), practical value (38.71%), or both (6.99%). Only 13 respondents said fish were unimportant, and only two gave reasons: "because fishing is prohibited" and "fish alter the ecosystem."

After being informed that alpine lakes are naturally fishless, only 18% did not know why fish had been introduced. Mentioned reasons included: stocking for fishing (29.4%), as a food resource for humans (22.7%), to increase biodiversity (7.6%), or as food for other animals (6.6%).

Attitudes toward fish removal: Initially, 63.55% viewed fish introductions as positive. After receiving information on their negative impact on native flora and fauna, 62.56% agreed on the

need to remove alien fish to restore alpine lakes.
Ordinal logistic regression indicated that **visit frequency and education level** were significant predictors of support for fish eradication. Occasional visitors and those with higher education were more likely to support removal than frequent visitors or those with lower education levels.

Economic analysis:

- Average travel cost for anglers: €389.68
- For other visitors: €884.68
- Extrapolated to 35,000 visitors/year, with 5% interested in fishing:
  - Estimated annual ITC for anglers = €681,940
  - For other visitors = €29,415,610
- Thus, anglers contribute only 2.27% of total economic value, well below the hypothetical 5% threshold ($p < 0.001$)

Discussions

The typical visitor to Retezat National Park is young, educated, and prefers activities like hiking or camping rather than fishing. Although fish are perceived as important in alpine lakes, informing participants about the natural fishless state of these ecosystems and the negative effects of alien fish led a majority to support removal measures. However, such actions may still generate social conflict with anglers, fishing associations, and other groups (Tiberti & Cardarelli, 2021).

Most respondents valued fish for their intrinsic or biodiversity-related role rather than for extraction. This also reflects the study context—within a strictly protected area where fishing is prohibited. Economically, anglers contribute only marginally compared to other tourists, suggesting that restoration measures could be implemented with minimal economic impact. Still, to avoid conflict, the implementation of education and outreach programs, as well as compensation schemes where needed, is recommended.

Managing alien fish in alpine lakes is thus a complex socio-ecological issue that requires integration of ecological restoration goals with the social and economic concerns of various stakeholder groups (Woodford et al., 2017). Effective outreach and awareness programs, along with compensation mechanisms, can facilitate social acceptance of eradication efforts.

GENERAL CONCLUSIONS

Aquatic ecosystems in Romania—from lowland rivers to alpine lakes—have been deeply affected by the introduction of alien fish species over the past century. Between 1910 and the present, 52 alien species have been identified, 11 of which are recognized as invasive and are now widespread across all major hydrographic basins. The main introduction pathways were aquaculture, intentional stocking, and unassisted dispersal along connected waterways.

Alpine lakes, due to their inaccessibility, have been less monitored, and thus information on the presence and persistence of fish in these ecosystems remains limited. In Retezat National Park, stocking campaigns in the last century introduced both native and alien trout species; however, these did not establish stable populations due to harsh conditions (limited spawning habitats, hydrological isolation). In contrast, the minnow (*Phoxinus* sp.), native to lowland and hill streams, proved invasive in alpine lakes where it was previously absent, managing to colonize and persist where stocked trout failed.

The study shows that minnows reached and established in 12 of the 25 alpine lakes surveyed, following accidental releases linked to recreational fishing (use of live bait), in the absence of a management plan. Over time, these minnow populations became permanent—even after trout disappeared—and altered aquatic community structures. This pattern has also been observed in other European mountain regions, such as the Pyrenees and the Alps, where *Phoxinus* sp. came to dominate lakes after failed salmonid stockings.

From a conservation management perspective, the results highlight the difficulty of managing native species with invasive behavior in novel contexts, where they become dominant and hard to eradicate. Although *Phoxinus* is native to Romania, it is an efficient invader in historically fishless alpine lakes, causing persistent changes in local fauna and severely impacting invertebrates and amphibians. Conventional removal methods (intensive fishing, lake drainage, piscicides) are either ineffective or risky for sensitive and hard-to-access ecosystems.

Beyond the ecological analysis, the study also investigated public perceptions of alien fish removal. Support for such measures increased significantly after visitors were informed about the negative impact on biodiversity and water quality. Furthermore, fishing plays only a marginal economic role in these areas, where tourism and natural scenery are much more valuable to local communities.

Therefore, the success of biodiversity protection and alpine ecosystem restoration depends on the integration of legislation, scientific research, local implementation, and—critically—public awareness and involvement. Only in this way can we move from passive tolerance of invasive species to active protection of Romania's mountain freshwater ecosystems.

LIST OF PUBLICATIONS

Thesis related

Articles published

- **Drăgan, O.**, Rozylowicz, L., Ureche, D., Falka, I., & Cogălniceanu, D. (2024). Invasive fish species in Romanian freshwater. A review of over 100 years of occurrence

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Posters

- **Drăgan, O**. 2021. The necessity to integrate Citizen Science into non-native fish species monitoring and inventory. The 28th International Scientific Jubilee Symposium "Deltas and Wetlands" 2021", Tulcea, Romania
- **Drăgan, O**., Cogălniceanu, D. 2022. Introduced fish species in Romanian alpine lakes: Retezat National Park case study. Joint ESENIAS and DIAS Scientific Conference 2022 and 11th ESENIAS Workshop Invasive alien species under conditions of global crisis. 13–15 November 2022. Demre, Antalya, Turkey
- **Dragan, O**., Cogălniceanu, D., Rozylowicz, L. 2023. Invasive fish species distribution in Romanian freshwaters. Joint ESENIAS and DIAS Scientific Conference 2023 and 12th ESENIAS Workshop: Globalisation and invasive alien species in the Black Sea and Mediterranean regions – management challenges and regional cooperation, 11–14 October 2023, Varna, Bulgaria. Communication awarded "Best Talk on Animal Invasions".
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- Cogălniceanu D., Stănescu F., Tudor, M., Cobzaru I., **Drăgan O**., Băncilă, R., Chișamera, G., Petrescu,A., Telea E.A., Samoilă, C., Ureche D., Ciubuc F., Popa A.M. (2022). Ghid de inventariere şi cartare a distribuţiei speciilor alogene de vertebrate terestre din România. Ghid întocmit în cadrul Proiectului POIM2014+120008 - Managementul adecvat al speciilor invazive din România, în conformitate cu Regulamentul UE 1143/2014 referitor la prevenirea și gestionarea introducerii și răspândirii speciilor alogene invazive. Bucureşti: Ministerul Mediului, Apelor şi Pădurilor & Universitatea din Bucureşti. ISBN: 978-973-0-36594-8

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- Skolka, M., Plăiașu, R., Băncilă, R.I., Ciubuc, C., Memedemin, D., **Drăgan, O**., Cogălniceanu, D. 2024 - The invertebrate fauna of the epigean layer from different types of habitats in the Retezat National Park (Romania), in Travaux du Museum d'Histoire Naturelle "Grigore Antipa", Vol.67, Supplement 1 – ZoologyCon 2024, Bucuresti, Romania.
- Skolka M., Cogălniceanu D., Memedemin D., **Drăgan O**., Gavrilescu C., Tanase T. 2022.– *Corytucha arcuata* (Say, 1832) (Heteroptera, Tingidae) in alpine habitats from the Romanian Carpathians. Joint ESENIAS and DIAS Scientific Conference 2022 and 11th ESENIAS Workshop Invasive alien species under conditions of global crisis. 13–15 November 2022. Demre, Antalya, Turkey
- Skolka M., Memedemin D., **Drăgan O**., Gavrilescu C. 2022. New data on the presence of *Sceliphron curvatum* (F. Smith, 1870) (Hymenoptera, Sphecidae) in Romania. Joint ESENIAS and DIAS Scientific Conference 2022 and 11th ESENIAS Workshop Invasive alien species under conditions of global crisis. 13–15 November 2022. Demre, Antalya, Turkey

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