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Research Article

Establishment of Regional Action Plan for conservation of critically endangered crucian carp in Czechia

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Abstract

The crucian carp (*Carassius carassius*) has declined markedly in recent decades due to the ongoing invasion of its congeneric species complex, the gibel carp (*Carassius gibelio*) and widespread habitat degradation. In Europe, the crucian carp occurs in two highly divergent phylogenetic lineages: the northern lineage distributed across northern and central-eastern Europe and occurs in the Elbe (Labe) and Oder (Odra) River Basins and the Danubian lineage restricted to the Danube (Dunaj) River Basin. Both lineages are naturally present in Czechia. However, their close spatial proximity in some areas, reflecting the natural contact areas between the Elbe and Danube basins, combined with intensive aquaculture practices and likely translocations by recreational anglers, may have led to local mixing of lineages or their introduction into non-native areas. Consequently, the prevailing conservation paradigm on effective conservation of the crucian carp requires maintaining these lineages as distinct conservation units. To address this need, a Regional Action Plan (RAP) was developed to preserve the current distribution of phylogenetic lineages of the crucian carp in the Vysočina Region, where both lineages intersect. A citizen-science project ("Save the crucian carp") was implemented to locate the remaining populations in the region. Populations identified through citizen-science tips were subsequently selected for systematic monitoring and samples were collected for genetic analyses. Based on lineage assignment (northern or Danubian), suitable populations were selected for conservation management. As part of the RAP, we initiated the repatriation of genetically verified crucian carp populations. Source populations representing both lineages were identified and individuals were transferred to newly-established sites located within their respective watersheds and in close geographical proximity. In total, five northern and eight Danubian populations were identified and three northern and four Danubian populations were successfully repatriated. This study provides a comprehensive conservation framework for a declining wetland fish species. Although regionally focused to the Bohemian-Moravian Highlands, situated at the boundary between the North Sea and Black Sea drainage basins, the approach is broadly applicable to other declining wetland species with similar ecological requirements and genetic structure. Our findings underscore the necessity of integrated, multi-level assessment of species threats and highlight the importance of evidence-based conservation management.

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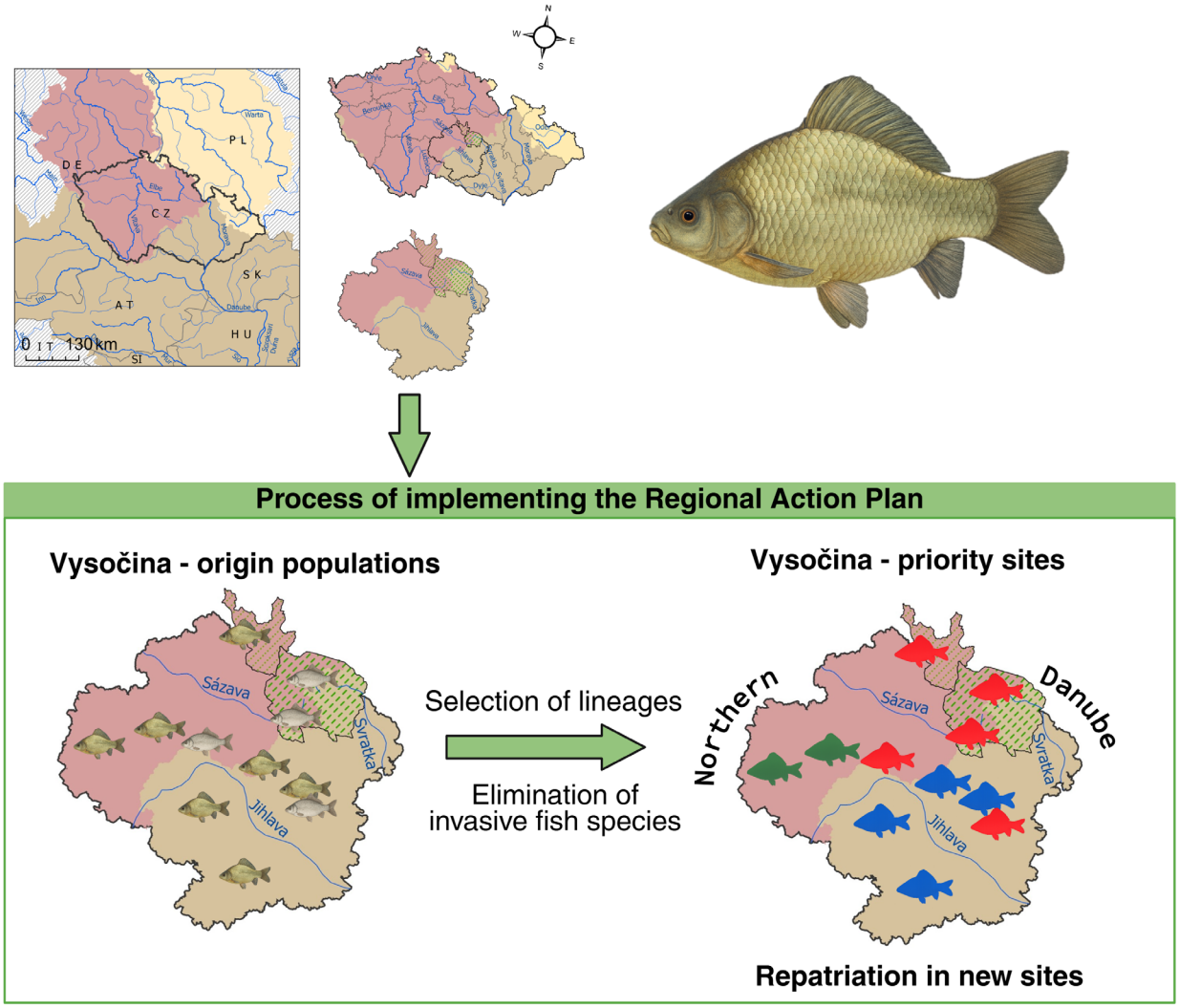
Graphical abstract

Graphical abstract showing the area where the Regional Action Plan was designed, along with a simplified workflow of suitable population identification.



Key words: Cyprinidae, freshwater conservation, genetic diversity, habitat restoration, metapopulation

Introduction

Wetland habitats play fundamental roles for many fish species as well as for other freshwater animal communities, such as amphibians or invertebrates (Dodd and Cade 1998; Trexler et al. 2005; Batzer and Boix 2016). However, freshwater ecosystems are vulnerable to environmental changes and human activities and they face the greatest biodiversity loss of all ecosystems (Dudgeon et al. 2006; Reid et al. 2019; Tickner et al. 2020). Flow regulation and other river modifications, such as canalisation, land use for agriculture, pollution, overexploitation and invasive non-native species are the main factors for biodiversity loss (Dudgeon et al. 2006; Šmejkal et al. 2025a). Reduced river connectivity and disrupted dynamic nature of alluvial floodplain rivers as a result

of river modifications have caused the disappearance of oxbows and pools in the floodplain of rivers in the majority of European rivers (Dynesius and Nilsson 1994; Aarts et al. 2004; Arthington 2012; EEA 2018), typical habitats for limnophilic and stagnophilic fish species, such as European weatherfish (*Misgurnus fossilis*), sunbleak (*Leucaspius delineatus*), mudminnow (*Umbra krameri*) and crucian carp (*Carassius carassius*) (Drozd et al. 2009; Chobot and Němec 2017; Bănăduc et al. 2022; Fedorčák et al. 2023). Habitat modifications and the spread of invasive non-native fish species are crucial factors contributing to the decline of native wetland fish species (Šmejkal et al. 2025a).

The crucian carp became critically endangered species in Czechia after an enormous population decline over the last few decades (Chobot and Němec 2017) and its populations have also dropped sharply in other EU countries (Šmejkal et al. 2025a). However, the species is absent in EU conservation legislation (Freyhof and Brooks 2011), despite a steep decline throughout its native range in northwest, central Europe or the Danube watershed (Kottelat and Freyhof 2007; Sayer et al. 2011). The primary threats to crucian carp are habitat destruction and the introduction of invasive non-native species. The polyploid complex of congeneric *Carassius* fishes, characterised by a complex genomic composition (Kuhl et al. 2022), hereafter referred to as species taxon gibel carp (*Carassius gibelio*), is the most successful invasive fish species in Europe. It is considered to be a major invasive species in EU (van der Veer and Nentwig 2015) and threat to crucian carp and other native fish species through resource competition, particularly for food and space (Tapkir et al. 2022, 2023, 2025; Šmejkal et al. 2024). Additionally, competition with the topmouth gudgeon (*Pseudorasbora parva*) may further limit its feeding niche and potentially reduce its reproductive success (Šmejkal et al. 2024). Another potential negative effect is the hybridisation with invasive *Carassius* species (Smartt 2007; Papoušek et al. 2008); however, recent studies suggest that its overall impact may be limited (Jeffries et al. 2024).

For the above reasons and people´s positive attitude towards this species, crucian carp has become an item for conservation initiatives from enthusiastic local angling associations to citizen-science actions to preserve remaining populations (Copp and Sayer 2010, 2020; Thomas et al. 2025a). However, there is hidden genetic diversity in the species, as it occurs in two highly divergent phylogenetic lineages in Europe. Lineage 1 (northern) is distributed throughout northern, central and part of eastern Europe. Lineage 2 (Danubian) seems to be associated only with the Danube catchment area. These lineages are separated by 2.16 million years (Jeffries et al. 2016). Czechia is situated in central Europe and includes river drainages flowing northwards, such as the Elbe and the Odra, as well as the Danube drainage. Thus, the crucian carp occurs naturally in the territory of Czechia in both phylogenetic lineages and these lineages can come into close proximity at border areas where the Danube-Oder and the Danube-Elbe watersheds meet. However, due to intensive aquaculture and transfer by recreational fisheries, the phylogenetic lineages may become mixed in some areas or misplaced in other watersheds. Therefore, the conservation actions for crucian carp should consider these lineages as separate conservation units, especially near watershed borders.

The Regional Action Plan (RAP) aims to achieve four main goals: i) secure existing populations of crucian carp in the Vysočina Region through conservation of current sites and re-population measures to suitable small water bodies;

ii) maintain both phylogenetic lineages of these species naturally occurring in this area; iii) keep crucian carp populations away from the presence of invasive fish species by working with fully drainable waterbodies; and iv) provide habitats to other endangered fauna, such as sunbleak or newts, serving as an umbrella species.

By combining ecological and genetic expertise, this study provides a comprehensive conservation approach for declining wetland fish species. Although geographically focused on the Bohemian-Moravian Highlands — situated at the boundary between the North Sea and Black Sea drainage basins — the approach is broadly applicable to other declining wetland species with similar ecological requirements and genetic structure and at larger geographical scales. The study highlights the importance of a comprehensive, multi-approach assessment of species threats and the necessity of managing conservation actions based on scientific evidence.

Materials and methods

Study sites

This study is based on sampling conducted at 66 sites located in the Vysočina Region between 2021 and 2024, Czechia (Suppl. material 1: table S1). Vysočina, for the Regional Action Plan, covers the Vysočina Region administered by the Vysočina Regional Authority and the Žďárské vrchy and the Železné hory Protected Landscape Areas (the former partly extending into the Pardubice Region), both managed by the regional office of the Nature Conservation Agency of the Czech Republic (hereafter AOPK ČR) with a total area of 7790 km^2 (area termed hereafter Vysočina). It is a key biogeographical zone where both northern and Danubian crucian carp lineages occur, with signs of partial mixing. The region spans two major drainage basins: the Elbe (with highest stream orders Sázava, Doubrava, Chrudimka) and the Danube (with highest stream orders Svratka, Jihlava, Moravská Dyje; Kraj Vysočina 2022). Vysočina is an upland part of the Bohemian–Moravian Highlands, typically ~ 400–800 m a.s.l. Flooded stone quarries are widespread in the Vysočina because mining activities exploit its near-surface crystalline Bohemian Massif bedrock.

The sites were selected based on information provided by the citizen-science project "Save the Crucian Carp" started on 16th August 2021 and in cooperation with the Vysočina Regional Authority and AOPK ČR. The "Save the Crucian Carp" project involves the public in efforts to protect endangered fish species in small freshwater ecosystems, with a particular focus on the crucian carp (Šmejkal et al. 2020). Volunteers registered on the web portal, completed a brief personal questionnaire and provided tips on crucian carp occurrences, while listing brief details: site characteristics such as a pond, pool or flooded quarry, fish community composition and assessment of population status at each site. An option then appeared to mark the location on Google Maps, which automatically populated the citizen-science database with the GPS coordinates. For the verification procedure of citizen-science tips, we selected sites according to their habitat characteristics, administrative status and accessibility of each site, considering that some waterbodies located on private property required the owner's consent for sampling.

Sample collection

During the growing seasons from 2021 to 2024, field samples were collected (Table 1). Fish abundance was assessed using a standardised sampling method. Five umbrella nets were deployed in the littoral zone and left overnight. Based on prior research, dog food pellets and bread slices were selected as bait to improve capture success (Thomas et al. 2023). To prevent suffocation, part of the device was kept above the water surface, allowing newts and other amphibians access to atmospheric air (Swartz and Miller 2018). The captured individuals were classified by species and each fish's standard length (SL, mm) and weight (W, g) were measured. Identification of species of the genus *Carassius* was based on morphological characteristics, following Szczerbowski (2002) and Kottelat and Freyhof (2007). For each sample of *C. carassius*, an approximately 0.5 cm^2 piece of tissue was excised from the pelvic fin and immediately placed in 98% ethanol, then stored at −20 °C.

DNA extraction, molecular markers and methods

DNA was isolated from fin clips preserved in 98% ethanol using the QIAamp® DNA Mini Kit (Qiagen, Germany), following the manufacturer's protocol. The cytochrome b gene was amplified following Rylková et al. (2010) using the

Table 1. Studied sites where crucian carp occurs in Vysočina.

Site ID	Site	Lineage	No. of tested ind.	Invasive species	No. of fish caught	Site type	Area (m^2)	Latitude (°N)/ Longitude (°E)
1	Vopál	Mix	5	yes	single digits	Pond	2228	49.1488778°N, 16.1347747°E
2	Olšoveček - Sklepy	Danubian	9	no	tens	Pond	1021	49.2566128°N, 16.2038536°E
3	Kocanda	Mix	8	no	single digits	Pond	2967	49.6791217°N, 15.9945942°E
4	Záborná 2	Not tested	–	yes	hundreds	Pond	1244	49.4784447°N, 15.7442303°E
5	Soudkův quarry	Not tested	–	yes	tens	Stone quarry	379	49.6281128°N, 15.3921500°E
6	Cihelna	Not tested	–	yes	tens	Pond	434	49.6880831°N, 15.7880061°E
7	Hřeben 1	Northern	10	no	tens	Stone quarry	1174	49.6162561°N, 15.3938011°E
8	U Vilímovce III	Northern	10	no	hundreds	Stone quarry	541	49.6231806°N, 15.4222875°E
9	Přibyslavice	Not tested	–	yes	single digits	Stone quarry	1203	49.8470353°N, 15.4091419°E
10	Olšoveček	Danubian	9	no	hundreds	Pond	1548	49.2563606°N, 16.1982103°E
11	Všeradov	Danubian	13	no	hundreds	Pond	642	49.7469564°N, 15.8329644°E
12	Radostín	Danubian	3	no	–	Pond	1256	49.6538039°N, 15.8854278°E
13	Pond U modré značky	Danubian	13	no	hundreds	Pond	295	49.0469889°N, 15.7283128°E
14	Pond U Komárovic	Danubian	13	no	hundreds	Pond	496	49.0641092°N, 15.7142364°E
15	Pond U parkoviště	Danubian	15	yes	tens	Pond	189	49.0368161°N, 15.7092153°E
16	Jednička quarry	Northern	15	yes	tens	Stone quarry	766	49.6182069°N, 15.4068547°E
17	Dvojka quarry	Northern	6	no	tens	Stone quarry	845	49.6191269°N, 15.4075875°E
18	Ranská ponds - 5	Danubian	15	no	tens	Pool	788	49.6550369°N, 15.8148111°E
19	Bělá	Northern	15	yes	tens	Pond	8431	49.3107539°N, 15.2648458°E
20	Kamenice	Not tested	–	yes	single digits	Pond	2341	49.2974231°N, 15.0718881°E
21	U Pavlova quarry	Mix	12	yes	single digits	Stone quarry	428	49.5039411°N, 15.4285000°E

forward primer Kai_F (5'-GAAGAACCACCGTTGTTATTC-3') and the reverse primer Kai_R (5'-ACCTCCRAYCTYCGGATTACA-3') described by Šlechtová et al. (2006). PCR products were purified and Sanger sequenced by Macrogen Inc. (Seoul, Republic of Korea). Obtained chromatograms were examined using FinchTV 1.4.0 (Geospiza, Inc., Seattle, WA, USA) to assess base-call quality. Sequences generated in this study were analysed together with supplementary sequence data retrieved from GenBank for other lineages of the genus *Carassius*, including northern and Danubian reference sequences of *C. carassius*, as well as the outgroup *Cyprinus carpio*. Sequences were aligned using MUSCLE 3.8.31 (Edgar 2004) and phylogenetic relationships were inferred using Maximum Likelihood (ML) analysis implemented in MEGA 11 (Tamura et al. 2021).

Defining taxa and identifying phylogenetic lineages

The aim of the genetic analysis was to verify species assignment, rule out hybridisation with mostly maternal *C. gibelio* and determine whether the individual belonged to the northern or Danubian phylogenetic lineage. Based on mtDNA analyses, maternal origin was inferred from the topology of the constructed phylogenetic tree, allowing assignment to both species and lineage, although this inference is limited to maternal inheritance.

Source populations

The tested populations from sites without invasive species were further subdivided according to the identified lineages (northern and Danubian) and selected as source populations for subsequent repatriations. For the purposes of this RAP, several priority areas were defined, each comprising multiple sites with surveyed populations (Table 2). Given the above-described risks to which natural populations are exposed (invasion by non-native species), establishing and maintaining source populations is an essential step.

The following was used for repatriations: i) to establish a population, at least 100 individuals were used (in the case of a single stocking event) or 50 individuals with additional individuals added in the future, in order to maintain genetic diversity; one of the verified populations were used as the source; ii) the populations were maintained with the highest possible level of isolation from the risk of invasion by non-native species, where invasion risk exists, all potential pathways of spread were considered (e.g. eggs attached to aquatic plants, fry introduced during feeding with natural zooplankton etc.) and iii) a subset of the populations at five-year intervals should be genetically tested to verify genetic purity. In this context, repatriation refers to stocking crucian carp back to the area of former occurrence.

New sites for repatriation

The aim of this RAP is also to identify additional suitable sites for stocking the crucian carp. As a new site is recommended to use a location outside floodplains (i.e. beyond the reach of floods, which may be the source of non-native fish species colonisation) and sites that are difficult for humans to access (to minimise the risk of unauthorised stocking). At present, many small waterbodies are being constructed to retain water in the landscape, making it possible to establish syn-

Table 2. Priority areas of the crucian carp populations. These areas will be subsequently used for the gradual repatriation of the species into suitable waterbodies in the region.

Area	Sites	Lineage	No. of sites	No. of ind./site	Competence
Lipnické quarries	Jednička quarry	Northern	4	hundreds	Vysočina Regional Authority
	Dvojka quarry				
	Hřeben I				
	U Vilímovce III				
Komárovice	Pond U Komárovic	Danubian	3	hundreds	Vysočina Regional Authority
	Skokan				
	Augustov				
Moravskobudějovicko	Pond U modré značky	Danubian	2	hundreds	Vysočina Regional Authority
	Pond U parkoviště				
Olšoveček	Olšoveček	Danubian	2	hundreds	Vysočina Regional Authority
	Olšoveček-sklepy				
Těchobuz	Polský pond	Northern	3	hundreds	Vysočina Regional Authority
	Dubinka				
	U buku				
Žďírec nad Doubravou	Všeradov	Danubian	2	hundreds	Regional office of the Nature Conservation Agency (AOPK) Žďárské vrchy Protected Landscape Area Administration
	Ranská ponds				

ergies with the conservation of crucian carp. During the implementation of the RAP in the following years, it will be possible to add new sites to these areas or remove them as needed using the repatriation principles defined above.

Stocking and verifications

The stocking of selected crucian carp populations, tested in previous surveys, into selected suitable ponds without any aquaculture further upstream of the pond (due to potential unwanted source of invasive fish species). The following year, the success rate of repopulation measures was verified using a sampling procedure with five umbrella traps described above. Successful repopulation was defined as catch of more than 50 individuals with some coming from obvious recruitment (fish under 50 mm SL in the year or two after stocking).

Results

Presence of the crucian carp in selected sites

The crucian carp were found at 21 sites (Table 1, Fig. 1) within a total of 66 studied sites (Suppl. material 1: table S1). In total, we collected 171 genetic samples of *C. carassius*. At half of these sites, only native species were recorded (crucian carp, rudd *Scardinius erythrophthalmus*, common carp *Cyprinus carpio*, European perch *Perca fluviatilis*, gudgeon *Gobio gobio*, tench *Tinca tinca* and sunbleak). In contrast, the remaining sites also harboured non-native invasive species (Fig. 1), including gibel carp and topmouth gudgeon. Five of these sites were dominated by invasive species and were, therefore, excluded from genetic testing (Table 1).

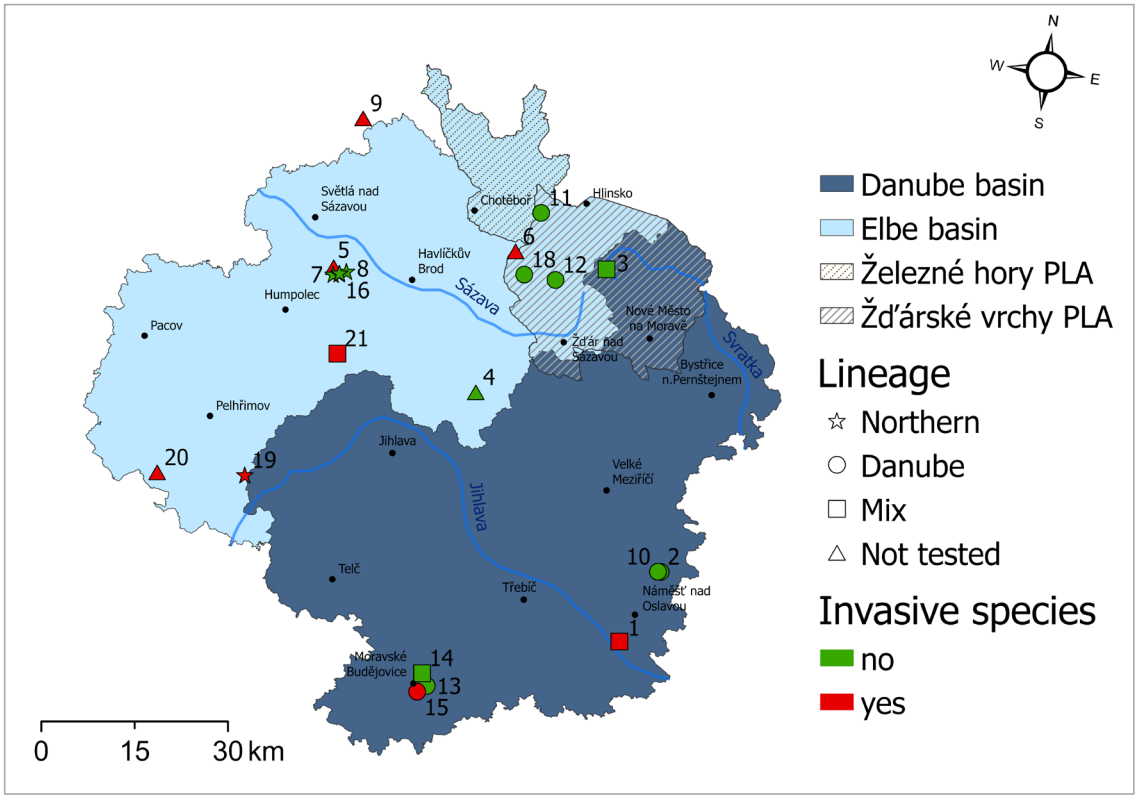


Figure 1. Map of sampled sites in the Vysočina Region and its division into two main watersheds. These contain two protected areas (Železné hory PLA and Žďárské vrchy PLA; PLA = Protected Landscape Area). Sites with dominance of invasive species and low populations of crucian carp (*Carassius carassius*) were not selected for genetic testing due to their unsuitability for use in repopulation measures. Presence of the crucian carp lineages in Vysočina Region (symbols) and presence of invasive species in tested sites (green – site without invasive species, red – site with invasive species).

Taxon delimitation and identification of hybrids

With the exception of a single individual, all sampled specimens were identified as crucian carp.

A total of 11 surviving crucian carp populations were identified (Table 1), for which: a) DNA analyses confirmed that none of these populations included visible hybrids with a maternal lineage from non-native *Carassius* species, including maternal hybrids and b) all occurred at sites where non-native *Carassius* species were absent (Table 1).

Phylogenetic analyses of mitochondrial data

Based on genetic analyses, both the two genetically distinct lineages of the crucian carp (northern and Danubian), were identified in Vysočina. In total, five northern and eight Danubian populations were identified and three populations were classified as mixtures of the two (Table 1).

Repatriation and verification of population viability

Overall, three northern and four Danubian populations were repatriated, prioritising populations in closest proximity to newly-established sites within their corresponding watersheds. For the repatriation of the crucian carp, the following sites

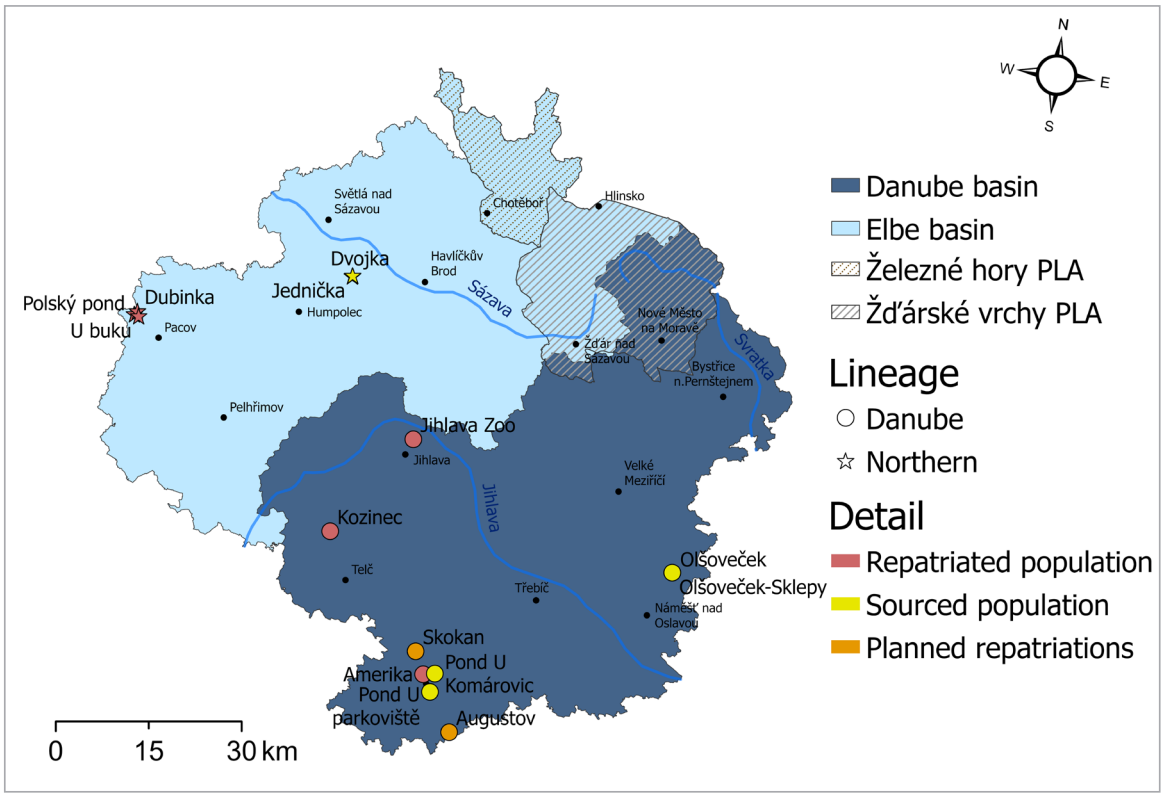


Figure 2. Map of source populations and current and future repatriations in the Vysočina Region with respect to two phylogenetic lineages of the crucian carp (*Carassius carassius*); PLA = Protected Landscape Area.

were used: Polský pond, Dubinka and U buku (northern lineage, originating from the Jednička and Dvojka quarries) and Jihlava Zoo and Olšoveček (Danubian lineage, originating from Olšoveček–Sklepy) and Skokan and Augustov ponds (Danubian lineage, originating from pond U Komárovic; Fig. 2, Suppl. material 1: table S2). Thus, this RAP identified six priority areas (Table 2), where natural populations occur, each encompassing multiple sites with tested populations. Natural recruitment was confirmed at the ponds of Augustov, Dubinka, Olšoveček, Polský and Skokan, while it was unsuccessful in the Jihlava Zoo and U buku ponds likely due to the spillover of wastewater and a flash flood, respectively (Fig. 3).

Discussion

This action plan seeks to conserve two phylogenetically distinct units of crucian carp within a relatively small region (7790 km^2), where both northern and Danubian watersheds occupy similar area. While 38 percent out of the total populations found in this area were mixtures of both lineages or populations had been reduced so severely by invasions that they could not be used as conservation units or as sources for repatriation, remaining populations showed distinct belonging to either the northern or Danubian lineage and good population size for potential repatriations. At the same time, around half of Vysočina is part of the Sázava watershed, a tributary of the Elbe. The headwater and upper reaches of small rivers and streams in the watershed between the Sázava and Jihlava rivers have historically shifted their drainage, flowing either into the Danube or into the Elbe Basin (Brzák 1997; Balatka et al. 2010). Thus, this region provided natural proximity between

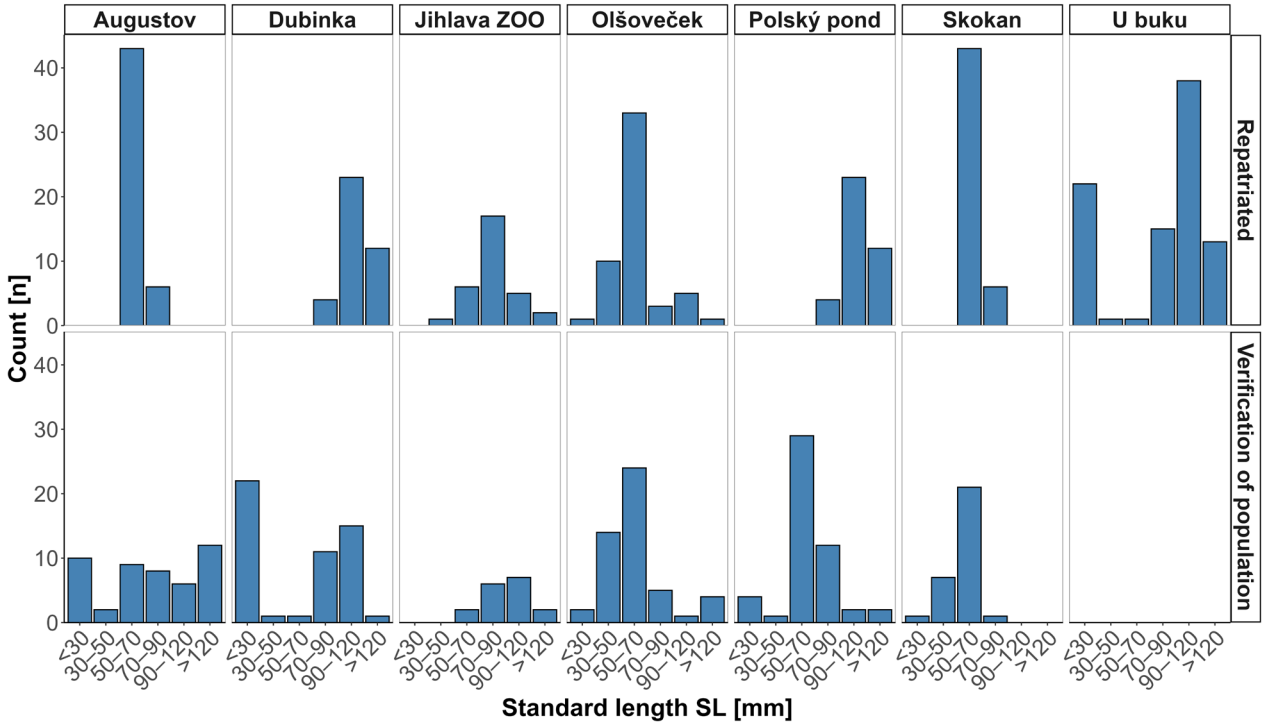


Figure 3. Length-frequency distribution of captured crucian carp (*Carassius carassius*) in repatriated sites. Fish up to 50 mm indicate recruitment.

the lineages, which may have come into contact in parts of the region and some mixtures of the lineages found in this study may have originated from natural processes. These findings are in line with first geographically relevant data on weatherfish with divergent lineages that might have crossed the watersheds (Bohlen et al. 2025). This also demonstrates that mixtures of both lineages are part of historical and ongoing biogeographical processes and that such genetic mixtures may warrant conservation consideration. More detailed analyses of genetic variation across identified populations should be addressed in future studies, as they may reveal additional conservation-relevant units within mixed populations. The spatial distribution of phylogenetic lineages in European fish taxa reflects historical colonisation processes driven by Quaternary glacial–interglacial cycles, during which populations persisted in geographically distinct refugia and subsequently expanded during postglacial periods (Takács et al. 2022). In the case of crucian carp, there were three refugia located presumably around the Black Sea and two situated on the territory of Ukraine (Jeffries et al. 2016).

Current intensive interaction between humans and nature in the Anthropocene resulted in homogenisation of biodiversity at various levels, from fish communities to genetic variability (Rahel 2002; Olden et al. 2004). Species with intense aquaculture management and public attention may end up with mixed populations and genetic homogenisation (Östergren et al. 2021), which can threaten the genetic variability and species integrity of taxa (Olden et al. 2004). An example of such a situation is mixed genetic diversity of brown trout (*Salmo trutta*), a species of high interest to recreational anglers. To meet angling demand, populations have been extensively stocked, often using material from distant sources by the Czech Anglers Union. As a result, only a few locations in Czechia

retain genetically unadmixed brown trout populations (Kohout et al. 2012). Thus, maintaining genetic diversity should be a priority in species for which large-scale conservation is attempted, as it should secure the genetic variability needed for future population resilience. In small wetland species that receive limited attention from hobbyists and recreational anglers, there is still likely space to conserve remaining populations with original genetic information.

Maintenance of crucian carp sites without invasive fish species

Invasive species have become increasingly widespread in Central Europe due to intense aquaculture in the last decades (Musil et al. 2010; Takács et al. 2017) and so mitigating their invasions will be needed at repatriation sites as well as in identified refugia. Ponds provided by state enterprise Lesy České republiky s.p. [Forests of the Czech Republic] in cooperation with the Municipality of Vysočina Region and AOPK ČR, were carefully selected so that they were built as the first waterbody on the stream, which eliminates downstream migration of invasive fishes when eventual upper waterbodies are drained (Davies and Britton 2016; Bojarski et al. 2022). Although this approach is likely an effective measure against downstream drift of invasive species, another pathway, the spread of invasive fishes by waterfowl (Hirsch et al. 2018; Lovas-Kiss et al. 2020) cannot be fully excluded. Selected ponds are fully accessible to waterfowl in the landscape and often have other larger waters in close vicinity. The eggs of gibel carp can survive (albeit with relatively low success) in the digestive tract of water birds (Lovas-Kiss et al. 2020, 2024). Another important pathway is human-mediated transfer via intentional releases of invasive fish (Kalous et al. 2013; Janáč et al. 2025), which can be mitigated by installing informational boards at sites. Therefore, ponds were also selected, based on the possibility of complete drainage, allowing them to be fully harvested and subsequently left dry for one month. This management practice should ensure that habitats are free of invasive fish species for a certain period.

Repatriation success and an active management approach in the conservation of the crucian carp

Decline of formerly common and historically considered "coarse" species, the crucian carp, was firstly seriously considered in England, where the gibel carp probably had not yet invaded and the decline was related more to intensive common carp stocking practices (Sayer et al. 2011) and competition with feral forms of goldfish (*C. auratus*), which seem not to be as aggressive competitors as gibel carp (Tarkan et al. 2009; Tapkir et al. 2022; Tapkir et al. 2025). The first action plan for crucian carp populations has been established (Copp and Sayer 2010) and successful results have been presented to a scientific audience (Sayer et al. 2020). Although it was later discovered that crucian carp was most likely introduced into England during the 15th century and does not represent truly native fauna (Jeffries et al. 2017), these initiatives laid the foundation for similar actions in other European countries.

The conference "The Fish of Muddy Waters 2025" brought together scientists and practitioners with similar conservation goals for the four focal species. As a result, it contained contributions on crucian carp conservation, breeding

and natural population management from Hungary (Müller et al. 2025), Croatia (Buj et al. 2025), Slovakia (Fedorčák 2025) and Czechia (Choleva et al. 2025; Šmejkal et al. 2025b), with altogether 19 contributions to that topic. Thus, it seems that crucian carp had finally gained scientific and conservation attention across wide range of its distribution. In the circumstances of invasive species and direct competitors for food such as gibel carp and topmouth gudgeon (*Pseudorasbora parva*) in most of suitable habitats (Musil et al. 2010; Šmejkal et al. 2024, 2025a), repatriation of the crucian carp in carefully selected water bodies represents the only practical way of re-establishing populations.

In that context, stocking was generally successful with indication of recruitment and population boost in most of the ponds that were stocked in the past two years. This aligns with other findings of Lyach (2022) and Sayer et al. (2020). In contrast to quite easy translocation activities and successful recruitment of crucian carp, conservation efforts of other more specialised fish are remarkably more challenging. The example of much more difficult conservation can be Devil's Hole pupfish (*Cyprinodon diabolis*), where its very specific demands on water temperature and other characteristics limit translocation success (Karam et al. 2012). In this study and other crucian carp conservation efforts, the species' high resilience to environmental fluctuations and harsh conditions (Blažka 1958; Holopainen et al. 1997) represents a key advantage and should be leveraged to reverse population declines in the focal area, as well as in other countries where the species is listed in threatened categories.

Crucian carp as an umbrella species of floodplain pools and secondary abandoned ponds and flooded quarries

Ponds and other artificial waterbodies are important secondary habitats for supporting biodiversity in a fragmented landscape (Céréghino et al. 2008; Oertli 2018). Crucian carp is a characteristic species of small, isolated ponds rich in amphibians and invertebrates (Sayer et al. 2011; Thomas et al. 2025b) and plays an important ecological role. It is typically associated with ponds exhibiting higher invertebrate diversity compared to those inhabited by other common fish species (Stefanoudis et al. 2017; Harper et al. 2021) and its presence is often indicative of higher habitat quality. Together, these findings suggest that crucian carp is a valuable species for ecosystem conservation (Harper et al. 2021; Thomas et al. 2025b). In the latter study, comparison of invaded sites with gibel carp and sites with native crucian carp showed that native sites exhibited higher overall biodiversity, including the presence of newt populations and higher densities of *Dytiscus* water beetles, compared to sites invaded by gibel carp (Thomas et al. 2025b). Thus, crucian carp can be potentially useful as an umbrella species in non-productive ponds providing primarily environmental services supporting healthy pond diversity. One reason for such findings can also be simply that crucian carp does not sustain well intensive aquaculture (Sayer et al. 2011) and its presence is an indication of less intense or no fish management at the site, which has naturally also higher invertebrate or amphibian diversity (Sayer et al. 2011).

In any case, it seems that establishing conservation action plans, large-scale programmes, as well as bottom-up initiatives of citizens for crucian carp may also help to promote other diversity that thrives with their presence, but would

not sustain common pond practices such as intensive aquaculture or invasive fish species presence common in Czechia and central Europe (Fedorčák et al. 2025; Musil et al. 2010; Sayer et al. 2011). Additionally, aside from its role for biodiversity, crucian carp also gained substantial attention in countries where conservation placed it as one of the targeted species (Sayer et al. 2020; Thomas et al. 2025a). Thus, it may also be promoted as not only an umbrella species, but also as a charismatic species to gain larger support of public attention for wetland conservation (Gottwald et al. 2025). Its popularity has a high potential to drive conservation of other fish species such as sunbleak or weatherfish that had, so far, received less popularity amongst the public.

The populations of sunbleak and weatherfish have also experienced substantial declines across their native range in the EU due to habitat modification and the spread of invasive species; therefore, providing refugia may help reverse the trend in their population sizes (Šmejkal et al. 2025a). In line with these thoughts, the sunbleak has already been introduced to five selected ponds within this action plan to support its populations and thrives in four of them, while the remaining one will receive another population surge. Thus, although an action plan is defined in Czechia as a document targeting only one species, the ponds designated for re-population can also host other declining taxa that will benefit from the crucian carp's popularity and conservation interests.

Conclusions

In the modified environment of river floodplains inhabited by invasive species with very similar Eltonian niches (Tapkir et al. 2023; Šmejkal et al. 2024), active conservation management will be necessary for species of conservation concern to prevent their population declines. The crucian carp would profit from various conservation management measures in large part of Europe where invasive gibel carp thrives. This Regional Action Plan for the region in Czechia represents only a small fraction of activities that are going on in EU to conserve this species (see also Buj et al. (2025); Fedorčák (2025); Müller et al. (2025); Šmejkal et al. (2025b)). However, it shows important change in conservation of this species and that is giving emphasis on preserving phylogenetically distinct units (Choleva et al. 2025). In contrast with more commercially important species, crucian carp received less attention from recreational anglers and stocking activities and, thus, some intact populations of distinct phylogenetic units can be defined and given priority. To safeguard these phylogenetically distinct populations, actions must be carried out carefully, and citizens involved in breeding crucian carp should be informed about these measures and priority populations, as well as warned about the consequences of translocating crucian carp between watersheds.

Lastly, re-populations conducted in line with this Regional Action Plan seems to be generally promising and, thus, establishing of new sites to multiply population sizes of crucian carp are goals that are feasible to achieve, if state enterprises or private sector provide suitable places for this declining species. Such debates were the foundations of this Regional Action Plan for Vysočina and this shows that bridging scientific evidence into practical solutions and its effective communication to authorities are of utmost importance to achieve conservation goals.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

The field sampling was conducted under the permission of the Ministry of Agriculture (ref. no. MZE-22409/2024-13143).

Artificial Intelligence (AI) use

The authors accept full responsibility for the content of the manuscript, including the disclosure of any use of AI.
Regarding the use of AI in the preparation of this manuscript, the authors declare the following:
Description: AI was used to draw items in the graphical abstract.

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Author contributions

MŠ, LK, ZŠ, VV conducted the fieldwork; MŠ, LK, LC designed the study; ZŠ, MŠ prepared data for the analysis; ZŠ conducted the data analysis; LK, LC conducted genetic analysis; ZŠ, MŠ wrote the first draft. All authors contributed substantial feedback during manuscript preparation.

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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

Sampled sites and repatriations summarized in tables

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