Nature Conservation

Nature Conservation 65: 135–152 (2026)
DOI: 10.3897/natureconservation.65.185650

Research Article

Goldfish, gibel carp, or crucian carp? Testing public recognition of *Carassius* species

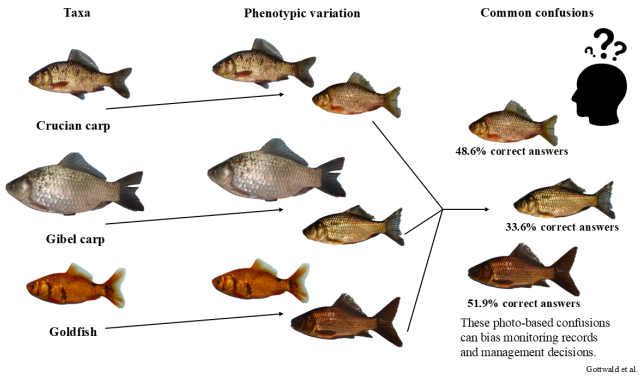
Milan Gottwald[1,2], Yevdokiia Stepanyshyna[2], Marek Šmejkal[2,3]

1 *Department of Zoology and Fisheries, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences Prague, Prague, Kamýcká 129, 165 00 Praha Suchdol, Czech Republic*
2 *Institute of Hydrobiology, Biology Centre of the Czech Academy of Sciences, Na Sádkách 7, 370 05 České Budějovice, Czech Republic*
3 *Department of Zoology, Faculty of Science, University of South Bohemia, České Budějovice, Czech Republic*
Corresponding author: Marek Šmejkal (marek.smejkal@hbu.cas.cz)

Abstract

Crucian carp (*Carassius carassius*) has declined across much of Europe and is listed as critically endangered in the Czech Republic. A major threat is the spread of non-native congeners, especially gibel carp (*Carassius gibelio*) and goldfish (*Carassius auratus*), which overlap in habitat use and can hybridise with crucian carp. Because these taxa are morphologically largely similar, public misidentification may bias citizen science monitoring and lead to counterproductive freshwater management by hobbyists or stakeholders. We quantified photo-based species recognition during the recreational angling fair "For Fishing 2023" in Prague (Czechia) using a three-alternative forced-choice task with printed photographs representing three individuals per species. After quality control, responses from 325 participants were retained for analysis, yielding 2925 trials. Overall accuracy across answered trials was 64.3%. Descriptively, accuracy was highest for goldfish, intermediate for crucian carp, and lowest for gibel carp; however, mixed-model analyses indicated that performance was dominated by image-level heterogeneity, with some photographs consistently easy or difficult regardless of respondent background. Misidentifications were directional: small gibel carp were commonly labelled as crucian carp, and a naturalised goldfish phenotype was also frequently classified as crucian carp. These results showed that photo-based *Carassius* records can contain systematic, phenotype-driven errors, supporting the need for uncertainty recording, validation workflows, and public training materials that explicitly include ambiguous phenotypes rather than only prototypical phenotypes. Although live individuals may be easier to identify, misidentification may still represent one pathway contributing to the spread of invasive *Carassius* species in Czechia.

Graphical abstract



OPEN ACCESS

Academic editor: Josef Wanzenböck
Received: 19 January 2026
Accepted: 9 April 2026
Published: 9 October 2026

ZooBank: https://zoobank.org/FA8D590C-D5EC-4213-A495-D7875355A579

Citation: Gottwald M, Stepanyshyna Y, Šmejkal M (2026) Goldfish, gibel carp, or crucian carp? Testing public recognition of *Carassius* species. 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: 135–152. https://doi.org/10.3897/natureconservation.65.185650

Copyright: © Milan Gottwald et al.
This is an open access article distributed under terms of the Creative Commons Attribution License (Attribution 4.0 International – CC BY 4.0).

Key words: *Carassius carassius*, freshwater conservation, invasive species, species misidentification, visual perception

Introduction

Freshwater fishes comprise roughly half of all described fish species, yet experience disproportionate biodiversity loss and elevated extinction risk (Vardakas et al. 2025). Across Europe, multiple pressures frequently occur together within catchments and coincide with high proportions of threatened freshwater fishes (Costa et al. 2021). Small cyprinids that are culturally devalued (receiving low attention and termed as "coarse" species) are often overlooked in research, management and public communication, a bias captured by the rough fish or coarse fish paradigm (Rypel et al. 2021). Freshwater fish communities are also increasingly shaped by introductions and translocations mediated by human activities, including pathways linked to recreational angling (Carpio et al. 2019). Evidence from the Prague live bait market in the Czech Republic suggests that trade in live bait fish and the release of unused bait can generate substantial propagule pressure and promote long-distance translocations, including those of invasive cyprinids such as gibel carp (*Carassius gibelio* (Bloch, 1782)) (Kalous et al. 2013).

In this broader context, most so-called "coarse fish" species remain largely overlooked in conservation agendas and public communication (Rypel et al. 2021). A notable exception is the crucian carp (*Carassius carassius* (Linnaeus, 1758)), which has attracted targeted conservation attention in England through Biodiversity Action Plan initiatives, pond restoration and reintroductions, although its native status remains debated (Sayer et al. 2011, 2020; Jeffries et al. 2017). This species is closely associated with shallow, vegetated standing waters and small ponds, habitats that can support high biodiversity and important ecosystem functions (Copp et al. 2008; Harper et al. 2021; Thomas et al. 2025a). Similar declines in many European countries have also motivated debate over large-scale management responses (Šmejkal et al. 2025). At the same time, conservation programmes including *ex situ* breeding, reintroductions and habitat improvements have been initiated in several countries, with demonstrable success (Wanzenböck 2025; Šmejkalová et al. 2026).

A key driver of crucian carp decline is the spread of introduced *Carassius* congeners, particularly invasive gibel carp, which can competitively suppress native populations and complicate conservation management (Tapkir et al. 2023, 2025; Šmejkal et al. 2024). Gibel carp and goldfish (*Carassius auratus* (Linnaeus, 1758)) are now widespread across Europe through human-mediated introductions linked to aquaculture and the ornamental trade, including releases associated with the aquarium pathway (Kalous 2015; Haubrock et al. 2025). Private garden ponds represent an additional, weakly regulated interface between ornamental keeping and the wild, where deliberate release or escape of kept animals can generate propagule pressure (Patoka et al. 2014; Kalous 2015; Novák et al. 2022). Evidence from newly created, originally fishless ponds shows that fish colonisation can be rapid, with gibel carp among the most frequent colonisers (Janáč et al. 2025). Because members of the *Carassius* complex are widely similar in external appearance and hybrids can be

morphologically cryptic, reliable species assignment can be challenging when diagnostic traits are not clearly visible (Papoušek et al. 2008; Knytl et al. 2022).

In practice, external identification of crucian carp, gibel carp and goldfish relies chiefly on a limited set of characters that may also be visible in photographs, notably overall body depth and silhouette, general colouration, and the profile of the free edge of the dorsal fin; additional cues such as head shape or fin-base pigmentation may sometimes assist, but are not always clearly expressed (Szczerbowski 2002; Kottelat and Freyhof 2007; Masson et al. 2011). These traits are further complicated by marked intraspecific variation: crucian carp may range from high-bodied to more elongate forms depending on ecological context, gibel carp also shows substantial phenotypic plasticity, and goldfish encompasses an exceptionally broad spectrum from ornamental orange morphs to darker naturalised phenotypes (Holopainen et al. 1997; Blake et al. 2009; Tarkan et al. 2023). In broad terms, crucian carp is more often deep-bodied, with a more convex dorsal-fin edge and olive-green to bronze colouration, whereas gibel carp and goldfish more often show a straighter to slightly concave dorsal-fin edge; gibel carp is typically more silvery-brown, while goldfish may resemble either conspicuously ornamental or more wild-type forms (Hensel 1971; Kottelat and Freyhof 2007; Rylková et al. 2013). However, several formal diagnostic characters used in direct morphological examination, such as serration of the last simple dorsal- and anal-fin rays, gill-raker counts, lateral-line scale counts and peritoneum colour, cannot be assessed reliably from standard lateral photographs, so some individuals may remain difficult to assign confidently even for experienced observers (Kalous et al. 2012; Khosravi et al. 2022).

These identification challenges are increasingly relevant because aquatic biodiversity monitoring is supported by stakeholder and citizen science observations submitted via digital platforms, where records are commonly photo-based and accompanied by spatiotemporal information (DiBattista et al. 2021; Dwivedi 2021; Lameira et al. 2025). Citizen science has mobilised anglers, pond owners and naturalists and can meaningfully complement professional surveys by improving coverage and supporting early detection and management of invasive fishes, as illustrated by citizen science monitoring of *Carassius* in Central Europe (Thomas et al. 2025b) and angler-based reporting of invasive gibel carp in Alberta, Canada (Pentyliuk et al. 2023). However, unstructured biodiversity observations are not necessarily a neutral sample: they can amplify systematic biases in what is noticed, photographed, identified and ultimately reported, which in turn requires explicit quality control and cautious interpretation (Troudet et al. 2017; Callaghan et al. 2021). In fishes, public perception and stereotypes further shape attention and reporting, with consequences for which taxa receive interest, monitoring effort and conservation management (Clusa et al. 2018; Kochalski et al. 2019; Rypel et al. 2021). Misidentification is also documented in other applied contexts, including angler-reported data and fisheries surveys (Page et al. 2012; Chizinski et al. 2014; Lyon et al. 2018), studies that elicit local ecological knowledge and assess its agreement with scientific evidence (Petriki et al. 2024), and seafood authentication (Crego-Prieto et al. 2012; Di Pinto et al. 2015).

Mechanistically, misclassification can arise when observers must rely primarily on stimulus-driven visual cues whose diagnostic value varies among

individuals, even under standardised photographic protocols. Novices tend to prioritise superficial morphological similarity, whereas experts can integrate functional or ecological knowledge, but both groups remain constrained when key cues are weak, occluded, or visually ambiguous in the presented image (Boster and Johnson 1989; Shafto and Coley 2003). Visual attention is strongly shaped by feature contrast and salience, which can dominate rapid decisions, especially under distraction and limited viewing time (Itti and Koch 2001; Veale et al. 2017). Rapid categorisation is efficient for coarse distinctions but shows clear limits when fine-grained discrimination among closely related species must be made from variable individuals (Fabre-Thorpe 2011). Applied to *Carassius* photo identification scrutinised in this study, this implies that a subset of images may systematically elicit errors because key traits are less visible and that confusions may be directional rather than random.

We therefore quantified how accurately visitors at a national angling fair in the Czech Republic could distinguish crucian carp, gibel carp and goldfish using a questionnaire-based forced-choice task with three photographs per taxon under realistic field conditions. We hypothesised that (i) recognition accuracy would differ among the three taxa, with the ornamental goldfish being identified more accurately than the naturally coloured crucian carp and gibel carp; (ii) image-level variation in the salience of diagnostic traits would be a major determinant of success, leading to systematic confusions between crucian carp and gibel carp and lower accuracy for a naturalised goldfish phenotype than for typical ornamental goldfish images; and (iii) respondent groups would differ in recognition accuracy, with visitors possessing angling-related expertise achieving higher accuracy than those without prior experience.

Materials and methods

Study setting and participants

The study was conducted as an on-site identification quiz during the For Fishing 2023 fair at the PVA EXPO Prague Letňany venue (Prague, Czechia). The fair covered over 18,000 m^2 of exhibition area across two halls, attracted more than 27,000 anglers and angling enthusiasts, and hosted 215 exhibitors with extensive displays of fishing equipment, techniques, and an accompanying educational and popularisation programme. Participation in this study was voluntary and without financial incentives; as part of outreach for the “Save the Crucian Carp” campaign, symbolic merchandise prizes were offered to top-performing participants. All participation was voluntary and anonymous; completion of the task was taken as informed consent.

Photo questionnaire

Participants completed a forced-choice identification task using printed photo sheets (Fig. 1). Each sheet contained nine photographs, three per species: crucian carp, gibel carp and goldfish. Photographs were taken under controlled conditions with standardised lighting, background, camera distance and angle. Individuals were selected to represent realistic within-species

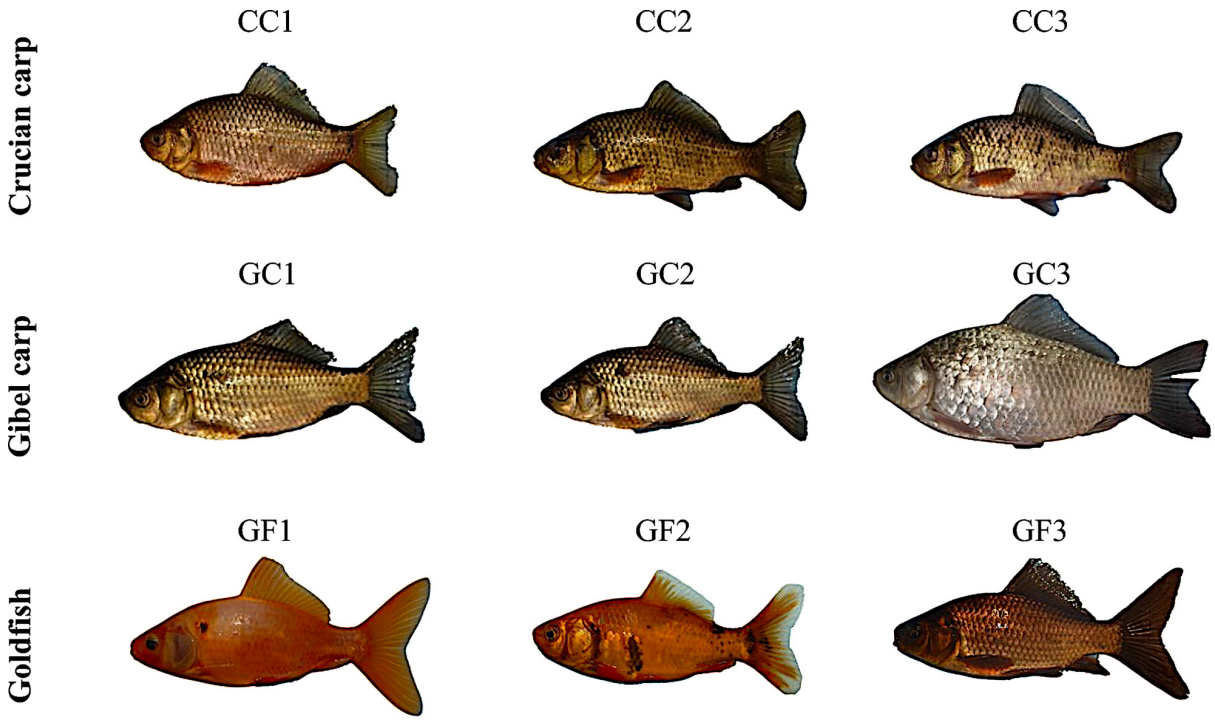


Figure 1. Photographic stimuli used in the species identification quiz, showing the nine fish photographs presented to participants, comprising three individuals per species: crucian carp (CC1–CC3), gibel carp (GC1–GC3), and goldfish (GF1–GF3). PhotoCodes correspond to identifiers used in the dataset and subsequent analyses.

variation, including ambiguous phenotypes typical of field identification rather than idealised textbook depictions. For each photograph, species identity, life stage, standard length, phenotypic note, visible external traits considered potentially informative for photo-based identification, and the rationale for inclusion in the stimulus set are summarised in Table 1. No single external trait visible in standard lateral photographs was unequivocal across all individuals of these three taxa. Species identities were verified by expert morphological assessment using established diagnostic traits and contextual information on the origin and phenotype of the individuals (Szczerbowski 2002; Kottelat and Freyhof 2007). Specimens were photographed at sites with verified species presence and no hybridisation records.

To minimise learning effects and discourage cross-participant comparison, five parallel stimulus layouts were used, labelled A to E. Each layout contained the same nine photographs in different positions and orders to reduce mutual assistance among participants tested simultaneously.

Procedure and data processing

Participants received brief standardised oral instructions and completed a short questionnaire recording gender, age category, region of permanent residence, education (level and field), and relationship to fishing before labelling each photograph with one of three species names. A “do not know” option was not provided; when unsure, participants still selected one of the three labels (forced-choice). External aids and consultation were not permitted. Response sheets were scored against an answer key, and data were digitised at the trial level. Each participant contributed nine Bernoulli trials, one per

Table 1. Overview of the photographic stimuli used in the experiment, including species identity, life stage, standard length, phenotypic note, visible external traits considered potentially informative for photo-based identification, and the rationale for inclusion of each image in the stimulus set. The traits listed refer only to external characters that were discernible in the photographs, and their interpretation was guided by standard morphological references for European representatives of the genus *Carassius* and by detailed species accounts available for this group (Szczerbowski 2002; Kottelat and Freyhof 2007). Several diagnostic characters commonly used in formal morphological identification, such as gill-raker counts, lateral-line scale counts, peritoneum colour, or the degree of serration of the last simple dorsal- and anal-fin rays, cannot be assessed reliably from standard lateral photographs. SL = standard length.

Photo-Code	Species identity	Life stage	SL (mm)	Phenotypic note	Visible traits considered informative	Reason for inclusion in the stimulus set
CC1	*C. carassius*	young adult	88	typical crucian carp phenotype	deep-bodied profile convex free edge of the dorsal fin golden-green to bronze natural colouration	representative of a typical crucian carp image
CC2	*C. carassius*	adult	141	typical crucian carp phenotype	moderately deep-bodied profile convex free edge of the dorsal fin bronze to olive-green natural colouration	representative of a typical crucian carp image showing slightly less pronounced body depth
CC3	*C. carassius*	adult	136	typical crucian carp phenotype	deep-bodied profile convex free edge of the dorsal fin dark olive-bronze natural colouration	representative of a typical crucian carp image
GC1	*C. gibelio*	young adult	89	small-bodied gibel phenotype	relatively shallow body profile straight free edge of the dorsal fin darker silvery-brown colouration	included as a confusion-prone small-bodied gibel carp
GC2	*C. gibelio*	young adult	91	small-bodied gibel phenotype	relatively shallow body profile straight to slightly concave free edge of the dorsal fin silvery-brown natural colouration	included as a confusion-prone small-bodied gibel carp
GC3	*C. gibelio*	adult	286	robust-bodied gibel phenotype	pale silvery-brown colouration straight free edge of the dorsal fin more typical gibel carp appearance	representative of a more typical adult gibel carp phenotype
GF1	*C. auratus*	adult	130	orange ornamental phenotype	bright orange ornamental colouration straight free edge of the dorsal fin conspicuously non-natural appearance	representative of a typical ornamental goldfish image
GF2	*C. auratus*	adult	129	orange ornamental phenotype	uniform orange ornamental colouration straight free edge of the dorsal fin readily recognisable goldfish appearance	representative of a typical ornamental goldfish image
GF3	*C. auratus*	adult	156	naturalised goldfish phenotype	dark bronze wild-type colouration straight to slightly concave free edge of the dorsal fin non-ornamental appearance	included to represent a naturalised, potentially confusion-prone goldfish phenotype

photograph. Responses were coded as correct (1) when the chosen label matched the answer key and incorrect (0) otherwise. No separate "don't know" category was used; uncertainty therefore contributed to incorrect responses (0). Each image had a unique identifier: crucian carp (CC1–CC3), gibel carp (GC1–GC3), and goldfish (GF1–GF3).

Statistical analysis

All statistical analyses were conducted in R (v4.3.3; R Core Team 2024) at the trial level, with identification accuracy treated as a binary response (variable name – Correct; 1 = True, 0 = False). Data preparation and descriptive summaries were performed using dplyr (v1.1.4; Wickham et al. 2023) and tibble (v3.2.1; Müller and Wickham 2023), including exclusion of duplicate participants and recoding of predictors (Species derived from the correct answer; PhotoCode identifying each photograph; respondent characteristics summarised into

coarse categories of angling-related expertise and education, with age and sex retained as additional covariates). Trials with no response were retained for descriptive reporting but were excluded from binomial modelling.

To address hypothesis I, we tested whether recognition accuracy differed among the three taxa by fitting binomial generalised linear mixed models (GLMMs) with a logit link using lme4 (v1.1-34; Bates et al. 2015), including Species as a fixed effect and random intercepts for respondent (ID) and photograph (PhotoCode) to account for repeated measures and image-to-image heterogeneity. The overall contribution of Species was evaluated using likelihood-ratio tests against an otherwise equivalent null model.

To address hypothesis II, we quantified image-level heterogeneity in two complementary ways. First, we tested the global contribution of photograph identity by comparing models with and without a random effect of PhotoCode. Second, because each photograph belonged to a single species, we fitted within-species models with PhotoCode as a fixed effect to evaluate whether accuracy differed among photographs of the same taxon and estimated planned contrasts between specific image types. Model-based contrasts and marginal means were obtained with emmeans (v1.8.8; Lenth 2023), with Holm adjustment for multiple comparisons.

To address hypothesis III, we evaluated differences among respondent groups by fitting candidate binomial generalised linear mixed models (GLMMs) with a logit link using lme4 (v1.1-34; Bates et al. 2015), including angling-related expertise and education as primary predictors (with age and sex as additional covariates) while retaining the same random-effects structure. Competing models were ranked using an information-theoretic approach based on the corrected Akaike Information Criterion (AICc) (Akaike 1974), where lower AICc values indicate better-supported models after penalising model complexity (Burnham and Anderson 2010). Where more than one model received substantial support (ΔAICc < 2), we performed model averaging across the top model set using MuMIn (v1.48.4; Bartoń 2024); otherwise, inference was based on the single best-supported model.

Results

After quality control, responses from 325 participants were retained for analysis, yielding 2925 trials (nine identifications per participant). A small fraction of trials were missing responses (18/2925, 0.62%); across answered trials (n = 2907), overall accuracy was 64.3%. Species-level accuracies (answered trials only) were 63.1% for crucian carp (*C. carassius*), 52.4% for gibel carp (*C. gibelio*), and 77.6% for goldfish (*C. auratus*).

Hypothesis I: Taxon-level differences in identification accuracy

In the GLMM, the qualitative pattern matched the descriptive results (lower odds for gibel carp and higher odds for goldfish relative to crucian carp; Fig. 2). However, Species contrasts were not statistically significant at α = 0.05, and a likelihood-ratio test (LRT) comparing the Species model to a null model without Species did not indicate improved fit (LRT: Chisq = 2.25, DF = 2, p = 0.325). Random-effects estimates indicated substantial

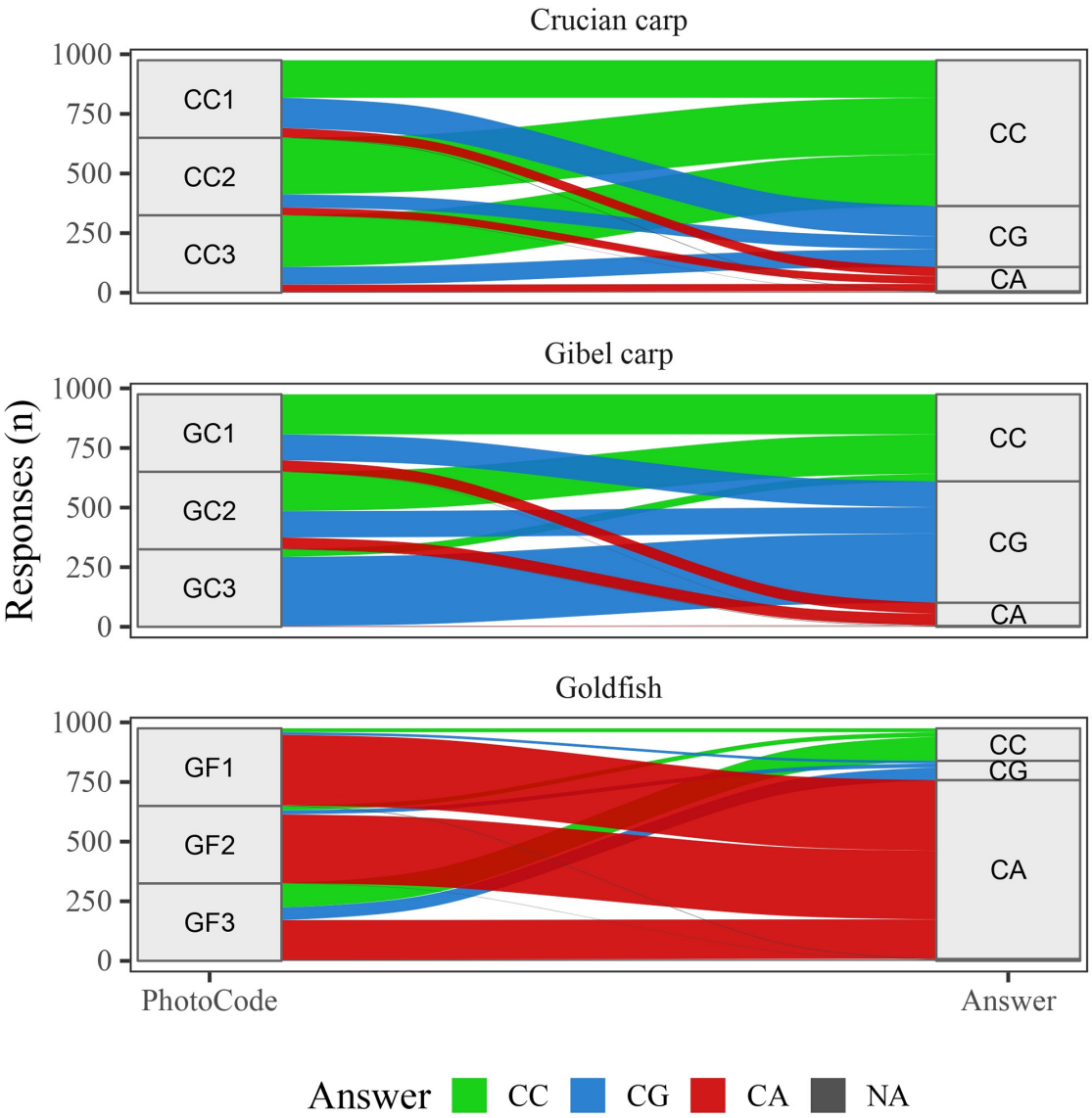


Figure 2. Sankey diagram showing photograph-level response patterns in the forced-choice species identification quiz. Each panel represents the true species identity of the photographed individual (top: crucian carp; middle: gibel carp; bottom: goldfish). The left-hand blocks denote the individual stimulus photographs used in the quiz, coded as CC1–CC3 for *C. carassius*, GC1–GC3 for *C. gibelio*, and GF1–GF3 for *C. auratus*. Flows connect each stimulus photograph to the response category selected by participants on the right (CC = *C. carassius*, CG = *C. gibelio*, CA = *C. auratus*; NA = no answer). Flow width is proportional to the number of responses, illustrating both correct identifications and the main directions of misclassification.

heterogeneity among respondents and among photographs, with stronger variability attributable to photographs than to respondents (standard deviation (SD) PhotoCode = 1.10; SD ID = 0.78).

Hypothesis II: Image-level heterogeneity and salience of diagnostic traits

Image identity had a very strong effect on recognition success. Adding PhotoCode as a random effect substantially improved model fit compared with a model without PhotoCode (LRT: Chisq = 515.33, DF = 1, $p < 0.001$), confirming

pronounced image-level heterogeneity consistent with differences in the salience of phenotypic diagnostic traits.

Performance varied widely among the nine photographs (Fig. 2; Table 2). Crucian carp ranged from 48.6% correct for CC1 to 73.1% for CC2, with CC3 intermediate at 67.4%. Gibel carp ranged from 33.6% for GC1 and 34.1% for GC2 to 89.5% for GC3. Goldfish ranged from 51.9% for GF3 to 91.6% for GF1 and 88.9% for GF2. Model-based predicted probabilities of correct identification (p_est) ranged from 0.33 (GC1–GC2) to 0.92 (GF1) (Table 2; Fig. 2).

Within each taxon, photographs differed significantly in accuracy (LRT, PhotoCode as fixed effect within species): gibel carp (Chisq = 305.15, DF = 2, $p < 0.001$), goldfish (Chisq = 187.55, DF = 2, $p < 0.001$), and crucian carp (Chisq = 50.81, DF = 2, $p < 0.001$). Planned pairwise contrasts (emmeans; Holm correction) showed that GC3 was markedly easier than GC1 (OR = 22.88, $p < 0.001$) and GC2 (OR = 22.44, $p < 0.001$), while GC1 and GC2 did not differ significantly (OR = 0.98, $p = 0.914$). For goldfish, GF1 and GF2 did not differ (OR = 1.41, $p = 0.220$), whereas both were substantially easier than GF3 (GF1 vs GF3: OR = 15.23, $p < 0.001$; GF2 vs GF3: OR = 10.82, $p < 0.001$). For crucian carp, CC1 was significantly more difficult than CC2 (OR = 0.299, $p < 0.001$) and CC3 (OR = 0.407, $p < 0.001$), while CC2 and CC3 did not differ after correction (OR = 1.36, $p = 0.090$).

Misidentifications were directional and concentrated in specific phenotypes (Table 2; Fig. 2). For the small gibel carp images (GC1 and GC2), the most frequent wrong choice was crucian carp: respondents selected CC in 51.9% (GC1) and 51.1% (GC2) of answered trials (Table 2; Fig. 2). Conversely, crucian carp images were frequently mistaken for gibel carp, especially CC1 (GC chosen in 39.3% of answered trials; CC2: 17.0%; CC3: 23.0%; Table 2; Fig. 2). For the naturalised goldfish phenotype (GF3), besides correct CA responses (51.9%), a substantial share of responses shifted towards crucian carp (31.6%) and gibel carp (16.6%), indicating increased visual overlap with the naturally coloured taxa. In contrast, GC3 and the typical ornamental goldfish images (GF1, GF2) were comparatively unambiguous (Table 2; Fig. 2).

Table 2. For each photograph (PhotoCode), we report the true species, the number of answered trials (*n*), accuracy (% correct), and the distribution of chosen labels among answered trials (CC = *Carassius carassius*, CG = *Carassius gibelio*, CA = *Carassius auratus*). "No answer" gives the number and percentage of missing responses for each photograph. p_{est} is the model-based predicted probability of a correct identification for each photograph from a binomial generalised linear mixed model including random intercepts for respondent (ID) and photograph (PhotoCode).

PhotoCode	True species	Answered (n)	Correct (%)	Chosen CC (%)	Chosen CG (%)	Chosen CA (%)	No answer (n)	No answer (%)	*p*_est
CC1	*C. carassius*	323	48.6	48.6	39.3	12.1	2	0.6	0.49
CC2	*C. carassius*	324	73.1	73.1	17.0	9.9	1	0.3	0.74
CC3	*C. carassius*	322	67.4	67.4	23.0	9.6	3	0.9	0.68
GC1	*C. gibelio*	324	33.6	51.9	33.6	14.5	1	0.3	0.33
GC2	*C. gibelio*	323	34.1	51.1	34.1	14.9	2	0.6	0.33
GC3	*C. gibelio*	324	89.5	9.9	89.5	0.6	1	0.3	0.90
GF1	*C. auratus*	323	91.6	5.0	3.4	91.6	2	0.6	0.92
GF2	*C. auratus*	324	88.9	5.9	5.2	88.9	1	0.3	0.90
GF3	*C. auratus*	320	51.9	31.6	16.6	51.9	5	1.5	0.52

Table 3. Candidate binomial GLMMs (logit link) ranked by the small-sample corrected Akaike Information Criterion (AICc). All models included random intercepts for respondent ID and PhotoCode. *K* denotes the number of estimated parameters. ΔAICc = AICc − min(AICc). wAICc denotes Akaike weights (summing to 1 across the candidate set). The best-supported model (ΔAICc < 2) is shown in bold.

Model	FixedEffects	*K*	AICc	ΔAICc	wAICc
m1	Species	5	3072.3	21.4	< 0.001
m2	Species + ExpertiseGroup	7	3072.6	21.7	< 0.001
m3	Species + ExpertiseGroup + Age (numeric)	8	3067.8	16.8	< 0.001
m4	**Species + ExpertiseGroup + EducationGroup**	**10**	**3050.9**	**0.0**	**0.816**
m5	Species + ExpertiseGroup + Sex	8	3074.2	23.3	< 0.001
m6	Species + ExpertiseGroup + Age (numeric) + EducationGroup + Sex	12	3053.5	3.0	0.181
m7	Species + ExpertiseGroup + Species × ExpertiseGroup	11	3078.1	27.2	< 0.001

Hypothesis III: Differences among respondent groups

Model selection based on Akaike's Information Criterion corrected for small sample size (AICc) supported a parsimonious model including Species, angling-related expertise (ExpertiseGroup), and education category (EducationGroup) as the best-supported specification (wAICc = 0.816; Table 3). Adding age and sex provided only limited additional support (ΔAICc = 3.01; wAICc = 0.181). Because only one model fell within ΔAICc < 2, model averaging was not required. In the best-supported model, angling-related expertise was associated with a modest improvement in accuracy (Angler vs reference: OR = 1.56; $p = 0.017$), while the FishSector category was not supported as different from the reference group (OR = 0.91; $p = 0.769$). Education contributed to performance (global LRT for EducationGroup: Chisq = 23.22, DF = 3, $p < 0.001$). Species was not supported once photograph-level heterogeneity was accounted for (LRT for Species in the best model: $p = 0.325$).

Discussion

This study tested whether recreational anglers could distinguish crucian carp, gibel carp and goldfish using a forced-choice photo identification task. Overall accuracy of photo recognition was moderate, but performance was shaped far more by which individual photograph was shown than by respondent background, and the resulting confusions were directional in ways that matter for *Carassius* monitoring and management. Accordingly, our results suggest that phenotypic variation among individuals strongly shapes the reliability of photo-based identification by citizens, with respondent characteristics playing a smaller role.

Taxon-level differences were descriptively apparent but not robust once image heterogeneity was modelled

Although goldfish tended to be recognised more reliably than the naturally coloured *Carassius* forms, this taxon-level signal became weak once image-to-image heterogeneity was accounted for. In the mixed-model framework, adding Species did not improve explanatory power beyond the significant respondent- and photograph-level heterogeneity. Rather than indicating an absence of species differences *per se*, this suggests that the visibility and expression

of diagnostic cues vary strongly among individual photographs and can overshadow average differences among taxa. High within-taxon phenotypic variability (Holopainen et al. 1997; Tarkan et al. 2023) and overlap in the *Carassius* complex likely contributed to this outcome.

This suggests that identification success depends heavily on whether the photograph exposes clearly recognisable diagnostic traits. For monitoring and outreach, the implication is that species-level accuracy estimates may not be transferable unless the image set represents the full range of phenotypes, sizes and viewpoints likely to be encountered.

Image-level salience and phenotypic variability dominated recognition success

Hypothesis II was strongly supported, indicating that recognition success was driven primarily by phenotype-level properties rather than by respondent background. Model comparisons demonstrated that photograph identity contributed strongly to recognition success, confirming pronounced image-level heterogeneity. This indicates that recognition success depended primarily on how clearly potentially diagnostic external traits were expressed and visible in a given image, rather than on respondent background alone, a pattern also reported in other image-based species identification contexts (Austen et al. 2018; Zett et al. 2022).

Two image classes were particularly misidentified. First, small gibel carp images were repeatedly labelled as crucian carp, whereas a third gibel carp image was comparatively unambiguous. In other words, confusions were not distributed evenly across photographs: they concentrated in particular phenotypes. This suggests that diagnostic cues distinguishing gibel carp from crucian carp may be weakly expressed in small-bodied individuals. Morphological discrimination between these taxa is challenging because they are highly similar and external characters can overlap substantially (Hänfling et al. 2005; Wouters et al. 2012; Knytl et al. 2022).

The naturalised goldfish phenotype attracted substantially more confusion with the naturally coloured taxa than did typical ornamental goldfish photographs. This is consistent with classic typicality effects in categorisation (Rosch et al. 1976) and with the extensive phenotypic diversity produced by goldfish domestication and feralisation (Blake et al. 2009; Rylková et al. 2010, 2013). For monitoring, the practical message is that “goldfish” is not a single, visually stable target: when feral phenotypes converge on wild-type colouration, photographic identification becomes substantially less reliable.

Directional confusions are conservation-relevant in the *Carassius* genus

Beyond overall error rates, the structure of mistakes matters. Misidentifications were asymmetric and concentrated in specific phenotypes: small gibel carp were most often labelled as crucian carp. Similarly, crucian carp was also mislabelled as gibel carp (especially in one image), and the naturalised goldfish phenotype frequently shifted towards crucian carp responses. Such asymmetries are plausible given morphological overlap within the *Carassius* genus (Hensel 1971).

In field monitoring, such asymmetric confusions in species recognition translate directly into false-positive and false-negative records (Kirsch et al. 2018). These

errors can bias estimated distributions and abundance and may disproportionately affect rare or protected taxa, thereby influencing management decisions if left unaccounted for (Kirsch et al. 2018). For example, in a recent participatory science dataset on crucian carp occurrence, field verification confirmed crucian carp presence in only 35% of submitted tips, illustrating how unvalidated records can inflate apparent occurrences (Thomas et al. 2025b). From a conservation perspective, both pathways are problematic: misreporting gibel carp as crucian carp risks inflating the apparent occurrence of the threatened species and obscuring invasive spread, and it may also motivate well-intentioned actions that inadvertently favour gibel carp, for example when anglers or pond managers attempt to "support crucian carp" by moving, stocking, or protecting fish they have misidentified. Conversely, misreporting crucian carp as gibel carp can discourage protection or trigger inappropriate actions. This is particularly consequential in European wetlands and secondary water bodies where native wetland fishes, including crucian carp, face compounding pressures from habitat loss and biological invasions (Šmejkal et al. 2025) and where misidentification in angler-facing contexts has been shown to create tangible conservation costs, including inadvertent retention or mortality of protected fish (Lyon et al. 2018). Because the dominant confusions were directional, their consequences are also directional: they can systematically inflate one taxon while suppressing another in opportunistic records.

Respondent group differences existed but were modest relative to image effects

Hypothesis III received limited support. Model selection supported a parsimonious specification in which angling-related expertise and education contributed to explaining variation in identification accuracy, while age and sex received little support. Angling-related expertise was associated with a small but statistically supported increase in accuracy, while education improved model AIC. Age and sex received little support in the top model set. Importantly, even among visitors likely to have interest in fish and angling, performance remained strongly constrained by image-level ambiguity, consistent with evidence that experience and training can reduce misidentification yet often do not eliminate it in applied fish monitoring (Kirsch et al. 2018). Overall, these patterns suggest that improving respondent expertise can help but cannot compensate for low cue visibility in particular photographs or phenotypes.

Implications for monitoring, outreach and reporting design

Taken together, the results argue for treating photo-based *Carassius* identifications as observations with structured error (Austen et al. 2018; Kirsch et al. 2018; Zett et al. 2022). Practically, outreach and reporting tools should include small-bodied and otherwise ambiguous individuals in training materials, encourage uncertainty recording rather than forced categorical choices, and implement verification workflows for records resembling known confusion-prone phenotypes (Austen et al. 2018; Kirsch et al. 2018; Zett et al. 2022). For atypical phenotypes, management-sensitive records, or suspected hybrids, photo-based identification should ideally be complemented by expert validation and, where feasible, by molecular verification (Hänfling et al. 2005; Wouters

et al. 2012; Knytl et al. 2022). In addition, even low rates of missing responses ("no answer") can be informative as a behavioural indicator of ambiguity and could be captured explicitly in reporting interfaces.

Future research should expand the stimulus set across a wider range of phenotypes, sizes and viewpoints to refine misidentification estimates and improve transferability to monitoring contexts (Austen et al. 2018; Zett et al. 2022). More broadly, these measures align with the increasing role of citizen science in fish conservation, where reliability depends on validation and careful interpretation of public records (DiBattista et al. 2021; Lameira et al. 2025; Šmejkal 2025).

Conclusion

Public forced-choice identification of *Carassius* fishes focused on recreational anglers was only moderately accurate overall and was strongly dependent on which species and phenotype was presented. Once repeated measures and image-to-image heterogeneity were modelled, taxon-level differences were not robust, indicating that variation in how diagnostic cues are expressed or visible in particular phenotypes can outweigh average differences among species. Errors were directional rather than random: small gibel carp and a naturalised goldfish phenotype were frequently labelled as crucian carp, while at least one crucian carp image was often labelled as gibel carp, creating a risk of false-positive and false-negative records in photo-based reporting. Where monitoring and management depend on reliable discrimination between crucian carp and non-native congeners, reporting schemes should record uncertainty (e.g., confidence ratings), prioritise verification workflows for confusion-prone phenotypes (multi-observer confirmation or expert review), and provide educational materials that deliberately include various sizes and ambiguous individuals rather than only typical phenotypes.

Acknowledgements

We thank the Communication (PR) Department of the Institute of Hydrobiology, Biology Centre of the Czech Academy of Sciences, for enabling us to host an outreach stand at the exhibition. We also thank the organisers of the For Fishing fair and PVA EXPO Praha Letňany for providing the venue and logistical support. We are grateful to the student volunteers Daniel Gombos, Václav Bína, František Konopásek, Pavel Čamrda, and Lucie Hrdličková for their assistance during data collection. We also thank Mikuláš Gottwald for providing photographs from the exhibition and Kiran Thomas for data reorganisation. Finally, we thank all visitors and participants who contributed their time and responses.

References

Akaike H (1974) A new look at the statistical model identification. IEEE Transactions on Automatic Control 19: 716–723. https://doi.org/10.1109/TAC.1974.1100705

Austen GE, Bindemann M, Griffiths RA, Roberts DL (2018) Species identification by conservation practitioners using online images: accuracy and agreement between experts. PeerJ 6: e4157. https://doi.org/10.7717/peerj.4157

Bartoń K (2024) MuMIn: Multi-Model Inference. https://doi.org/10.32614/cran.package.mumin

Bates D, Mächler M, Bolker B, Walker S (2015) Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67: 1–48. https://doi.org/10.18637/jss.v067.i01

Blake RW, Li J, Chan KHS (2009) Swimming in four goldfish *Carassius auratus* morphotypes: understanding functional design and performance employing artificially selected forms. Journal of Fish Biology 75: 591–617. https://doi.org/10.1111/j.1095-8649.2009.02309.x

Boster JS, Johnson JC (1989) Form or function: A comparison of expert and novice judgments of similarity among fish. American Anthropologist 91: 866–889. https://doi.org/10.1525/aa.1989.91.4.02a00040

Burnham KP, Anderson DR (2010) Model selection and multimodel inference: a practical information-theoretic approach. Softcover reprint of the original 2nd ed. 2002. Springer, New York, NY, 488 pp. https://doi.org/10.1177/0049124104268644

Callaghan CT, Poore AGB, Hofmann M, Roberts CJ, Pereira HM (2021) Large-bodied birds are over-represented in unstructured citizen science data. Scientific Reports 11: 19073. https://doi.org/10.1038/s41598-021-98584-7

Carpio AJ, De Miguel RJ, Oteros J, Hillström L, Tortosa FS (2019) Angling as a source of non-native freshwater fish: a European review. Biological Invasions 21: 3233–3248. https://doi.org/10.1007/s10530-019-02042-5

Chizinski CJ, Martin DR, Pope KL (2014) Self confidence of anglers in identification of freshwater sport fish. Fisheries Management and Ecology 21: 448–453. https://doi.org/10.1111/fme.12094

Clusa L, Miralles L, Fernández S, García-Vázquez E, Dopico E (2018) Public knowledge of alien species: a case study on aquatic biodiversity in North Iberian rivers. Journal for Nature Conservation 42: 53–61. https://doi.org/10.1016/j.jnc.2018.01.001

Copp GH, Warrington S, Wesley KJ (2008) Management of an ornamental pond as a conservation site for a threatened native fish species, crucian carp *Carassius carassius*. Hydrobiologia 597: 149–155. https://doi.org/10.1007/s10750-007-9220-0

Costa MJ, Duarte G, Segurado P, Branco P (2021) Major threats to European freshwater fish species. Science of The Total Environment 797: 149105. https://doi.org/10.1016/j.scitotenv.2021.149105

Crego-Prieto V, Campo D, Perez J, Martinez JL, Garcia-Vazquez E, Roca A (2012) Inaccurate labelling detected at landings and markets: The case of European megrims. Fisheries Research 129–130: 106–109. https://doi.org/10.1016/j.fishres.2012.06.017

Di Pinto A, Marchetti P, Mottola A, Bozzo G, Bonerba E, Ceci E, Bottaro M, Tantillo G (2015) Species identification in fish fillet products using DNA barcoding. Fisheries Research 170: 9–13. https://doi.org/10.1016/j.fishres.2015.05.006

DiBattista JD, West KM, Hay AC, Hughes JM, Fowler AM, McGrouther MA (2021) Community based citizen science projects can support the distributional monitoring of fishes. Aquatic Conservation: Marine and Freshwater Ecosystems 31: 3580–3593. https://doi.org/10.1002/aqc.3726

Dwivedi AK (2021) Role of digital technology in freshwater biodiversity monitoring through citizen science during COVID 19 pandemic. River Research and Applications 37: 1025–1031. https://doi.org/10.1002/rra.3820

Fabre-Thorpe M (2011) The characteristics and limits of rapid visual categorization. Frontiers in Psychology 2. https://doi.org/10.3389/fpsyg.2011.00243

Hänfling B, Bolton P, Harley M, Carvalho GR (2005) A molecular approach to detect hybridisation between crucian carp (*Carassius carassius*) and non indigenous carp species (*Carassius* spp. and *Cyprinus carpio*). Freshwater Biology 50: 403–417. https://doi.org/10.1111/j.1365-2427.2004.01330.x

Harper LR, Lawson Handley L, Sayer CD, Read DS, Benucci M, Blackman RC, Hill MJ, Hänfling B (2021) Assessing the impact of the threatened crucian carp (*Carassius carassius*) on pond invertebrate diversity: A comparison of conventional and molecular tools. Molecular Ecology 30: 3252–3269. https://doi.org/10.1111/mec.15670

Haubrock PJ, Novello M, Abreo NA, Błońska D, Sampaio Franco AC, Soto I, Castaldelli G, Katsanevakis S, Kouba A, Balzani P, Kurtul I, Tarkan AS, Briski E, Britton R (2025) A global account of established non native fish species. Global Change Biology 31: e70451. https://doi.org/10.1111/gcb.70451

Hensel K (1971) Some notes on the systematic status of *Carassius auratus gibelio* (Bloch, 1782) with further record of this fish from the Danube River in Czechoslovakia. Věstník Československé Společnosti Zoologické 3: 186–198.

Holopainen IJ, Tonn WM, Paszkowski CA (1997) Tales of two fish: the dichotomous biology of crucian carp (*Carassius carassius* (L.)) in northern Europe. Annales Zoologici Fennici 34: 1–22. https://doi.org/10.7939/r3xg9fd5n

Itti L, Koch C (2001) Computational modelling of visual attention. Nature Reviews Neuroscience 2: 194–203. https://doi.org/10.1038/35058500

Janáč M, Bojková J, Hnilička M, Jurajda P, Palupová E, Šlapanský L, Sychra J (2025) Factors affecting colonization and assemblage structure of fish in newly created ponds. Scientific Reports 15: 43146. https://doi.org/10.1038/s41598-025-27349-3

Jeffries DL, Copp GH, Maes GE, Lawson Handley L, Sayer CD, Hänfling B (2017) Genetic evidence challenges the native status of a threatened freshwater fish (*Carassius carassius*) in England. Ecology and Evolution 7: 2871–2882. https://doi.org/10.1002/ece3.2831

Kalous L (2015) European hub for invaders: Risk assessment of freshwater aquarium fishes exported from the Czech Republic. Acta Ichthyologica et Piscatoria 45: 239–245. https://doi.org/10.3750/AIP2015.45.3.03

Kalous L, Bohlen J, Rylková K, Petrtýl M (2012) Hidden diversity within the Prussian carp and designation of a neotype for *Carassius gibelio* (Teleostei: Cyprinidae). Ichthyological Exploration of Freshwaters 23: 11–18.

Kalous L, Musil J, Petrtýl M, Vajglová T, Romočuský Š, Bušta L (2013) The danger in the anglers' bucket: qualitative and quantitative insight into bait fish market in Prague (Czech Republic). Acta Societatis Zoologicae Bohemicae 77: 27–35. https://www.cabidigitallibrary.org/doi/full/10.5555/20143168591

Khosravi M, Abdoli A, Tajbakhsh F, Ahmadzadeh F, Nemati H, Kiabi BH (2022) An effort toward species delimitation in the genus *Carassius* (Cyprinidae) using morphology and the related challenges: A case study from inland waters of Iran. Journal of Ichthyology 62: 185–194. https://doi.org/10.1134/S0032945222020096

Kirsch JE, Day JL, Peterson JT, Fullerton DK (2018) Fish misidentification and potential implications to monitoring within the San Francisco estuary, California. Journal of Fish and Wildlife Management 9: 467–485. https://doi.org/10.3996/032018-JFWM-020

Knytl M, Forsythe A, Kalous L (2022) A fish of multiple faces, which show us enigmatic and incredible phenomena in nature: Biology and cytogenetics of the genus *Carassius*. International Journal of Molecular Sciences 23: 8095. https://doi.org/10.3390/ijms23158095

Kochalski S, Riepe C, Fujitani M, Aas Ø, Arlinghaus R (2019) Public perception of river fish biodiversity in four European countries. Conservation Biology 33: 164–175. https://doi.org/10.1111/cobi.13180

Kottelat M, Freyhof J (2007) Handbook of European Freshwater Fishes. Publications Kottelat, Kottelat, Cornol, Switzerland and Freyhof, Berlin, Germany, 646 pp.

Lameira HLN, Guerrero-Moreno MA, Da Silva EC, Oliveira FA, Teodósio MA, Dias-Silva K, Moura JF, Juen L, Oliveira-Junior JMB (2025) Citizen science as a monitoring tool

in aquatic ecology: Trends, gaps, and future perspectives. Sustainability 17: 4972. https://doi.org/10.3390/su17114972

Lenth RV (2023) emmeans: Estimated Marginal Means, aka Least-Squares Means. https://doi.org/10.32614/cran.package.emmeans

Lyon JP, Tonkin Z, Moloney PD, Todd C, Nicol S (2018) Conservation implications of angler misidentification of an endangered fish. Aquatic Conservation: Marine and Freshwater Ecosystems 28: 1396–1402. https://doi.org/10.1002/aqc.2980

Masson L, Almeida D, Tarkan AS, Önsoy B, Miranda R, Godard MJ, Copp GH (2011) Diagnostic features and biometry of head bones for identifying *Carassius* species in faecal and archaeological remains: *Carassius* head bone diagnostics and biometry in Europe. Journal of Applied Ichthyology 27: 1286–1290. https://doi.org/10.1111/j.1439-0426.2011.01869.x

Müller K, Wickham H (2023) tibble: Simple Data Frames. https://doi.org/10.32614/cran.package.tibble

Novák J, Magalhães ALB, Faulkes Z, Yonvitner, Maceda-Veiga A, Dahanukar N, Kawai T, Kalous L, Patoka J (2022) Ornamental aquaculture significantly affected by the "Czech aquarium phenomenon". Aquaculture 555: 738259. https://doi.org/10.1016/j.aquaculture.2022.738259

Page KS, Zweifel RD, Carter G, Radabaugh N, Wilkerson M, Wolfe M, Greenlee M, Brown K (2012) Do anglers know what they catch? Identification accuracy and its effect on angler survey-derived catch estimates. North American Journal of Fisheries Management 32: 1080–1089. https://doi.org/10.1080/02755947.2012.728180

Papoušek I, Vetešník L, Halačka K, Lusková V, Humpl M, Mendel J (2008) Identification of natural hybrids of gibel carp *Carassius auratus gibelio* (Bloch) and crucian carp *Carassius carassius* (L.) from lower Dyje River floodplain (Czech Republic). Journal of Fish Biology 72: 1230–1235. https://doi.org/10.1111/j.1095-8649.2007.01783.x

Patoka J, Petrtýl M, Kalous L (2014) Garden ponds as potential introduction pathway of ornamental crayfish. Knowledge and Management of Aquatic Ecosystems 414: 13. https://doi.org/10.1051/kmae/2014019

Pentyliuk N, Schmidt B, Poesch MS, Green SJ (2023) Recreational angler reporting as a tool for tracking the distribution of invasive Prussian carp (*Carassius gibelio*). Conservation Science and Practice 5: e12850. https://doi.org/10.1111/csp2.12850

Petriki O, Kouletsos A, Ntislidou C, Bobori DC (2024) Local Ecological Knowledge (LEK) can guide decision-making in Inland fisheries management. Applied Sciences 14: 8819. https://doi.org/10.3390/app14198819

R Core Team (2024) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Rosch E, Simpson C, Miller RS (1976) Structural bases of typicality effects. Journal of Experimental Psychology: Human Perception and Performance 2: 491–502. https://doi.org/10.1037/0096-1523.2.4.491

Rylková K, Kalous L, Šlechtová V, Bohlen J (2010) Many branches, one root: First evidence for a monophyly of the morphologically highly diverse goldfish (*Carassius auratus*). Aquaculture 302: 36–41. https://doi.org/10.1016/j.aquaculture.2010.02.003

Rylková K, Kalous L, Bohlen J, Lamatsch DK, Petrtýl M (2013) Phylogeny and biogeographic history of the cyprinid fish genus *Carassius* (Teleostei: Cyprinidae) with focus on natural and anthropogenic arrivals in Europe. Aquaculture 380–383: 13–20. https://doi.org/10.1016/j.aquaculture.2012.11.027

Rypel AL, Saffarinia P, Vaughn CC, Nesper L, O'Reilly K, Parisek CA, Miller ML, Moyle PB, Fangue NA, Bell-Tilcock M, Ayers D, David SR (2021) Goodbye to "Rough Fish": Par-

adigm shift in the conservation of native fishes. Fisheries 46: 605–616. https://doi.org/10.1002/fsh.10660

Sayer CD, Copp GH, Emson D, Godard MJ, Zięba G, Wesley KJ (2011) Towards the conservation of crucian carp *Carassius carassius*: understanding the extent and causes of decline within part of its native English range. Journal of Fish Biology 79: 1608–1624. https://doi.org/10.1111/j.1095-8649.2011.03059.x

Sayer CD, Emson D, Patmore IR, Greaves HM, West WP, Payne J, Davies GD, Tarkan AS, Wiseman G, Cooper B, Grapes T, Cooper G, Copp GH (2020) Recovery of the crucian carp *Carassius carassius* (L.): Approach and early results of an English conservation project. Aquatic Conservation: Marine and Freshwater Ecosystems 30: 2240–2253. https://doi.org/10.1002/aqc.3422

Shafto P, Coley JD (2003) Development of categorization and reasoning in the natural world: Novices to experts, naive similarity to ecological knowledge. Journal of Experimental Psychology: Learning, Memory, and Cognition 29: 641–649. https://doi.org/10.1037/0278-7393.29.4.641

Šmejkal M (2025) Workshop: Engaging people in conservation of crucian carp through a citizen science approach. ARPHA Conference Abstracts 8: e177742. https://doi.org/10.3897/aca.8.e177742

Šmejkal M, Thomas K, Kořen V, Kubečka J (2024) The 50-year history of anglers' record catches of genus *Carassius*: circumstantial evidence of wiping out the native species by invasive conspecific. NeoBiota 92: 111–128. https://doi.org/10.3897/neobiota.92.121288

Šmejkal M, Kalous L, Auwerx J, Gorule PA, Jarić I, Dočkal O, Fedorčák J, Muška M, Thomas K, Takács P, Ferincz Á, Choleva L, Lamatsch DK, Wanzenböck J, Van Wichelen J (2025) Wetland fish in peril: A synergy between habitat loss and biological invasions drives the extinction of neglected native fauna. Biological Conservation 302: 110948. https://doi.org/10.1016/j.biocon.2024.110948

Šmejkalová Z, Váchová V, Kalous L, Choleva L, Šmejkal M (2026) Establishment of Regional Action Plan for conservation of critically endangered crucian carp in Czechia. 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: 153–171. https://doi.org/10.3897/natureconservation.65.186764

Szczerbowski JA (2002) Cyprinidae 2, Part III: *Carassius* to *Cyprinus*. In: Bănărescu PM, Paepke H-J (Eds), The Freshwater Fishes of Europe. AULA-Verlag, Wiesbaden, 1–305.

Tapkir S, Thomas K, Kalous L, Vašek M, Meador TB, Šmejkal M (2023) Invasive gibel carp use vacant space and occupy lower trophic niche compared to endangered native crucian carp. Biological Invasions 25: 2917–2928. https://doi.org/10.1007/s10530-023-03081-9

Tapkir S, Boukal D, Kalous L, Thomas K, Stepanyshyna Y, Kolar V, Duchet C, Šmejkal M (2025) Eutrophication boosts the competitive advantage of invasive gibel carp over endangered crucian carp. NeoBiota 101: 161–184. https://doi.org/10.3897/neobiota.101.167955

Tarkan AS, Mol O, Aksu S, Köse E, Kurtul I, Başkurt S, Haubrock PJ, Balzani P, Çınar E, Britton JR, Oztopcu-Vatan P, Emiroğlu Ö (2023) Phenotypic responses to piscivory in invasive gibel carp populations. Aquatic Sciences 85: 75. https://doi.org/10.1007/s00027-023-00974-8

Thomas K, Brabec M, Kalous L, Gottwald M, Bartoň D, Grill S, Kořen V, Tapkir S, Šmejkal M (2025a) Anthropogenic induced drivers of fish assemblages in small water bodies and conservation implications. Ecohydrology & Hydrobiology 25: 691–699. https://doi.org/10.1016/j.ecohyd.2024.11.003

Thomas K, Kalous L, Brabec M, Velenský P, Gottwald M, Bartoň D, Tapkir S, Stepanyshyna Y, Šmejkalová Z, Šmejkal M (2025b) Participatory science to complement professional

data: Towards conservation of declining native freshwater fish, the crucian carp. Ecological Solutions and Evidence 6: e70055. https://doi.org/10.1002/2688-8319.70055

Troudet J, Grandcolas P, Blin A, Vignes-Lebbe R, Legendre F (2017) Taxonomic bias in biodiversity data and societal preferences. Scientific Reports 7: 9132. https://doi.org/10.1038/s41598-017-09084-6

Vardakas L, Perdikaris C, Freyhof J, Zimmerman B, Ford M, Vlachopoulos K, Koutsikos N, Karaouzas I, Chamoglou M, Kalogianni E (2025) Global patterns and drivers of freshwater fish extinctions: Can we learn from our losses? Global Change Biology 31: e70244. https://doi.org/10.1111/gcb.70244

Veale R, Hafed ZM, Yoshida M (2017) How is visual salience computed in the brain? Insights from behaviour, neurobiology and modelling. Philosophical Transactions of the Royal Society B: Biological Sciences 372: 20160113. https://doi.org/10.1098/rstb.2016.0113

Wanzenböck J (2025) Introduction to the "Second International Workshop on *Umbra krameri*"- 30 years after: gains in knowledge on the biology of the species. ARPHA Conference Abstracts 8: e179506. https://doi.org/10.3897/aca.8.e179506

Wickham H, François R, Henry L, Müller K, Vaughan D (2023) dplyr: A Grammar of Data Manipulation. https://doi.org/10.32614/cran.package.dplyr

Wouters J, Janson S, Lusková V, Olsén KH (2012) Molecular identification of hybrids of the invasive gibel carp *Carassius auratus gibelio* and crucian carp *Carassius carassius* in Swedish waters. Journal of Fish Biology 80: 2595–2604. https://doi.org/10.1111/j.1095-8649.2012.03312.x

Zett T, Stratford KJ, Weise FJ (2022) Inter-observer variance and agreement of wildlife information extracted from camera trap images. Biodiversity and Conservation 31: 3019–3037. https://doi.org/10.1007/s10531-022-02472-z

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

Participation was voluntary, and informed consent was obtained from all participants. The study complied with relevant institutional and national regulations for research involving human participants. Ethical review and approval were not required in accordance with the institutional policy of the Institute of Hydrobiology, Biology Centre CAS (Czech Academy of Sciences) because participation was voluntary, the study involved minimal risk, and no sensitive personal data were collected. No direct personal identifiers (e.g. names or contact details) were collected, and data were processed and stored in accordance with the EU General Data Protection Regulation (GDPR; Regulation (EU) 2016/679). Informed consent was obtained from all participants through their voluntary completion of the questionnaire.

Artificial Intelligence (AI) use

The authors accept full responsibility for the content of the manuscript, including the disclosure of any use of AI.
AI-assisted tools were used to improve language and clarity during manuscript preparation. No AI system meets authorship criteria, and no AI system was listed as an author.

Funding

MŠ and YS were supported by the Interreg Austria–Czech Republic project [ATCZ00180 – Living Treasures], co-funded by the European Union.

Author contributions

MŠ designed the study and led the project. MG and YS collected the data. MG prepared the dataset and performed the statistical analyses. MG wrote the first draft. MG and MŠ jointly revised the manuscript. All authors approved the final version.

Author ORCIDs

M. Gottwald https://orcid.org/0000-0001-9769-2346
Y. Stepanyshyna https://orcid.org/0009-0005-4682-3779
M. Šmejkal https://orcid.org/0000-0002-7887-6411

Data availability

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