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The Knowledge and Perceptions of Recreational Anglers Related to Alien Plant Species in Freshwater Ecosystems: A Case Study From Hungary

András Nagy[1] | Zsolt Neményi[1] | Attila Hagyó[1] | Balázs András Lukács[2,3] | Zoltán Vitál[4] | Attila Mozsár[5] | S. James Reynolds[6,7] | Jenő Nagy[8] | Viktor Löki[2,3]

[1]Pál Juhász-Nagy Doctoral School of Biology and Environmental Sciences, University of Debrecen, Debrecen, Hungary | [2]Wetland Ecology Research Group, HUN-REN Centre for Ecological Research, IAE, Debrecen, Hungary | [3]National Laboratory for Climate Change, HUN-REN Centre for Ecological Research, Debrecen, Hungary | [4]Research Center for Fisheries and Aquaculture, Institute of Aquaculture and Environmental Safety, Hungarian University of Agriculture and Life Sciences, Szarvas, Hungary | [5]HUN-REN Balaton Limnological Research Institute, Tihany, Hungary | [6]Centre for Ornithology, School of Biosciences, College of Life & Environmental Sciences, University of Birmingham, Birmingham, UK | [7]Army Ornithological Society (AOS), c/o Prince Consort Library, Knollys Road, Aldershot, Hampshire, UK | [8]HUN-REN-UD Conservation Biology Research Group, Department of Botany, University of Debrecen, Debrecen, Hungary

Correspondence: Viktor Löki (loki.viktor@ecolres.hu)

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ABSTRACT

The value of recreational anglers' ecological knowledge and perceptions have come to prominence in the past few decades. Based on recent studies, their observations might include those of alien organisms and, therefore, might be particularly important in monitoring and revealing the causes of aquatic invasions. Although the number of registered anglers in Hungary has doubled in less than 5 years, exceeding 1 million by May 2024, little is known about their ecological knowledge. To learn more about anglers' knowledge and perceptions of alien plant species, 72 field interviews were conducted between December 2021 and May 2023 at four regularly fished freshwater bodies in Hungary: Hévíz Canal and Lakes Fényes, Balaton and Velence. During interviews, photographs of 12 alien plant species, occurring mostly at thermal water habitats, were shown to anglers as their observations on the effects of biological plant invasions were recorded. Overall, most anglers were unable to name all of the presented species, but at least half of the respondents could confidently identify four species, whereas those regularly fishing at thermal water habitats were able to identify correctly more of the invasive plants. Sixteen of the 72 interviewed anglers were engaged in aquaristics, two of whom confessed that a plant species (i.e., water lettuce [*Pistia stratiotes*]) and a fish species (i.e., goldfish [*Carassius auratus*]) previously held in aquaria had been intentionally released into the wild by them. Our research underlines the importance of anglers' observations about alien organisms, but anglers also have the potential to promote aquatic invasions, especially if they are aquarists too. Anglers might also facilitate early detection of plant invasives before biological invasions occur. We suggest that anglers are an untapped resource in defining and implementing conservation strategies that could counter the spread and establishment of aquatic plant invasives.

Jenő Nagy and Viktor Löki contributed equally to this work.

1 | Introduction

Traditional and local ecological knowledge (TEK and LEK, respectively) have become a topic of considerable interest in the last few decades (Berkes 2017). Although knowledge of indigenous people (i.e., TEK) is widely used to understand nature, LEK of specific stakeholder groups has only recently been at the focus of research (e.g., Aswani, Lemahieu, and Sauer 2018; Kor et al. 2024). For instance, the incorporation of recreational anglers' ecological knowledge (recreational AEK, also referred to as 'recreational FEK'; see Pita et al. 2020, van den Heuvel and Rönnbäck 2023) in conservation management decisions has only begun in the last few decades, resulting in improved socio-ecological outcomes for both freshwater and marine fisheries (Hind 2015; Löki et al. 2023). Recreational AEK is now widely part of species management of fisheries, including in the generation of fish population trends (e.g., Colloca et al. 2020; Poissant et al. 2024) and in defining measures in fish species' conservation (e.g., Cooke et al. 2016; Granek et al. 2008). In addition, recreational anglers can shape and enhance sustainable management and conservation of both marine and freshwater habitats (Mamun 2007; Pita et al. 2020).

Recreational AEK is not restricted taxonomically to solely fish species because anglers can increase understanding of other taxa as well, including, for example, sea turtles (Chelonioidea; Cook, Dunch, and Coleman 2020), sea mammals (Beaudreau and Levin 2014) and decapods (Zukowski et al. 2018). Furthermore, their interest in the natural world may also extend beyond fauna to include freshwater plants, some of which are involved directly and indirectly in their fishing activities through maintenance of ecosystem function (Löki et al. 2021). As many recreational anglers have extensive experience of biology from years engaged in their pastime in freshwater habitats, as their numbers (Pecaverzum 2024) and environmental awareness grow (Cummins 2010; Lewin et al. 2020), they are emerging as important environmental stewards (Shephard, List, and Arlinghaus 2023). In parallel with their interests in the natural world, recreational AEK can be also particularly important in monitoring and understanding processes of aquatic invasions such as dispersal, establishment and propagation of invasive species (Banha et al. 2022; Cerri et al. 2018; Cliff and Campbell 2012). In the past few years, recreational anglers' observations have been used to assess occurrence, distribution and population dynamics of invasive fish species (e.g., Azzurro and Cerri 2021; Öndes et al. 2018; Özbek et al. 2017).

In stark contrast to assisting in positive conservation efforts, recreational anglers can also act purposefully or unintentionally as vectors for biological invasion. By travelling extensively (Morreale, Lauber, and Stedman 2023; Smith et al. 2020), and through the use of unclean (biofouled) fishing tackle and boats (Anderson et al. 2014), and of live bait (Kilian et al. 2012), anglers can facilitate the spread of invasive species, including alien fish species (Grabowska, Kotusz, and Witkowski 2010), mussels (*Mytilus* spp.) (Oyarzún et al. 2024), or even freshwater plants (Coetzee, Hill, and Schlange 2009). Although these contributions to biological invasion processes are likely to be predominantly unintentional, Cerri et al. (2018) suggested that anglers may sometimes deliberately release different organisms, mostly alien fish species, into freshwater habitats to enhance their fishing experience, which can lead to the arrival and establishment of new fish species in freshwater habitats (Banha, Veríssimo, et al. 2017; Hirsch, N'Guyen, and Burkhardt-Holm 2021).

Freshwater ecosystems provide essential ecosystem services and support a vast array of species, yet they face numerous human-induced threats (Vári et al. 2022). Among these, aquatic plant invasions significantly contribute to the biodiversity crisis by undermining the functioning and benefits of these ecosystems (Koleszár et al. 2023). These invasions degrade water quality, threaten fish habitats (Gallardo et al. 2016), disrupt food webs, alter nutrient cycling, exacerbate sedimentation and weaken natural flood protection mechanisms (Ricciardi and MacIsaac 2011; Liao et al. 2008). Additionally, invasive aquatic plants obstruct waterways and diminish the aesthetic and recreational value of freshwater systems, impacting activities such as tourism and sports (Eiswerth et al. 2005).

In our study, we applied the unified invasion framework proposed by Blackburn et al. (2011) to define established and invasive alien species. In this framework, invasions conceptualized as a series of stages and barriers that a species must overcome to become either established or invasive. A species is considered as established if it successfully surpasses the geographic, cultivation and survival barriers. It is classified as invasive when it not only reproduces successfully but also disperses effectively in the new environment.

Human activities have played a substantial role in spreading invasive aquatic species. Practices such as intentional stocking, aquarium releases, canal construction and international shipping have facilitated their proliferation (Rahel 2007; Brunel 2009). Among these, the ornamental trade stands out as a major pathway for the introduction of aquatic plants across continents and climatic regions (Champion, Clayton, and Hofstra 2010). This underscores the need for better regulation and management of human activities like angling to mitigate the impacts of aquatic plant invasions on freshwater ecosystems.

As in many countries of the globe, fishing is one of the most popular water-related sports and hobbies in Hungary. The high numbers of anglers in Hungary with currently more than a million registered to fish, of which at least half are active (Pecaverzum 2024), they offer a valuable source of observations that gained from more traditional catch-based surveys (Vitál et al. 2021). Because recreational AEK also includes freshwater plants (Löki et al. 2021), it is highly likely that anglers may be able to provide valuable conservation insights from their observations and perceptions about alien plant species. According to Lukács et al. (2014), at least 48 alien plant taxa occurred in Hungarian thermal water habitats. It is certain that some of these alien species may have been released into Hungarian freshwater habitats as a result of human activity, and we predict that new alien species may be detected year-upon-year as the popularity of angling in Hungary increases (Mesterházy, Riezing, and Vidéki 2019; Riezing 2019). Such activities may be performed by both anglers and aquarists, being one and the same in some instances (Hirsch, N'Guyen, and Burkhardt-Holm 2021).

In this study, we set out to document the knowledge and perceptions of Hungarian recreational anglers related to a dozen alien plant species occurring mainly in thermal water habitats. The study was guided by three objectives: (a) to assess angler familiarity with native and alien plant species; (b) to understand angler beliefs about the vectors associated with species invasions; and (c) to examine relationships between angler beliefs and familiarity with native and alien plant species. In parallel, we also aimed to collect anglers' perceptions more generally about biological invasions in the country. More specifically, we wished to investigate if anglers would have (i) generally limited knowledge when asked to name alien plant species compared to native plant species; (ii) more limited knowledge of alien plants when fishing in non-thermal versus thermal habitats; and (iii) valuable perceptions about plant species' invasions, acknowledging their potential role in understanding the processes of aquatic plant species' invasion. Using the collected information on the anglers and their perceptions about invasive aquatic species, we applied statistical methods to identify factors influencing their knowledge.

2 | Methods

2.1 | Study Areas

Our research was conducted at two thermal water bodies (Hévíz Canal and Lake Fényes) and two non-thermal water bodies (Lakes Balaton and Velence) in western Hungary (Figure 1). Hévíz Canal and Lake Fényes complexes are two of the few thermal water bodies where fishing is allowed in Hungary, but at Lakes Balaton and Velence, the two largest lakes in the country, tens of thousands of Hungarian anglers fish every year (LikeBalaton 2023; Velma 2023).

Hévíz Canal is a 13-km-long outflow of one of the largest (4.44 ha) swimmable thermal lakes in the world. The canal is inhabited by 22 fish species, at least 14 species of which are non-native with many of them being ornamental (Takács et al. 2015). Starting mainly in the 1980s (Szabó 1998), aquarium alien plant cultivation was conducted in the upstream section of the canal. Therefore, these alien species formed dense mats, which were harvested, and, hence, habitat structure was altered dramatically compared to the lower section of the canal where native

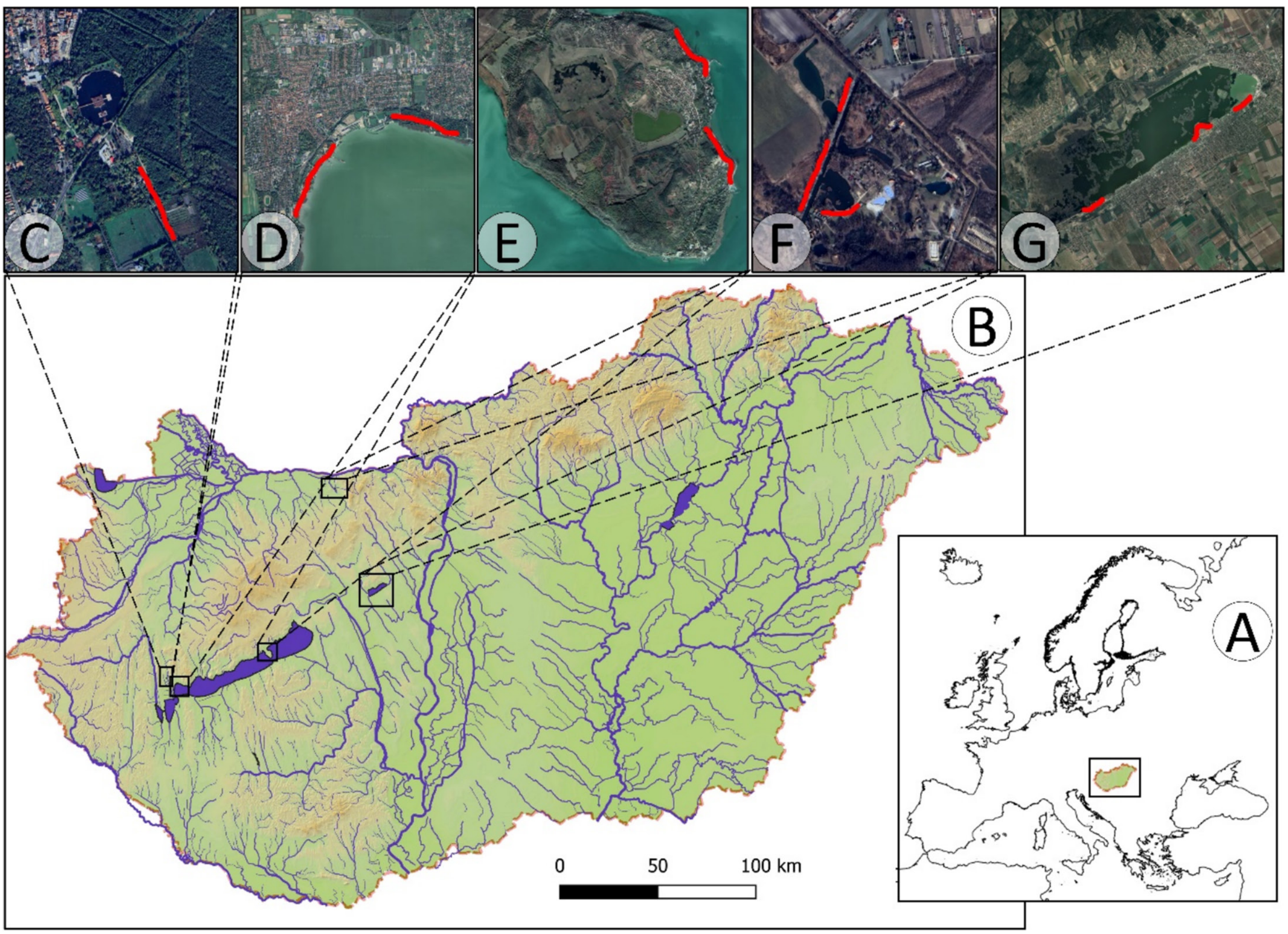

FIGURE 1 | Map of the study area in (A) central Europe and (B) Hungary. Rectangles indicate locations of data collection at (C) Hévíz Canal, (D and E) Lake Balaton, (F) Lake Fényes, and (G) Lake Velence. The red lines indicate the coastline where interviews were conducted. Source of the base maps: Natural Earth; satellite images of the study locations were exported from Google Earth Pro, whereas QGIS (2023) software and Google Earth Pro were used for map visualization.

vegetation remained free from alien plant species' incursion and invasion (Koleszár et al. 2023).

Lake Fényes is a small (0.91 ha) thermal lake complex in which, in the middle of the last century, there were at least 30 fish species (Horváth 1965). Mainly due to the periodic drying of the springs caused by past mining activities, no animal species' monitoring has been conducted recently. This habitat complex has been settled by at least 12 alien aquatic plant species typical of thermal water habitats (Mesterházy, Riezing, and Vidéki 2019; Vascular plants of Hungary Online Database 2018).

Lake Balaton covers 59,200 ha and is the largest lake in central Europe. It has one dominant inflow (i.e., the River Zala), and the only outflow is the mostly canalized Sió Channel. A total of 34 fish species are found in the lake, of which nine are non-native (Takács et al. 2011). The first botanical surveys of the lake took place in the late 18th and early 19th centuries (Lóczy 1896), but the vegetation of the lake, especially in the reed zones and the deep water macrophytes, started to suffer marked declines from the 1970s, resulting in the homogenisation of the indigenous vegetation (Szabó 1997). In parallel, several alien plants, many of which are neophytes, have spread in the last 20 years especially in the western part of the lake (Sipos, Padisák, and Hahn 2000).

Lake Velence is a large 2,600 ha shallow lake inhabited by 29 fish species (Sallai et al. 2018). The wetland habitat extends to the western half of the lake and the salt marsh that is connected to it, but the southwestern part is also a nature conservation area. The vegetation is currently under significant human pressure

TABLE 1 | Details of 12 non-native plant species presented for identification to Hungarian anglers during 72 interviews about plant invasives conducted between 2021 and 2023 at six locations (see Figure 1 for further details). Numbers of responses in each response category are detailed. The nomenclature and taxonomic order of plant species follow the World Flora Online (2024). Year of first observation of each species is from Lukács et al. (2014), whereas their presence/absence in non-thermal waters is determined following the Vascular plants of Hungary Online Database (2018). Their status of invasion in Hungary was determined following Richardson et al. (2000) and the Vascular plants of Hungary Online Database (2018).

				Number of interviewees indicating that plant species were:		
Scientific name (authority name follows)	**Year of first observation**	**Presence (+) or absence (−) in non-thermal waters**	**Invasion status (Est.: established; Inv.: invasive)**	**Known by name**	**Known but not by name**	**Unknown**
Azolla filiculoides Lam.	1940	+	Est.	1	13	58
Limnobium laevigatum (Humb. & Bonpl. ex Willd.) Heine	2018	−	Est.	1	13	58
Ludwigia grandiflora (Michx.) Greuter & Burdet	2005	−	Inv.	0	10	62
Cabomba caroliniana A. Gray	1937	+	Inv.	0	36	36
Elodea canadensis Fraser ex Spach	1885	+	Inv.	5	55	12
Hydrocotyle ranunculoides L.f.	2005	−	Inv.	0	5	67
Impatiens glandulifera Royle	1920	+	Inv.	0	2	70
Monochoria korsakowii Regel & Maack	1988	+	Inv.	0	2	70
Nymphaea rubra Roxb. ex Andrews	1891	−	Est.	45	17	10
Pistia stratiotes L.	1966	+	Inv.	2	7	63
Rotala rotundifolia (Buch.-Ham. ex Roxb.) Koehne	1998	−	Inv.	0	18	54
Vallisneria spiralis L.	1808	+	Inv.	4	36	32

mainly from recreational activities, although the extent of alien plant species' incursion is limited due, in part, to sustained high salinity (Fekete 2010; Bőhm 2011).

2.2 | Data Collection

Interviews with anglers were conducted in Hungarian between December 2021 and May 2023. The duration of the interviews varied between approximately 20 and 40 mins. To perform structured interviews (Newing 2010), two different fishing locations were visited at Lake Balaton, three at Lake Velence, one in the upper section of the Hévíz Canal, and at three small lakes along the Lake Fényes complex where fishing was allowed (Figure 1). Anglers in the sampling areas were randomly approached during fishing and invited to be interviewed at Lake Balaton and Lake Velence, whereas all anglers were asked for an interview at Hévíz Canal and Lake Fényes complex. Approximately every second person gave us an interview at the two non-thermal locations, but engagement was higher at the two thermal habitats where almost every angler engaged in an interview. A total of 72 interviews were conducted, 12 at each of the Hévíz Canal and the Lake Fényes complex and 24 at each of Lakes Balaton and Velence.

The interview questions were developed based on the methodology of Löki et al. (2021) but were refined to address the topic of plant invasions specifically. Prior to the interviews, 12 non-native plant species with widespread or sporadic distribution in Hungary and occurring mainly at thermal water habitats were selected (see details in Table 1) and presented as colour photographs during interviews with anglers. When selecting these focal species they had to be (1) found at the two thermal locations where interviews were conducted or (2) common (i.e., widespread distribution in Hungarian freshwater ecosystems) or salient (i.e., anglers come into close association with them while fishing); but (3) at least half of them (i.e., at least seven species) had to also occur in colder, non-thermal freshwater habitats (see also Table 1). Taxon names follow WFO - The World Flora Online (2024). Each species was presented to anglers as a full page of detailed and more general photographs showing the most important characteristic details of the given species.

During interviews with anglers, extensive notes were taken on pre-printed data collection sheets. The first part of the structured interview focused on the socio-demographic characteristics of anglers: age, gender, occupation, fishing experience, etc. (see details in Table 2). The second part of the interview explored their non-native plant-related knowledge and their perceptions of aquatic plant invasions through a series of 15 questions (see S1 in Supporting Information for all questions asked during the structured interviews). The basis of the interview was the first question: (1) Do you know the name of the plant in these images? In the absence of a named plant in the answer, but after the interviewees claimed that they had seen the plant previously, we asked at least two of the following three control questions to validate their knowledge of the species: (2) Which month (or period of the year) does the plant bloom? (3) What kind of aquatic habitat is preferred by this species? (4) Where exactly did you see it in the country? If a person could answer only one, or could not answer any of these three questions correctly, their answer about recognizing the species was regarded as not confirmed. To learn more about the perceptions of anglers

TABLE 2 | Responses to a series of questions about socio-economic and demographics, and their fishing habits conducted with 72 anglers at six freshwater angling sites in Hungary between 2021 and 2023. Anglers who perform manual labour were considered as blue-collar workers and those who work in offices were considered as white-collar workers.

Subject of question	Number of responses by interviewees (% of those interviewed)
Age (years)	
20–39	9 (12.5)
40–59	28 (38.9)
60+	35 (48.6)
Occupation	
White-collared worker	15 (20.8)
Blue-collared worker	26 (36.1)
Retired	28 (38.9)
Unknown	3 (4.2)
Fishing frequency	
Daily	13 (18.0)
Weekly	39 (54.2)
Monthly	20 (27.8)
Fishing experience (years)	
1–5	4 (5.5)
6–19	7 (9.8)
20–39	27 (37.5)
40+	34 (47.2)
Consumption of caught fish	
Yes	63 (87.5)
No	9 (12.5)
Attendance at fishing competitions	
Yes	19 (26.4)
No	53 (73.6)
Boat use for fishing	
Yes	20 (27.7)
No	52 (72.3)
Number of regularly visited fishing places	
1	34 (47.2)
2–5	35 (48.6)
6+	3 (4.2)

of aquatic plant invasions, nine additional questions were asked, and two statements were read to determine whether the interviewee agreed with them on a 10-point scale. Of the 11 questions and statements, five were dichotomous, four were open-ended, and two were answered by scoring response on a 10-point scale. Responses to open-ended questions were systematically categorized line-by-line according to their content prefixes (neutral, positive or negative perceptions) and the detail provided in the responses (see Table 3 for specifics). Given that the impact of alien species on ecosystem functions is not exclusively negative and can vary subjectively depending on individual perspectives and priorities, we assessed the content prefixes using a categorical scale: positive, negative and neutral. This classification was determined by analysing the intrinsic meaning and sentiment expressed in the participants' responses. The coding and grouping of the responses by content prefixes were conducted by the authors.

2.3 | Statistical Analyses

We calculated the proportion of known (correctly identified or at least recognized) invasive plant species by each angler and used it as response variable in our statistical models (Löki et al. 2021). As the response variable is bound (i.e., its value falls between 0 and 1), we applied the beta regression approach (Ferrari and Cribari-Neto 2004) implemented in the 'betareg' package (Cribari-Neto and Zeileis 2010) in R v4.2.2. (R Core Team 2022). Due to the high number of potential predictors compared to the sample size ($n = 72$), first we evaluated two separate models. The first model included only predictors related to fishing activity (i.e., water type, years of fishing experience, participation in fishing competitions, number of regularly visited fishing locations, boat use for fishing and gear usage at different fishing locations). The second model included the perceptions of anglers of aquatic plant invasions (i.e., engagement in aquaristics, introduction of aquarium-held species to the wild, dispersal mode, effects of alien plants on water, potential of anglers to contribute to alien plant dispersal, negative effects of alien plants on habitat quality and control of alien plants contributing to habitat health) and their demography (i.e., age and occupation). Anglers who perform manual labour were considered as blue-collar workers and those who work in offices were considered as white-collar workers. We used these variables because some of them were found to be relevant to our topic (e.g., Löki et al. 2021) or originated from the interview questions specifically designed for the current study. We eliminated all predictors with associated p values > 0.05 through a stepwise approach to derive minimally adequate models (MAMs). Then, we performed a final model including all predictors found to be significant in the previous steps and again removed all predictors with associated p values > 0.05 to obtain a global MAM. We calculated variance inflation factors (VIFs), implemented in the 'usdm' package (Naimi et al. 2014), for the predictors to check multicollinearity. We considered VIFs < 2 as an acceptable threshold (Zuur, Ieno, and Elphick 2010).

TABLE 3 | Nature of questions asked of, and responses by, 72 recreational freshwater anglers in Hungary in interviews conducted between 2021 and 2023. Responses generated data on their engagement in aquaristics, maintenance of cleanliness of fishing gear and general perceptions of aquatic plant invasions.

Subject of question	Question format	Summary of anglers' responses
Engagement in aquaristics	Dichotomous	Yes = 16, no = 56
Introduction of aquarium-held species to the wild	Dichotomous	Yes = 2, no = 70
Cleaning of angling gear after fishing	Dichotomous	Yes = 61, no = 11
Non-native nature of photographed plant images shown	Dichotomous	Yes = 6, no = 0 Do not know = 66
Non-angler vectors of alien plant dispersal	Open-ended	See Figure 3
Potential of anglers to contribute to alien plant dispersal	Dichotomous	Yes = 34, no = 38
Nature of anglers' contribution to alien plant dispersal	Open-ended	By fishing tackle/other gear = 24, by boat = 4, by bait fish = 2, by clothes = 2, do not know = 2
Effects of alien plants on fish	Open-ended	Positive (by providing more hiding places or food) = 18, negative (poisonous, less sunlight) = 17, neutral = 8, do not know = 29
Effects of alien plants on native plants	Open-ended	Positive = 0, negative (competition, hybridization) = 55, neutral = 5, do not know = 12
Negative effects of alien plants on habitat quality	10-point scale (1 = *absolutely not*, 10 = *absolutely*)	Mean ± 1 SD = 7.8 ± 2.3
Control of alien plants contributing to habitat health	10-point scale (1 = *absolutely not*, 10 = *absolutely*)	Mean ± 1 SD = 8.1 ± 2.6

3 | Results

3.1 | Profiles of Interviewed Anglers

Of the 72 anglers interviewed, 71 were male and one was female. The youngest interviewee was 13, whereas the oldest was 77 (mean: 56 years). Anglers who had retired from paid work represented the highest number of interviewees ($n = 28$, 39%). Most anglers reported a fishing frequency of weekly ($n = 39$, 54%) and regularly visited two to five fishing locations ($n = 35$, 49%). The mean number of years of fishing experience was 34, but 34 of those interviewed (47%) had accrued at least 40 years of fishing experience. Twenty anglers (28%) regularly used boats for fishing. For detailed demographics and information about angling experience of the interviewed anglers, see Table 2.

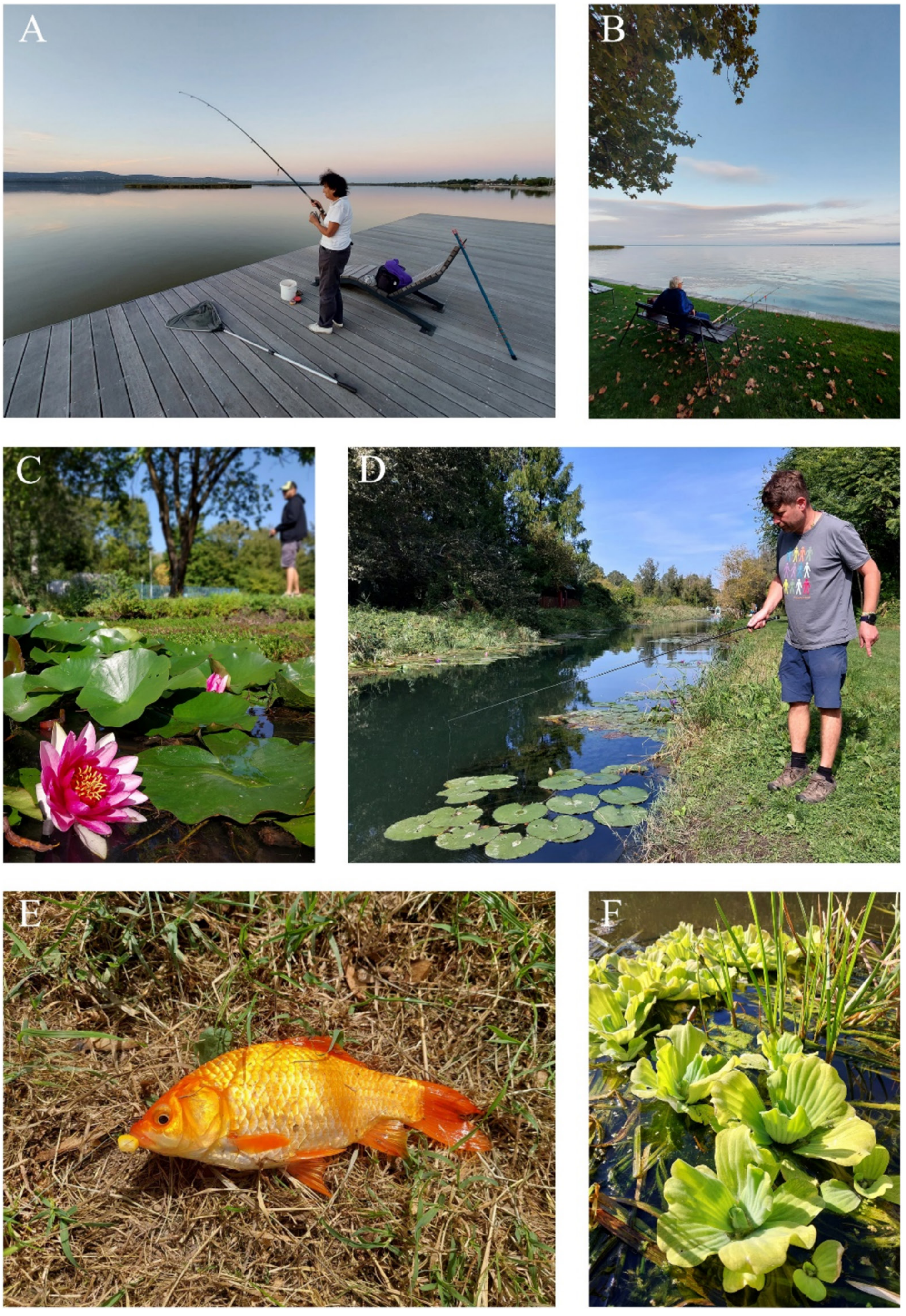

FIGURE 2 | (A) An almost completely vegetation-free angling site at Lake Velence. (B) A fishing spot at Lake Balaton poor in aquatic macrophytes and lacking reedbeds due to extensive habitat destruction. (C) One of six different small lakes fed by springs at Lake Fényes where the small lakes differ significantly in alien plant composition. (D) An angler on the Hévíz Canal where fishing is for leisure as opposed to for sustenance. (E) An invasive fish species, the goldfish (*Carassius auratus*), caught by an angler at Sió Canal, the only draining canal of Lake Balaton. (F) An invasive plant species, the water lettuce (*Pistia stratiotes*), that currently exists in > 20 populations in Hungary. Photographs: A–D and F: Viktor Löki, E: Györfi Henriett and Ferenc Babai.

3.2 | Anglers' Knowledge of Alien Plant Species

Anglers displayed limited knowledge in their abilities to name alien plant species during interviews (Table 1). Of the 12 focal species, six were not identified by a single participant in the study, and of the remainder, only a small minority of anglers knew them. The only exception was the *Nymphaea rubra*, which was named by a total of 45 anglers (63%). At least half of the anglers knew of but could not name *Vallisneria spiralis*, *Elodea canadensis* and *Cabomba caroliniana*, whereas 10 anglers (14%) were familiar with *Azolla filiculoides*, *Limnobium laevigatum*, *Rotala rotundifolia* and *Ludwigia grandiflora*. More than 80% of anglers did not recognize *A. filiculoides*, *L. laevigatum*, *L. grandiflora*, *Hydrocotyle ranunculoides*, *Impatiens glandulifera*, *Monochoria korsakowii* and *Pistia stratiotes*. In addition, most of the anglers (n = 66, 91%) did not know that the focal species presented to them were of an alien conservation status in the national flora (Table 3).

3.3 | Anglers' Potential Contribution to, and Their Perceptions of, Aquatic Plant Invasions

Of the 72 interviewed anglers, 16 (22%) were engaged in aquaristics (Table 3). Two anglers (3%) confessed that they had previously released into the wild an aquarium plant species (i.e., water lettuce [*P. stratiotes*]) and a fish species (i.e., goldfish [*Carassius auratus*]) (Figure 2). Most of the anglers cleaned their gear after fishing (n = 61, 84%). Nearly half of the anglers (n = 38, 52%) thought that anglers cannot contribute to alien plant dispersal, whereas out of the remaining 34 who thought they played some role, 24 (33%) stated that the most plausible vectors might be fishing tackle and associated equipment, with four proposing boats and two suggesting each of bait fish and clothes as modes of introduction. Anglers proposed 10 different ways that alien plant species can spread in the absence of their contribution to the process (Figure 3). Most anglers (n = 55, 76%) stated that alien plants might have negative effects on native plants, whereas most also believed they negatively impacted habitat too. In support of this, they also believed that control of alien plants contributes to habitat health. Table 3 provides full details of questions about invasive plant species and answers provided by anglers.

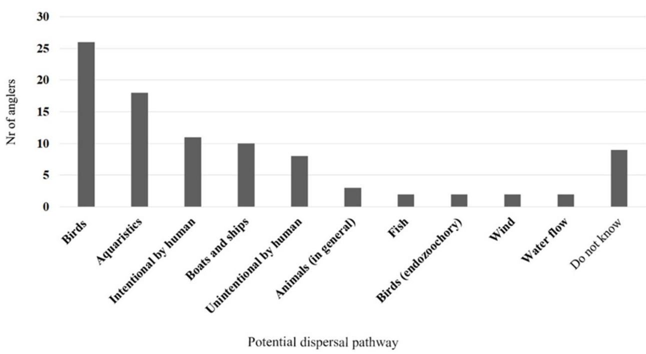

FIGURE 3 | Responses of 72 Hungarian freshwater anglers questioned between 2021 and 2023 about their perceptions of potential pathways of alien plant species' dispersal.

3.4 | Associations Between Invasive Species' Knowledge and Perceptions of Anglers

Anglers fishing at thermal waters recognized more invasive plants than those who predominantly did not fish at such locations. Although the regression coefficients suggested closely constant, but statistically significant relationship (Table 4), they also fished more frequently and fished from boats on more occasions (Figure 4), activities associated with a heightened ability to recognize invasive plant species. Anglers who were retired or white-collar workers were less likely to identify correctly the invasive plant species presented compared to blue-collar workers. Perceptions of invasive plant species by anglers, such as boats facilitating invasive plant dispersal or invasive plants negatively impacting the habitat, were also negatively associated with their ability to identify correctly invasive plant species. In contrast, anglers who engaged in aquaristics, and/or who acknowledged that they contributed to invasive plant species' dispersal, and/or who believed that habitat quality could be improved by mitigating plant invasions were more likely to identify correctly invasive plant species (see Figures S1–S4).

4 | Discussion

In this study, we have shown that anglers can provide valuable observations about alien freshwater plant species with which they are familiar while engaged in their pastime. Our results suggested that their collective knowledge of invasive plants mainly originates from field observations and quickly adapts to the habitat such as recognition of new plant species invaders. This was supported by anglers who fished in thermal waters being more familiar with alien plant species than those fishing predominantly in non-thermal habitats. Our results also indicated that anglers might promote the early detection of invasive aquatic plant species. Moreover, sixteen of 72 interviewed anglers were engaged in aquaristics, and two of them confessed to releasing into the wild a plant and a fish species previously kept in aquaria. Therefore, here, we report on a direct connection between aquaristics, angling habits and novel pathways for biological invasions.

We found that the socio-economic status and fishing habits of anglers can shape their knowledge and perceptions of invasive aquatic plant species. For example, the frequency of fishing activity and the use of boats during fishing excursions had significant positive influences on their abilities to identify invasive plant species. This is probably related to more field experience gathered of such species as a result of more trips to fishing locations and wider spatial coverage of such fishing trips (Lindgren 2006). Moreover, anglers who were retired or in white-collar jobs at the time of questioning were less likely to be able to identify invasive plant species correctly. Despite the extensive duration of fishing of the majority of interviewees (47% of them had been fishing for >40 years), fishing experience per se did not appear always to translate into close familiarity with invasive plant species that often only occur in some thermal habitats (Table 1). Instead, we conclude that greater coverage of potential fishing sites or more frequent shifts of angling locations, even within restricted areas, might result in anglers encountering these sporadically occurring invasive plants more often. Of course, there

TABLE 4 | Results of the minimally adequate beta regression models evaluating the associations between the proportion of recognized plants as a response variable and predictors related to fishing activity (Model 1) and perceptions of Hungarian anglers of aquatic plant invasions and socio-economic factors (Model 2). All such predictors are considered in Model 3, where 'Not selected' indicates that the predictor was dropped during the model selection procedure. The name of the category forming the basis of the comparison is displayed in-line with the name of the predictor (base level), whereas the rest of the categories with estimated values are shown in subsequent rows (estimated differences compared to the base level). Pseudo R^2 values, a goodness-of-fit measure for beta regression models, are provided below each model.

	Model					
	1		2		3	
Predictor	β	*p*	β	*p*	β	*p*
Water type (cold)						
Thermal	1.16	< 0.001			1.07	< 0.001
Annual fishing frequency (estimated number of fishing occasions in a year)						
	−0.01	0.001			< −0.01	0.002
Fishing occasions with boat (number of fishing with boat in a year)						
	0.02	0.002			0.02	0.001
Occupation (blue-collar)						
Retired			−1.02	< 0.001	−0.59	0.006
White-collar			−0.94	0.001	−0.89	< 0.001
Engagement in aquaristics						
			0.99	< 0.001	1.02	< 0.001
Plant dispersal by boat						
			−0.69	0.028	Not selected	
Potential of anglers to contribute to alien plant dispersal						
			0.09	0.031	Not selected	
Negative effects of alien plants on habitat quality						
			−0.14	0.017	Not selected	
Control of alien plants contributing to habitat health						
			0.21	< 0.001	0.16	< 0.001
Pseudo R^2	0.14		0.18		0.24	

Abbreviations: β, regression coefficient; *p*, *p* value (considered significant at $\alpha \leq 0.05$).

are always likely to be exceptions in a study such as ours. As an example, the red waterlily (*Nymphaea rubra*) was named correctly by all interviewed anglers probably because of its conspicuousness and many (pop)cultural references in Hungary. With this in mind, we believe that for monitoring and/or controlling non-native freshwater plants through engagement with anglers, a species such as this offers great benefits because it is salient, relatively common and widespread and thus familiar to most anglers (Löki et al. 2021). This also applies to species such as *V. spiralis*, *C. caroliniana* and *E. canadensis* that are also often found in both thermal and non-thermal waters visited regularly by Hungarian anglers. In the case of other species presented in the questionnaire such as *A. filiculoides* or *P. stratiotes*, they are relatively inconspicuous (cf. *M. korsakowii* and *I. glandulifera* that are highly salient) and relatively restricted in distribution. Accordingly, we hypothesize that the greater the salience, commonality and distribution of an invasive plant species, the greater the chance that they will be known by anglers in the country.

Moreover, although anglers were able to provide useful data about non-native plants in the present study, compared to our previous study of anglers' knowledge of freshwater plants (Löki et al. 2021), anglers were less likely to be able to provide correct scientific common names or folk names of non-native species during interviews. Unfamiliarity with their folk names, however, is not surprising given that most of the focal plants in our study are neophytes and, thus, have not had time to be integrated into the collective body of local knowledge (i.e., TEK). In particular, familiarity with, and knowledge of, such plant species are related to their prominence in the public consciousness; often, this occurs with plant species that provide us with medicinal, nutritional, cultural and other benefits (Schunko, Wild, and Brandner 2021). In summary, because this does not apply to

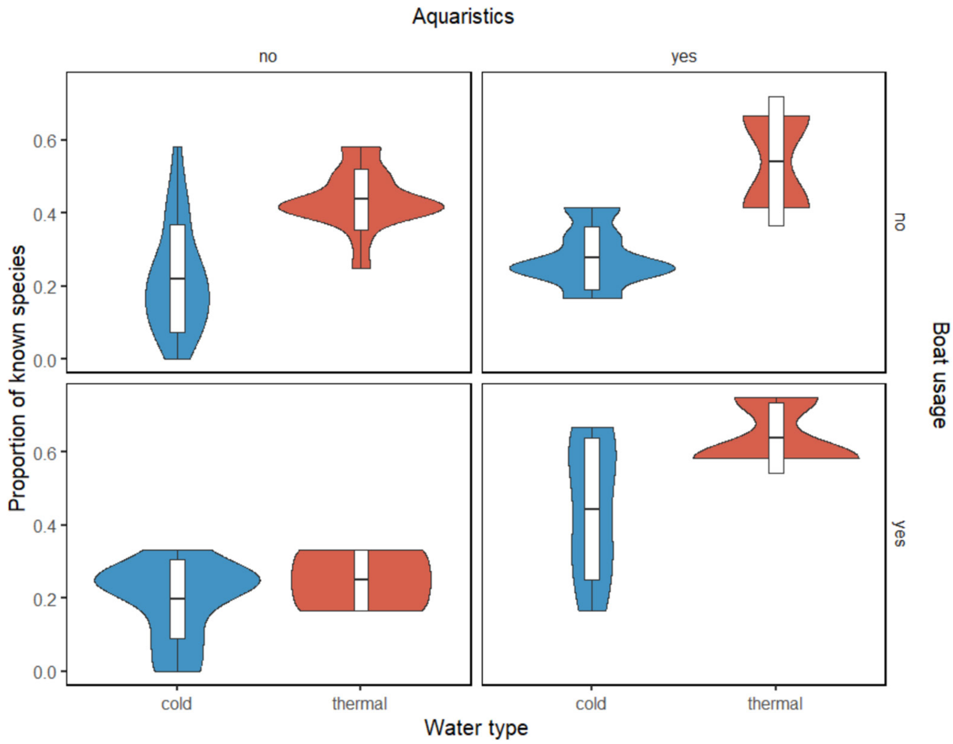

FIGURE 4 | The proportions of known (i.e., correctly identified or at least recognized) invasive plant species during interviews with 72 freshwater anglers held between 2021 and 2023 at Hungarian cold (blue) and thermal (red) fishing sites. Responses are split according to interview responses related to engagement in aquaristics (vertical split: aquaristics) and boat use for fishing (horizontal split: boat usage). The shapes indicate the distribution of the values, and box-and-whisker plots contained therein show the minimum, mean ± 1 standard deviation (SD) and maximum values of proportions.

most of the focal invasive plant species in our study, we predict that LEK of them will not gain traction, at least for the short term anyway.

From a conservation perspective, AEK is sure to play a crucial role in the early detection of biological invasions, increasing the success of eradication measures (Cerri et al. 2020; Izquierdo-Gómez 2022). In this study, one-third of the anglers could distinguish between alien and native plants, suggesting their potential role both in early detection and monitoring of spread of invasive species. However, anglers—even if they are mostly familiar with the negative effects of biological invasion—are also likely to facilitate aquatic invasion processes by releasing alien species. Anglers can unintentionally promote biological invasions (Anderson et al. 2015; Banha Diniz, and Anastácio 2017; Cerri et al. 2018) through the use of unclean equipment and alien fish as live baits that can result in alien species and their propagules being dispersed over great distances (Anderson et al. 2014, 2015; Drake and Mandrak 2014). Not only did two interviewees report two separate introduction events of alien ornamental species into the wild, but they were also engaged in aquaristics, constituting 22.2% of those questioned in our study and 22.5% in Hirsch, N'Guyen, and Burkhardt-Holm (2021). Therefore, the chances of similar introductions in the future in the Hungarian angler community are likely high. Anglers who are also aquarists are probably willing to spare the lives of previously kept organisms, despite being aware of negative effects of biological invasion. Although freshwater angling and keeping fish at home are, therefore, independently equivalent as potential sources of introductions of invasive species (Hirsch, N'Guyen, and Burkhardt-Holm 2021), aquarists who are also anglers can easily find suitable habitat for release of invasive species. Strecker, Campbell, and Olden (2011) reported that 6.4% of aquarists in the United States had released fish from their own aquaria into lakes or streams on at least one occasion.

Despite the likelihood of such introductions, there are no known established populations of *P. stratiotes* or *C. auratus* at the sites where they were released as confessed by the anglers in our study. As these are only one-off reintroduction events, their absence in our study sites is not surprising. It is clear that a single introduction event does not necessarily mean that the species persists after the introduction (Zenni and Nuñez 2013), as more frequent introduction events contribute to a higher probability of establishment (Simberloff 2009). However, the risk of a successful biological invasion (i.e., establishment of an invasive species) remains relatively high even in the case of one or just a few introduction events (Lockwood, Cassey, and Blackburn 2005), so their importance in invasive plant establishment should not be dismissed as trivial.

Approximately 80% of the alien aquatic plant species in Hungary have been recorded only in thermal waters (Lukács et al. 2014). This is not surprising given that the chance of survival of ornamental alien plants is higher in thermal waters due to the elevated water temperature (Šajna et al. 2023). Thermal waters are also invasion hotspots for (mostly ornamental) invasive animal species (Takács et al. 2015; Weiperth et al. 2019; Mozsár et al. 2021). Introduction events can markedly undermine eradication and restocking efforts without enforcing biosecurity protocols (Gozlan et al. 2010). Based on these previous findings, it is also likely that anglers have accelerated previous biological invasion events in Hungary, especially in thermal habitats where the proportion of species originating in aquaria was higher than the average native species number, such as at two of our sampled locations at the Lake Fényes complex and the Hévíz Canal (Lukács et al. 2014; Takács et al. 2015).

According to the anglers' perceptions reported in our study, the most important pathway of alien plant species' dispersal is through ectozoochory (dispersal via the fur or skin of animals) and endozoochory (dispersal through ingestion by animals), mostly by birds, although the role of humans was underestimated (Figure 3). Although birds can be considered important vectors in the transport of alien plant propagules both in continental Europe and more specifically in Hungary (Lovas-Kiss et al. 2019, 2023), and migratory birds strongly predict global native macrophyte distribution (Lobato-de Magalhães et al. 2023), previous studies have also emphasized the role of climate and anthropogenic activities, especially in dispersal of non-native species (Rodríguez-Merino et al. 2018). Moreover, it was found that any recreational activities (e.g., gardening, horticulture activity and boating) at larger lakes used by more recreationists were also the best predictors of the occurrence of alien invasive species (Reidy 2018). To raise awareness among anglers, environmental education campaigns should focus on the relative contributions of anthropogenic activities possibly to prevent biological invasions in aquatic habitats, highlighting also the importance of the informed behaviour of freshwater recreationists (including anglers) and their responsibilities in their prevention. Nevertheless, most anglers already reported environmentally conscious behaviours during interviews. Most used their boats in the same place and cleaned them frequently, thereby limiting the possibility of spreading different organisms.

Unsurprisingly, there is a disparity between the skills of fishers to identify fish compared to plant species. In the former case, fishers can recognize up to 97% of fish species from photographs and name correctly more than half of them in megadiverse tropical rivers (Silvano et al. 2022). Fishers may also contribute to fisheries management, research and conservation (Silvano and Begossi 2012, Hind 2015; Orensanz et al. 2014), sometimes providing critical information for researchers and resource managers (Johannes, Freeman, and Hamilton 2008). Whereas LEK of fishers may be useful in identifying non-native animal and plant species and where they are most concentrated and abundant (Perzia et al. 2023), and some may have detailed knowledge about plant species consumed by fish (Pereyra et al. 2023), from our study, clearly such knowledge is rather limited for alien aquatic plants. Despite this, we still believe that it could be key to filling some knowledge gaps in the monitoring of aquatic plant invasions. In addition, fishers can sometimes identify important medicinal plants (Merétika, Peroni, and Hanazaki 2010) or forest plants that can be used to build fishing gear and canoes (Orofino et al. 2018).

Previous research (e.g., Cole, Keller, and Garbach 2016; Golebie et al. 2021) has focused on understanding stakeholder awareness, their beliefs and their inputs of perceptions to aquatic biosecurity risk assessments (Cliff and Campbell 2012). Golebie et al. (2021) emphasized the importance of considering human behaviour in the spread of aquatic invasive species, as opposed to broader social and ecological consequences of biological invasions. In line with Hirsch, N'Guyen, and Burkhardt-Holm (2021), we suggest that the pet trade (i.e., release of invasive species from aquaria) and angling are synergistic in the role that they play in the translocation of alien species. We believe that a better understanding of the biological invasion process, key invasive taxa and defined solutions to prevent their release and establishment should be included in thematic environmental education campaigns for anglers and other recreationists to raise environmental awareness further (Seekamp et al. 2016). The involvement of more recreationists as stakeholders to facilitate the learning of lessons from discussions of shared knowledge and experiences (Velie, Poulos, and Green 2023) may prove crucial. Furthermore, the recruitment of outdoor recreationists as participants in alien plant control (Dehez 2023) might prove to be just as important. We also encourage the involvement of anglers in monitoring aquatic invasive species, potentially through thematic citizen science surveys.

5 | Conclusions

Probably because plants are for the most part only of marginal interest to them, anglers could not identify by name most of the alien aquatic plant species we presented to them. Despite this, they provided valuable observations and perceptions about them—and also about aquatic invasions generally—although they tended to underestimate anthropogenic effects. Compared with anglers regularly fishing at non-thermal waters, those fishing thermal waters were able to recognize more readily the 12 focal plant species. Albeit from just confessions of two of 72 anglers we interviewed, we conclude that, along with pet trade, anglers pose some risk as sources of invasive species introductions in Hungary, but, of course, further research is required to investigate this in greater detail. The pastimes of angling and aquaristics were identified as being shared by some of those interviewed. Although we highlight anglers as being potentially potent vectors for some alien species, most of those interviewed reported being engaged in environmentally conscious behaviours. Through collaboration with them, we propose that anglers may provide important additional information in monitoring alien species and, thereby, increase our understanding of how aquatic plant species' invasions start and progress.

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Ethics Statement

The methods of obtaining data during fieldwork followed the International Society of Ethnobiology's Code of Ethics (2013). No ethical committee permits were required.

Consent

All personal data published are anonymized. Prior and informed oral consent of local people in imagery was obtained for publication.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available in the Supporting Information of this article.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.