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PRIMARY RESEARCH PAPER

Intensive angling of non-native brook trout in high-mountain lakes: insights for eradication actions and awareness-building

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Abstract Introduced fish represent a widespread threat to the biodiversity of naturally fishless mountain and alpine lakes, a problem that can be mitigated through mechanical eradication. Recreational anglers, as key stakeholders, could be engaged in eradications via fish removal using angling techniques to raise awareness of high-mountain lake conservation, although the practical and educational effectiveness of such involvement remains uncertain. Prior to initiating the eradication of brook trout *Salvelinus fontinalis* (Mitchil, 1814) from four high-mountain lakes, we therefore tested the use of intensive angling sessions with two objectives: (i) removing non-native individuals to support subsequent eradication phases, and (ii) engaging anglers and promoting ecological awareness. Angling sessions substantially reduced the biomass of previously angling-naïve populations and attracted numerous participants, but without producing a measurable shift toward more conservation-oriented attitudes. High catch rates nonetheless highlight the potential of angling as both an engaging participatory tool and a complementary method to structured eradication techniques. At the same time, our results indicate that angler engagement alone does not guarantee effective environmental education. We therefore recommend considering angling sessions as a convenient complement to eradication actions, while embedding such initiatives within structured, long-term educational programs to foster tangible educational outcomes.

Keywords Fish stocking · Alien species · Recreational angling · Protected areas · *Salvelinus fontinalis*

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Introduction

Although recreational fishing generally exerts relatively modest harvest pressure compared to industrial fisheries, even such limited angling pressure can alter and deplete fish populations (Granek et al., 2008), especially in small and unproductive inland systems

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(Post et al., 2002), such as high-mountain streams and small lakes (Shepard et al., 2019). To sustain angling opportunities under these conditions, population reinforcement practices (i.e., stocking of hatchery reared fish) have been widely used for decades (Claussen & Philipp, 2023). This resulted in the widespread practice of translocating species within and beyond their native ranges, which has profoundly shaped freshwater ecosystems worldwide (Lewin et al., 2006; Villéger et al., 2011), increasing outdoor recreational opportunities and generating economic benefits, but at the cost of dramatic ecological impacts (Eby et al., 2006; Lewin et al., 2006; Araki et al., 2007). Such ecological impacts are often long-lasting, particularly in many cases where introduced populations become self-sustaining. Introduced game fish can disrupt natural food webs, and ecosystems by (i) affecting native biota through competition and predation (Nakano et al., 1998; Soto et al., 2006; Ventura et al., 2017), (ii) hybridizing with native species or genetic lineages (Splendiani et al., 2019), (iii) facilitating the spread of non-native organisms through the introduction or translocation of fish and live baits (Miró & Ventura, 2015), and (iv) acting as vectors for pathogens or contaminants associated with aquaculture (McEachran et al., 2023) or inadvertently transported on anglers' clothing and gear. These problems are amplified when populations are sustained by repeated stocking events, with each restocking representing a pulsed disturbance that exposes native species to renewed peaks in ecological, disease exposure, and genetic disturbances. An illustrative example of the pervasiveness of stocking-related impacts is the global spread of salmonids in mountain and alpine environments (Bahls, 1992; McDowall, 2006; Ventura et al., 2017). Several species have been translocated within their native ranges to colonize isolated headwater habitats that were naturally fishless, while others have been introduced far beyond their native ranges (Ventura et al., 2017). Notably, two of the eight fish species listed among the world's 100 worst invasive species are salmonids [brown trout *Salmo trutta* Linnaeus, 1758 and rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792)], whose invasion histories are closely linked to widespread and systematic introductions into mountain lakes and rivers (Lowe et al., 2000).

In this context, a fundamental conservation goal for mountain freshwater habitats is to reduce both the spread of non-native fish (Ventura et al., 2017) and the dependency of inland fishery management on stocking (Radinger et al., 2023). This can be achieved through conservation measures that discourage further introductions (Miró & Ventura, 2013) and potentially trigger a recession of the problem, as introduced populations that are not self-sustaining, in the absence of periodic restocking, are likely to disappear (Armstrong & Knapp 2004). In favourable contexts, such as within some protected areas, it is possible to take bolder actions, such as eradicating alien fish (Ventura et al., 2017).

This study is based on the eradication of non-native brook trout *Salvelinus fontinalis* (Mitchil, 1814) from four high-mountain lakes in the Gran Paradiso National Park (Italy), where fishing had been prohibited for decades and recreational anglers were involved as part of educational initiatives linked to eradication activities. The study included one lake where an experimental intervention in 2013 demonstrated the effectiveness of rod angling in engaging local anglers and reducing fish biomass (Tiberti et al., 2017), and three additional lakes where angling sessions were conducted in 2022. These recent actions aimed to test the generality of earlier results and were accompanied by a structured monitoring of educational outcomes. In all cases, anglers were involved at the beginning of each eradication action through two days of intensive rod-angling. The intervention was explicitly designed with two objectives: (i) to achieve the rapid removal of as many non-native fish as possible in preparation for subsequent eradication actions using nets and electrofishing (i.e., widely applied eradication methods in high-mountain lakes described by Knapp & Matthews, 1998), and (ii) to foster greater ecological awareness among anglers as key stakeholders. Importantly, recreational angling sessions were not conceived as an eradication method per se. Salmonid eradication in high-mountain lakes is primarily achieved through intensive gillnetting (Knapp & Matthews, 1998; Pacas & Taylor, 2015), sometimes complemented by electrofishing (e.g., in connected stream habitats; Tiberti et al., 2021). Accordingly, we do not evaluate angling as a substitute for these methods, but rather as a convenient complementary tool that can enhance removal efficiency and reduce net wear, while promoting stakeholder engagement.

While no clear a priori hypothesis was initially formulated (i.e., before the first angling sessions at

lake Dres) regarding the effectiveness of recreational angling in removing fish, we hypothesized that participation in the initiative would lead to a measurable shift in anglers' attitudes toward more conservation-oriented views of fishery management. This represented the primary original objective of the study and was assessed in the present study through pre- and post-event questionnaires. However, the strong impact of the angling sessions on non-native fish populations observed at lake Dres prompted us to formulate a second hypothesis: that intensive effort using recreational fishing techniques can significantly and rapidly reduce both the abundance and biomass of non-native fish populations in high-altitude lakes, which was subsequently tested by replicating angling sessions in three additional lakes.

We believe that the observations collected during these angling events have implications that extend beyond the specific case study and its immediate management context. This study evaluates whether similar actions can effectively support non-native fish eradication while delivering meaningful educational benefits and it explores how rapidly recreational fishing can alter demographic structure and reduce densities of fish populations. Understanding these short-term effects is relevant not only for conservation programs aimed at reducing or eradicating non-native species, but also for informing broader debates on how recreational fisheries might be managed with greater ecological responsibility.

Materials and methods

Study lakes

This study focuses on four originally fishless high-mountain lakes/ponds (hereafter referred to as lakes for simplicity) in the Gran Paradiso National Park (Western Italian Alps): lake Dres, lake Leità, lake Miserino, and the smaller waterbody Miserino-2 (Table 1). The sites are located above 2000 m a.s.l., at or above the local timberline, and are characterized by cold temperatures and 6–9 months of annual ice cover. Introduced fish consisted primarily of brook trout (*Salvelinus fontinalis*), with very few individuals of other species removed from lake Dres (i.e., four marble trout *Salmo marmoratus* Cuvier, 1829, one Languedoc minnow *Phoxinus septimaniae* Kottelat, 2007, and one brown trout *S. trutta*). Brook trout were introduced into lakes Leità, Miserino, and Miserino-2 during a single stocking event in the 1960s—more than forty years after the establishment of the National Park—at a time when awareness of the potential negative ecological consequences of fish introductions was still limited. In lake Dres, the first date of introduction is unknown, and additional introductions may have occurred until 1979, when the lake was incorporated into the protected area. Shortly after these introductions, and beginning in the 1970s, the Park Authority—already positioning itself at the forefront of aquatic ecosystem conservation—introduced a complete ban on fish stocking and recreational fishing throughout the protected area. This measure helped contain the further spread of introduced species, although it could not reverse the impacts already caused by past introductions. The fishing ban was efficiently enforced by the Park's wardens, ensuring that the fish populations remained free from exploitation for decades. All brook trout populations were naturalized and self-sustaining until the beginning of the eradication campaigns between 2013 and 2023.

Angling sessions

The two local angling associations from the Orco and Cogne valleys, located in the provinces of Turin and Aosta, respectively, were contacted to help identify and recruit interested anglers for the sessions at lakes within their respective territories (Table 1). Before

Table 1 Main geographic and morphometric characteristics of the lakes treated for fish eradication in the Gran Paradiso National Park (Western Italian Alps)

Lake	Code	Valley	Lat. N	Long. E	Elev (m)	Area (ha)	Depth (m)
Dres	DRE	Orco	45.4128	7.2240	2087	2.42	7.4
Leità	LEI	Orco	45.4937	7.1322	2703	6.48	11.0
Miserino-2	MI2	Cogne	45.5847	7.4701	2666	0.23	2.0
Miserino	MIS	Cogne	45.5832	7.4704	2667	4.22	9.9

the angling sessions began at the lakes, all participants took part in a participatory discussion lasting approximately 40 min, which focused on the conservation objectives of the project and the aims of the angling activities. Further discussions, responses to questions, and exchanges of views between project staff and anglers took place throughout the angling sessions.

Upon registration for the angling days, anglers agreed to adhere to the following rules: the use of live fish as bait was prohibited, whereas invertebrate and artificial baits were allowed without restrictions on hook number, hook size, and fish size; fishing was limited to the lake shores and connected tributaries; anglers were required to register to obtain a nominal fishing permit valid only for the two designated days; and they were instructed to wear a harness displaying the GPNP symbol for identification. Anglers were allowed to keep all captured fish, but only after the scientific staff had recorded each fish's length and weight. To prevent subsequent restocking, it was clearly communicated that no additional fishing sessions would be held in the target lakes.

Angling was conducted in each lake over two consecutive sampling sessions. In lake Dres, sessions took place on 22–23 June 2013, involving 21 and 14 anglers, for a total fishing effort of 157.5 h. In lake Leità, sampling was carried out on 22–23 July 2023, with 29 and 11 anglers, totalling 194.7 h of effort. In lakes Miserino and Miserino-2, angling occurred on 19–20 August 2022: Miserino involved 5 and 10 anglers, totalling 84 h of fishing effort, whereas Miserino-2 involved 1 and 6 anglers for a total of 15.8 h.

Eradication methods

Eradication efforts following the angling sessions relied on intensive gillnetting and electrofishing, consistent with established and widely replicated practices for non-native fish removal in high-mountain lakes (e.g., Knapp & Matthews, 1998; Pacas & Taylor, 2015; Tiberti et al., 2021). While mechanical removal methods are often inconsistently documented in the broader literature (Rytwinski et al., 2019), their application in isolated mountain lakes represents a notable exception, with a substantial body of evidence demonstrating their effectiveness across diverse ecological and management contexts (Tiberti et al., 2021 and references therein). In high-mountain lakes, an empirical yet well-established approach for declaring eradication is to maintain a consistent level of eradication effort and observe a full year without any captures (Knapp & Matthews, 1998; Tiberti et al., 2021).

Eradication efforts started immediately after the angling sessions at different times in each lake, on 24 June 2013 in lake Dres, 24 July 2023 in lake Leità, and 20 July 2022 in lakes Miserino and Miserino-2. Multi-mesh gillnets and fixed mesh gillnets were deployed across the lakes to capture the full range of fish sizes and maximize removal efficiency. The number of deployed gillnets varied among lakes according to their size, with the aim of achieving a net density of about twelve ha^{-1} or more (Knapp & Matthews, 1998): 30 nets were set in lake Dres (12.0 ha^{-1}), 85 in lake Leità (13.1 ha^{-1}), 47 in lake Miserino (10.9 ha^{-1}), and 5 in lake Miserino-2 (21.7 ha^{-1}). Net deployment was adapted to lake size and morphology to ensure adequate spatial coverage and maximize capture efficiency across habitats. Nets were regularly cleaned to maintain their effectiveness and remained in place continuously, including under ice cover, to ensure progressive depletion of the fish populations.

Electrofishing was conducted using two backpack-mounted electrofishing units (ELT60 IIGI and ELT62 II 160) with motor powers of 1300 W and 3000 W, respectively. Electrofishing was employed in shallow littoral zones, vegetated areas, and inflowing or outflowing streams where nets could not be effectively used. Electrofishing was conducted more intensively in lakes Dres and Leità (40 and 20 sessions, totalling 120.0 and 62.3 h, respectively), whereas effort was substantially lower in lakes Miserino and Miserino-2, with only two sessions conducted in each lake (3.2 and 1.5 h, respectively). Population density was monitored using gillnetting data as catch-per-unit-effort (CPUE) as number of fish removed per day per square metre of net (No. of fish day^{-1} m^{-2}).

Evaluating the effects of angling sessions on the fish population

To evaluate the effect of angling on the whole fish population, the number, biomass, and size of fish captured during the angling sessions were compared with data from the first year of the eradication campaign and the remainder of the eradication campaign. The numerical and biomass contribution of anglers was calculated as the percentage of the total number

and total biomass of fish removed. Biomass estimation required some approximation: total length was recorded for all fish in a sufficiently preserved state to allow accurate measurement, but weight was measured only on a subset of well-preserved individuals, without loss of body fluids or body parts. For some fish—particularly those captured after the long winter period—preservation was so compromised that neither length nor weight could be measured. To estimate the biomass of fish lacking direct weight measurements, we proceeded as follows: for fish with length measurements but no weight, a length–weight relationship was calculated for each lake using the available data, and the expected weight was assigned to each individual. For fish lacking both length and weight measurements, the mean weight of fish captured on the same date and by the same method (gillnets or electrofishing) was assigned as a default. This approach allowed for a consistent estimation of total biomass despite incomplete measurements.

Monitoring ecological awareness in anglers

All participants in the angling sessions at lakes Miserino, Miserino-2, and Leità—the three most recent sessions, conducted in 2022 and 2023—were asked to complete a short questionnaire. The questionnaires were distributed prior to the general discussion held at the start of the angling days, to assess the participants' baseline awareness regarding the project objectives. The questionnaire consisted of two main sections. The first collected personal information, including nationality, city of residence, age, sex, education level, and occupation, with an option to decline answering each item. The second section comprised 12 statements related to attitudes, perceptions, and interests, which were conceived through discussion and agreement among the authors to target specific aspects of respondents' perspectives, including personal interest in recreational angling, ecological awareness, involvement in fish management, and attitudes toward the recreational use of natural areas. Respondents were asked to rate their agreement with each statement on a 10-point Likert-type scale ranging from 1 (completely disagree) to 10 (completely agree). An English translation of the statements is provided in Table 2, while the original questionnaire format is available in Online Resource 1.

The questionnaire had previously been submitted to the Project Core Team, whose responses reflect expert knowledge and management experience. This group included 14 individuals composed of technical and scientific staff directly involved in the eradication actions, as well as several university students participating in the project.

Anglers were re-contacted in the months following the angling sessions and asked to complete the same questionnaire again, to evaluate the effect of our initiative on attitudes or awareness. The effectiveness of the initiative was assessed by comparing the anglers' post-session responses to their pre-session answers (within-subject analysis) and by evaluating whether any changes brought their responses closer to the Project Core Team's reference responses.

To assess baseline differences between anglers and Project Core Team members, nonparametric

Table 2 List of the 12 statements included in the second section of a questionnaire administered to participants in the angling sessions organized in the Gran Paradiso National Park prior to eradication actions at lakes Miserino, Miserino-2, and Leità

Respondents were asked to rate their agreement with each statement on a 10-point Likert-type scale ranging from 1 (completely disagree) to 10 (completely agree)

	Statement
1	Recreational angling is my passion and my main hobby
2	Fish presence in high mountain lakes is a sign of a good ecological state
3	Fish stocking (fish introductions) in lakes and rivers is harmful for such ecosystems
4	I am more interested in freshwater fish than in other animals
5	I am a professional in nature conservation
6	I love observing nature
7	I am involved in fish management
8	I think recreational angling is cruel for fish
9	If a fish is not native to a certain river or lake, it should, if possible, be removed
10	I don't know anything about fish (say 1 if you know everything, 10 if you don't)
11	Sports in the mountains are my passion
12	Protected areas should provide more recreational opportunities for people

Wilcoxon rank-sum tests (Mann–Whitney U tests) were applied to each survey item (Q1–Q12). Overall multivariate differences across all questionnaire items were evaluated using a Multivariate Analysis of Variance (MANOVA). To visualize patterns of variation and group separation, a principal component analysis (PCA) was performed on all questionnaire responses, and the first two principal components were plotted to illustrate group clustering and relative positions of individual respondents.

For anglers who completed both pre- and post-angling questionnaires, Wilcoxon paired tests were used to evaluate within-subject changes across survey items. To verify the representativeness of the repeated-response subset, baseline responses of anglers who repeated the questionnaire were compared to those who did not use Wilcoxon rank-sum tests. All analyses were performed in R version 5.2.0 (R Core Team, 2025). Nonparametric tests were used due to the small sample size and the ordinal nature of the questionnaire responses, which may not meet the assumptions of normality required for parametric tests.

Results

Fish population characteristics and eradication dynamics

The number of fish removed, and their size distribution of *Salvelinus fontinalis* varied considerably among the four high-mountain lakes (Fig. 1; Table 3), with lakes Dres and Miserino hosting larger fish, while length–weight relationships had similar curve parameters among lakes.

By the end of the third or fourth field season, eradication was considered achieved (according to the operational criterion of one year of zero captures while maintaining constant eradication effort, as well as more than 10 years without any fish sightings) from lake Dres (2015), and catch-per-unit-effort had declined to, or near to zero in the remaining lakes,

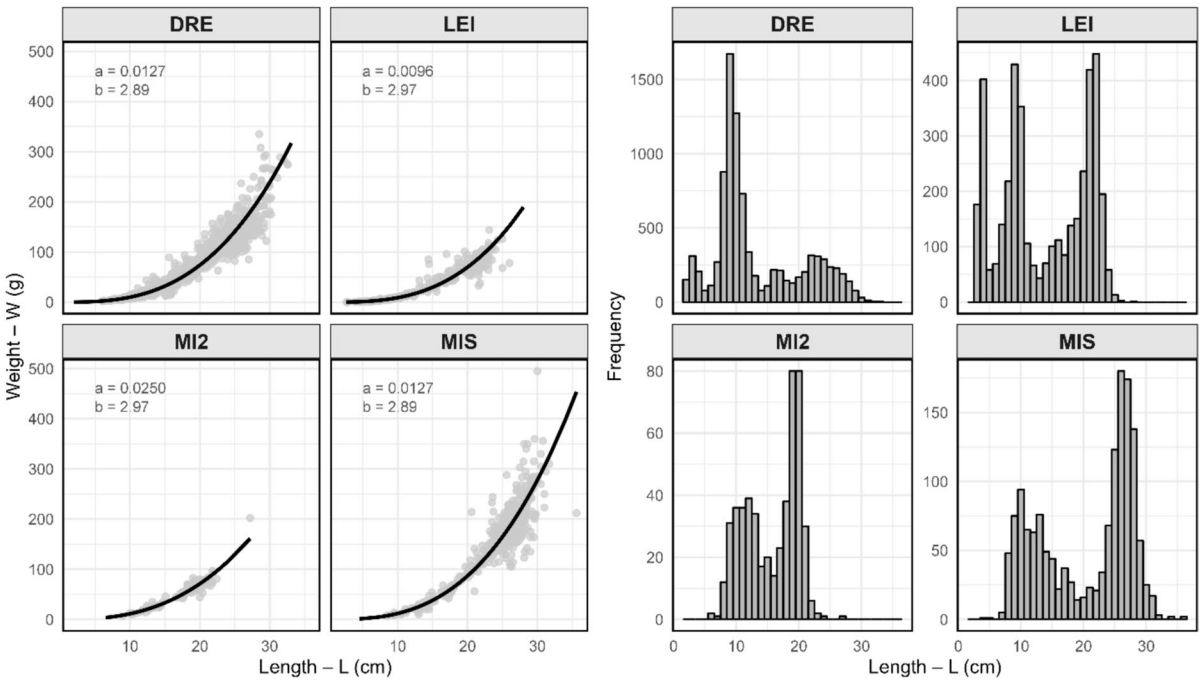


Fig. 1 Length–weight relationships ($W = a \cdot L.^{b}$) and total length distribution of brook trout *Salvelinus fontinalis* in four high-mountain lakes (Dres—DRE; Leità—LEI; Miserino—MIS; Miserino-2—MI2) treated for fish eradication in Gran Paradiso National Park, based on all available data from fish captured across the different methods employed (recreational angling, electrofishing, and gillnetting)

Table 3 Summary of the angling effort and brook trout (*Salvelinus fontinalis*) removal during two consecutive angling days (Day 1 and 2) and subsequent eradication efforts by gillnetting and electrofishing in four study lakes in the Gran Paradiso National Park (Western Italian Alps)

Lake	Dres			Leità			Miserino-2			Miserino		
Angling days	Day-1	Day-2	TOT	Day-1	Day-2	TOT	Day-1	Day-2	TOT	Day-1	Day-2	TOT
	22/06/13	23/06/13		22/7/23	23/07/23		19/08/22	20/08/22		19/08/22	20/08/22	
Angling sessions												
No. of anglers	21	14	30	29	11	38	1	6	7	5	10	15
Angling effort (Hours)	94.5	63.0	157.5	146.4	48.3	194.7	2	13.8	15.8	28.5	55.5	84
No. of fish removed	1217	456	1673	1309	258	1567	15	75	90	254	110	364
Biomass of fish removed (kg)	163.8	53.6	217.4	104.7	19.1	123.8	1.1	5.0	6.1	52.7	20.1	72.8
Angling CPUE (No. fish hour^{-1})	12.9	7.2	11.6	9.3	5.3	8.0	7.5	5.4	5.7	8.9	2.0	4.3
Gillnetting and electrofishing												
No. of fish removed	–	–	13,548	–	–	4664	–	–	578	–	–	1521
Biomass of fish removed (kg)	–	–	213.2	–	–	138.1	–	–	23.4	–	–	71.5
Tot												
Total No. of fish	–	–	15,221	–	–	6231	–	–	668	–	–	1885
Total biomass (kg)	–	–	430.6	–	–	261.9	–	–	29.5	–	–	144.3

CPUE capture per unit effort

indicating that eradication is complete or nearly complete at all sites (Fig. 2).

Did angling sessions effectively contribute to fish eradications?

Rod angling consistently captured the largest fish, while gillnets and electrofishing removed smaller individuals (Fig. 3). During the first year of eradication, rod angling removed a substantial share of total biomass across lakes (53.4 ± 15.3%, range: 35.6–70.1%), despite capturing only 34.1 ± 4.8% of the total number of fish, reflecting its preferential removal of larger individuals (Fig. 4). Over the entire eradication period, rod angling's contribution to biomass removal remained substantial (42.3 ± 18.7%, range: 20.6–63.4%), while its numerical contribution decreased by nearly half (17.4 ± 6.5%; Fig. 4). Although rod angling captured fewer small fish than the combined use of gillnets and electrofishing, it consistently removed a disproportionate proportion of total biomass across lakes, highlighting its strong size-selectivity and importance for biomass reduction (Table 3). During the angling sessions, catch per unit effort (CPUE; Fish hours^{-1}) substantially declined from the first to the second day of angling sessions, with a mean reduction of approximately 48 ± 21% (Table 3). Such reductions are consistent with early removal of the most readily catchable individuals, highlighting the potential for rapid short-term decreases in catch rates during consecutive angling sessions.

Did angling sessions change anglers' attitudes?

The study sample included 41 anglers and 14 members of the Project Core Team. Anglers were generally older (mean ± SD: 52.5 ± 17.2 years; range: 15–78), predominantly male (40 males, 1 female), and mostly had intermediate education (39 participants with

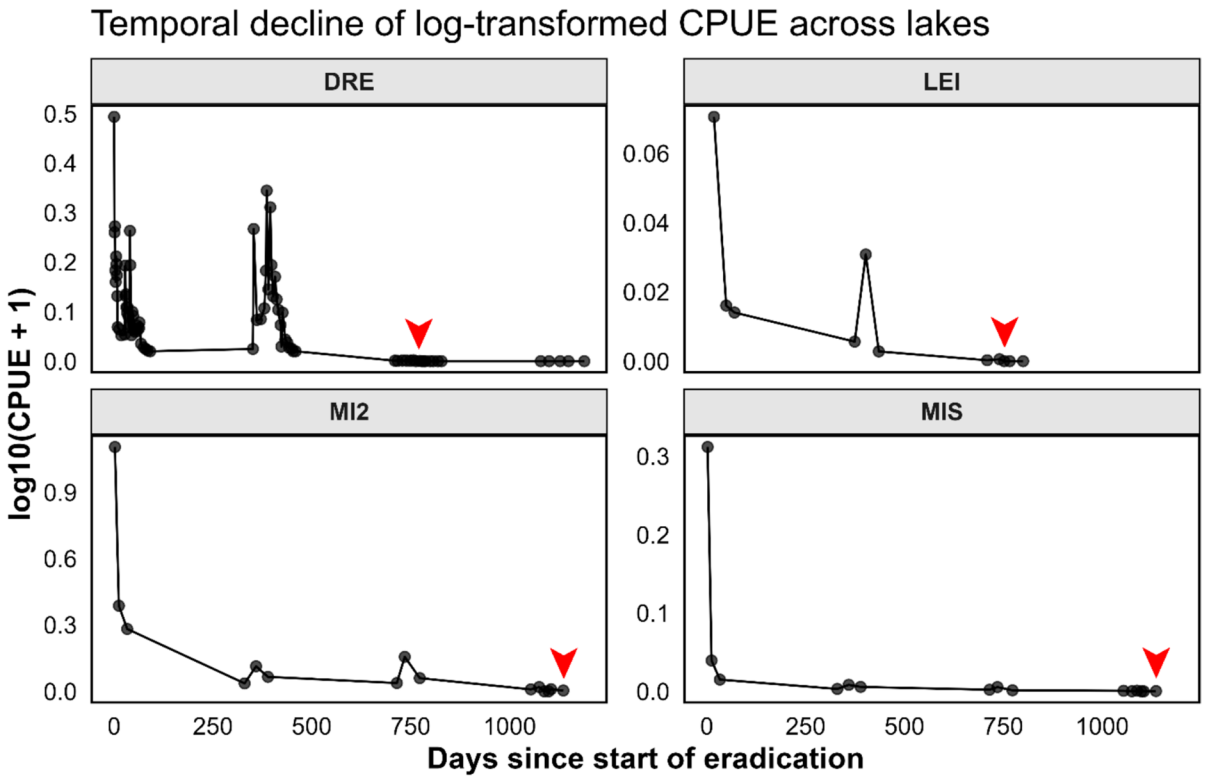


Fig. 2 Temporal decline of $\log_{10}$-transformed CPUE ($1^3 \times$number of fish captured$\times m^{-2}$ of nets$\times$day^{-1}) in four lakes (Dres—DRE; Leità—LEI; Miserino—MIS; Miserino-2—MI2) treated for non-native brook trout eradication in the Gran Paradiso National Park (Western Italian Alps). Day 0 was 24 June 2013 in lake Dres, 24 July 2023 in lake Leità, and 20 July 2022 in lakes Miserino and Miserino-2. Red arrows indicate the date of the last fish capture

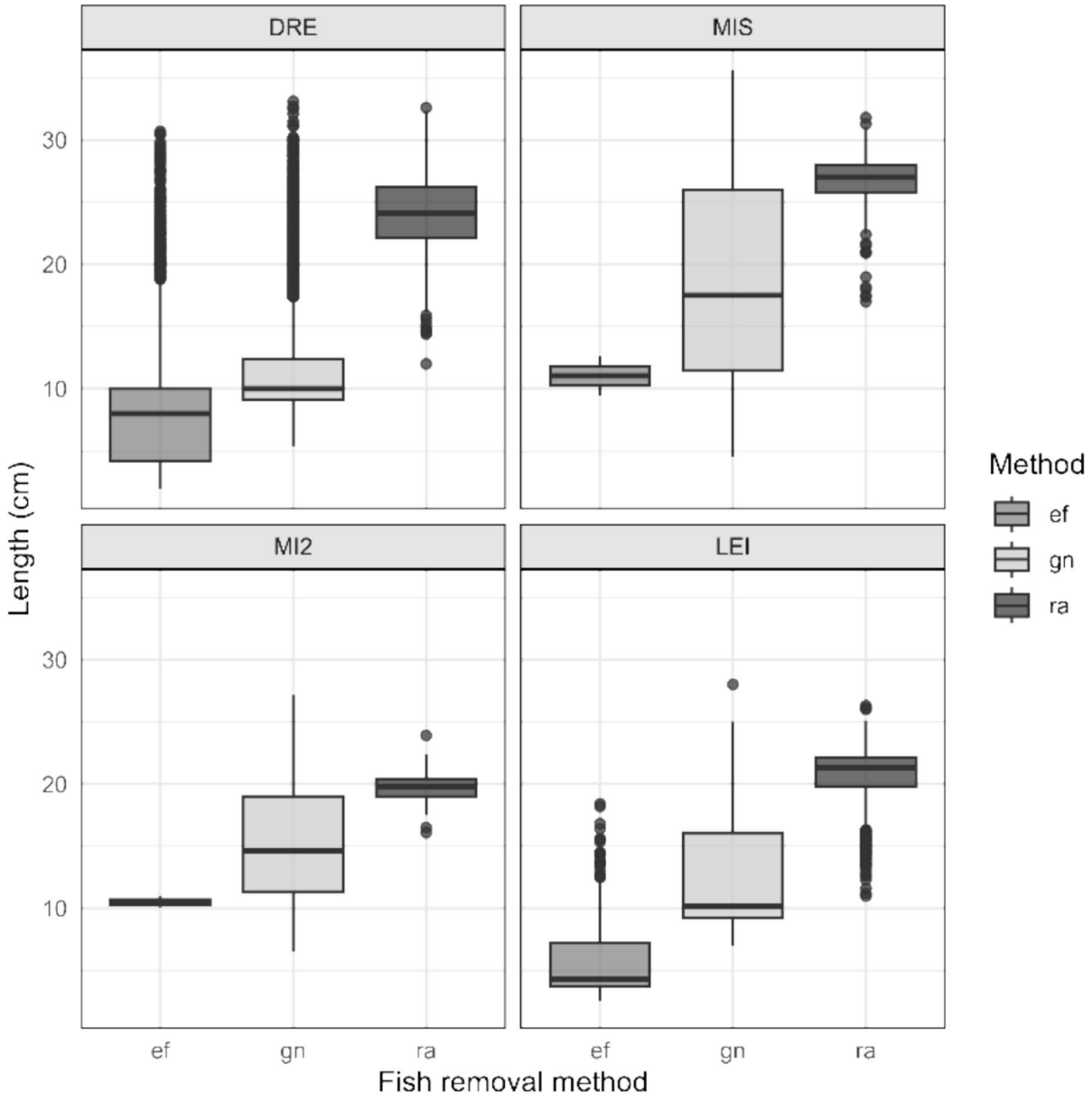


Fig. 3 Boxplots of fish lengths by removal method in four high mountain lakes (Dres—DRE; Leità—LEI; Miserino—MIS; Miserino-2—MI2). Rod angling (ra) removed significantly larger fish than gillnetting (gn) and electrofishing (ef) (ANOVA $F_{2,15393} = 49.06$, $p < 0.001$; Tukey HSD: ra > gn > ef, all $p < 0.001$)

lower or upper secondary school). Members of the Project Core Team were younger (31.1 ± 9.5 years; range: 21–53), more gender-balanced (6 males, 7 females, and 1 participant with unspecified sex), and had higher educational levels (3 with upper secondary school, 5 with a bachelor's degree, 3 with a master's degree, and 4 with a Ph.D.) in natural sciences, reflecting their status as subject-matter experts in biological and ecological sciences.

Prior to the educational angling sessions, the two groups differed in their questionnaire responses, showing a broad divergence in their perceptions and knowledge. Nonparametric Wilcoxon rank-sum test (Mann–Whitney U test) revealed statistically

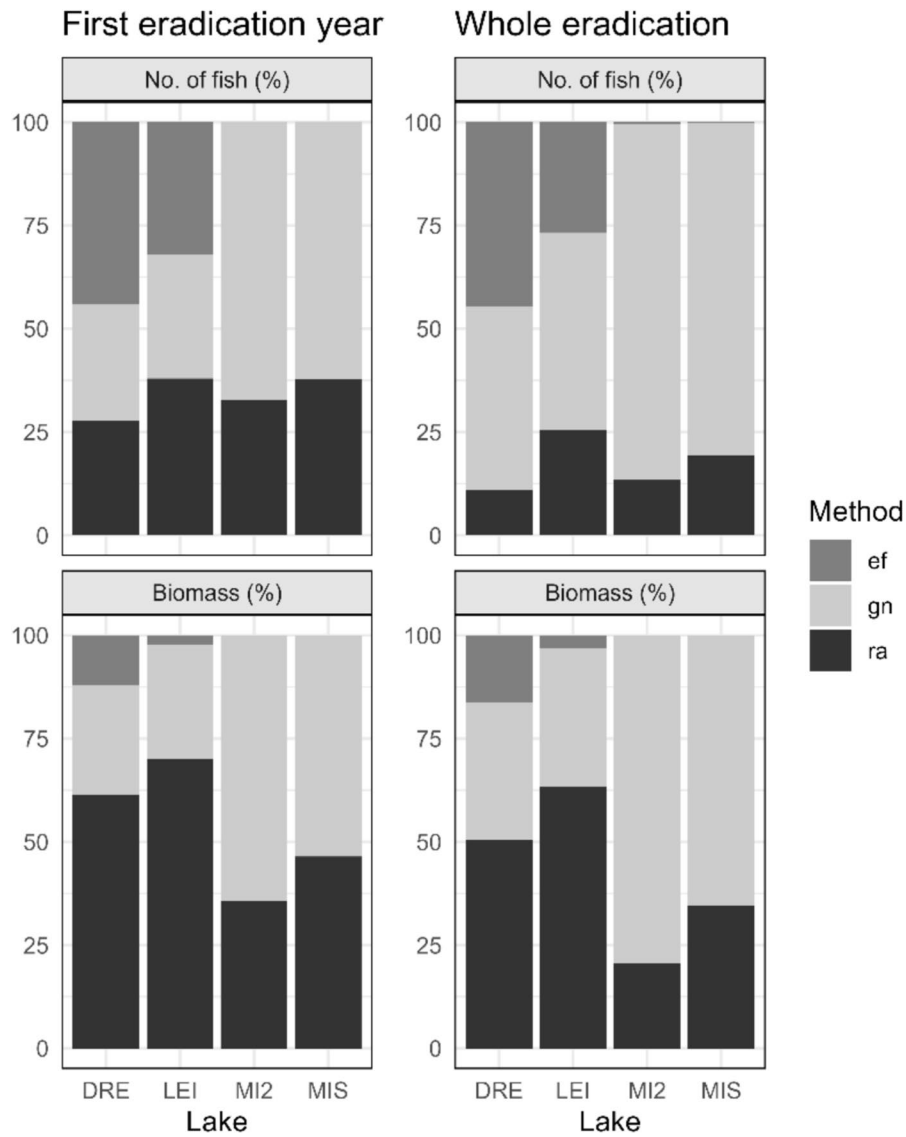


Fig. 4 Proportion of fish removed by road angling (ra), gillnetting (gn) and electrofishing (ef) during the first year of eradication and across the entire eradication period in four high mountain lakes (Dres—DRE; Leità—LEI; Miserino—MIS; Miserino-2—MI2). Values represent percentages of the total number of fish and biomass removed within each lake

significant differences for most questions, except Q5, Q6, and Q10, indicating substantial differences in most cases (Fig. 5a). These pronounced differences were further confirmed by a MANOVA, which showed a highly significant effect of respondent group on the combined set of questionnaire responses (Pillai's trace = 0.845, $F_{12,42} = 19.06$, $P < 0.001$). A complementary PCA further illustrates this clear separation, with anglers and Project Core Team members forming distinct clusters in the multivariate space defined by the first and second PCA axes, which explain 34.4% and 16.4% of the total variance, respectively (Fig. 5c).

Of the 41 participants who completed the first questionnaire, repeated (post-angling session) responses were obtained from only 14 respondents. Comparison of baseline responses between anglers who repeated the questionnaire and those who did not revealed no significant differences across any survey items (Wilcoxon rank-sum tests, all $P > 0.1$), suggesting that, despite the small sample size, the 14 anglers who repeated the questionnaire are broadly representative of the original group. Within this subset, Wilcoxon paired tests revealed limited overall changes (Fig. 5b), significant ($P < 0.05$) only for Q1 and Q11, corresponding to statements such as "Recreational

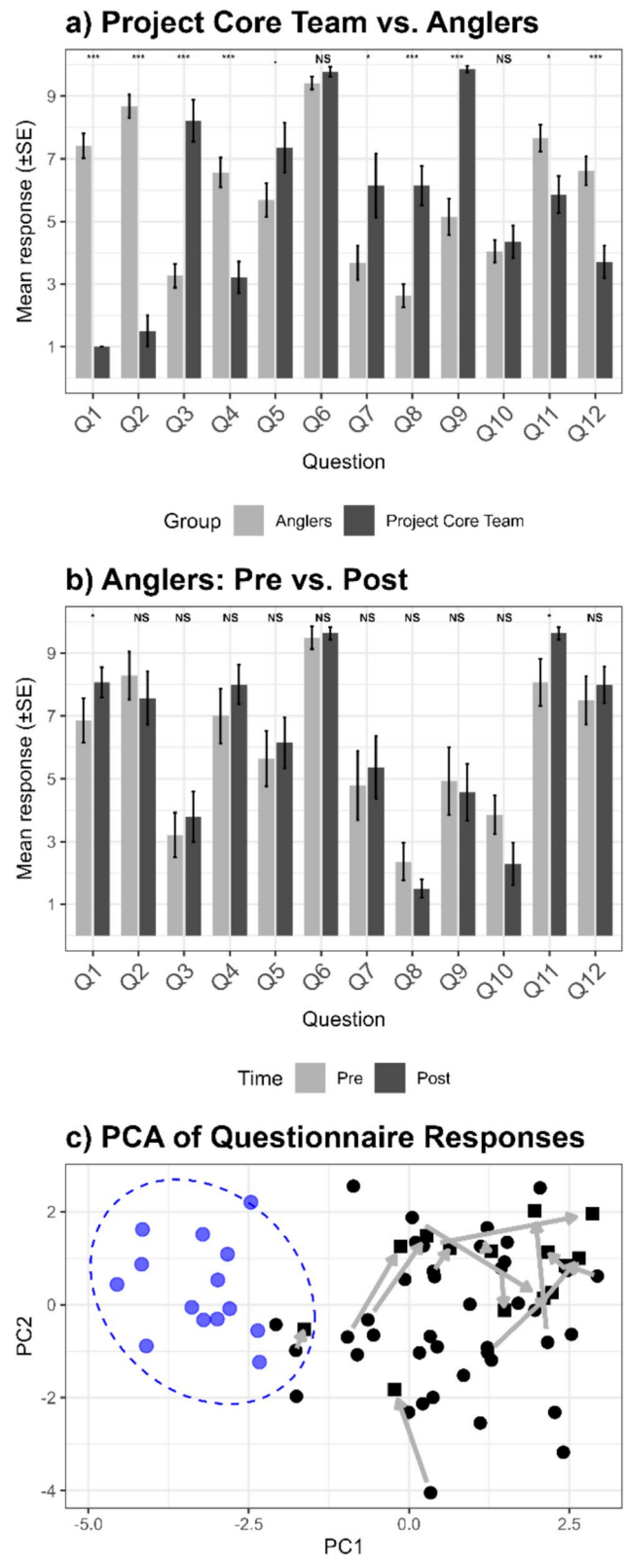


Fig. 5 Comparison of questionnaire responses and overall response patterns related to an educational initiative involving recreational anglers in the eradication of brook trout populations from high-mountain lakes in Gran Paradiso. Panel a: Mean responses (± SE) for Project Core Team (dark grey) and Anglers (light grey) prior to the educational angling sessions. Panel b: Mean responses (± SE) for Anglers pre (light grey) and post (dark grey) the sessions. Panel c: Principal Component Analysis (PCA) of all questionnaire responses. Project Core Team responses (blue circles) form a distinct cluster (enclosed by a blue dashed line) from Anglers' pre (grey circles) and post (grey squares) responses; arrows indicate the direction of change for each individual between pre- and post-session responses. Symbols for *P*-values: *** < 0.001, ** < 0.01, * < 0.05;.*P* < 0.1, NS non-significant

angling is my passion and my main hobby" (Q1) and "Sports in the mountains are my passion" (Q11) (Table 2). These limited changes did not align the anglers with the Project Core Team (Fig. 5c). Rather, the results suggest that the intervention may have reinforced anglers' enthusiasm for recreational fishing and outdoor sports. No other survey items showed significant pre–post differences, indicating that the initiative had limited impact on other attitudinal dimensions, including key issues such as ecological risks associated with introducing fish into alpine lakes, which remained unchanged despite the educational effort.

Discussion

Rod angling for fish eradication and awareness building

Rod angling proved a useful complement to the eradication actions, consistently removing the largest individuals and contributing disproportionately to total removed biomass, despite capturing fewer fish numerically compared to gillnets and electrofishing. These results confirm and extend the patterns first observed during the initial experimental angling sessions at lake Dres (Tiberti et al., 2017). The strong size selectivity of recreational hook-and-line angling is well documented (Tsuboi et al., 2021) and indicates that its primary utility in eradication actions lies in biomass reduction rather than in functioning as a stand-alone removal method; accordingly, recreational angling should be regarded as a complementary tool alongside other proven eradication techniques, which, unlike rod angling, can remove most of size classes and guarantee high capture effort even at low fish densities (Knapp & Matthews, 1998; Tiberti et al., 2019).

Importantly, the brook trout populations targeted in this study had never been previously fished and, as commonly observed in naïve or low–fishing-pressure systems, the absence of prior angling pressure likely contributed to the observed effectiveness of rod angling (Goedde & Coble, 1981; Tsuboi et al., 2016). Indeed, trout naïve to angling are known to exhibit little avoidance behaviour (Tsuboi et al., 2016), which in our case likely facilitated the capture of many large, and potentially bold, individuals. In contrast, other species or populations previously exposed to recreational fishing may respond differently, exhibiting learned avoidance, reduced activity, or decreased boldness (Tsuboi et al., 2016), ultimately lowering capture rates and biomass removal, and reducing both the efficiency and attractiveness of angling-based removal actions. In addition, our angling sessions were conducted shortly after ice-off, a period when fish may be particularly responsive to bait or lures, as they emerge from a prolonged period of food limitation and have not yet access to the abundant terrestrial insects that appear later in the summer and constitute an important component of their summer diet (Tiberti et al., 2016). Overall, these considerations suggest that the effectiveness and utility of recreational angling may be highly context dependent, being influenced by factors such as prior fishing pressure, population size and age structure, species-specific boldness, and seasonality. This context dependency may account for the initial scepticism expressed by some colleagues regarding the application of recreational angling to support eradication actions, as well as for their later recognition of its observed effectiveness, which contrasts with the prevailing perception of angling as a comparatively slow and inefficient removal method relative to passive gears, such as gillnets.

In contrast to the general practical utility of angling sessions, their educational component appeared largely ineffective in shifting participants' ecological knowledge or attitudes, with anglers' perceptions regarding ecological risks associated with introduced fish remaining largely unchanged. Several studies have shown that recreational anglers can be receptive to environmental education initiatives and participatory management approaches (Granek et al., 2008; Nguyen et al., 2013), sometimes even mobilizing significant conservation efforts (Bate, 2002). In this respect, our results are broadly consistent with the literature (Bate, 2002; Granek et al., 2008; Nguyen et al., 2013), as local anglers responded positively to our request to participate in the eradication actions. This indicates a clear willingness to engage, but note, however, that participation may partly reflect the opportunity to fish in the National Park rather than genuine conservation motives. Despite this positive response and against our hopes, active participation did not translate into a marked shift in attitudes toward key management issues, such as the

introduction of fish into mountain lakes, and the only significant change observed was an increased enthusiasm for angling and mountain outdoor activities. This general lack of attitudinal change is particularly noteworthy given that our initiative did not jeopardize any active fishing areas, as fishing was already prohibited within the park, a condition that was expected to facilitate greater receptiveness to conservation-oriented messages. This limited educational impact may reflect several factors, including pre-existing polarized opinions among participants, or the relatively short duration and single-format nature of the sessions. Taken together, these findings suggest that while direct involvement can be effective for initiating engagement, changing opinions on stocking practices and fish introductions likely requires longer-term, targeted educational efforts that extend beyond short-term participatory actions.

Implications for recreational fisheries management

Thanks to the successive 'total population sampling' made possible by the eradication efforts, our results provide a well-documented and compelling example of how recreational angling can act as a major and rapid source of disturbance for naturalized non-native trout populations in mountain lakes. Although our focal systems host non-native trout, the underlying mechanisms we observed likely apply as well to native populations of conservation concern inhabiting similar, colonizable lacustrine systems such as many boreal lakes. Our case studies show that even limited fishing pressure can selectively remove larger individuals, rapidly altering population size structure and substantially reducing total biomass. As noted above, this marked reduction may be context-dependent, reflecting species-specific traits, seasonal factors, and the lack of prior exposure to angling. For example, in previously exploited populations, outcomes may differ, as fish can learn to avoid capture and become less catchable over time (Tsuboi et al., 2016; Klefoth et al., 2017; Monk et al., 2021). However, the observed short-term structural shifts are consistent with patterns commonly reported in inland and mountain lake fisheries, where stock depletion and declining catch rates represent recurrent management concerns (Erhardt & Scarnecchia, 2014). A popular, operationally straightforward response to declining population abundance and reduced recreational quality is restocking with hatchery-reared fish, an ecologically disruptive practice (Eby et al., 2006; Lewin et al., 2006; Ventura et al., 2017; McEachran et al., 2023).

The observed vulnerability of introduced fish populations to rod angling is highly relevant from a conservation perspective, both for native populations (e.g., in boreal lakes) and, albeit only apparently paradoxically, for introduced ones. Current management of recreational fisheries is often driven by pragmatic considerations and still relies on practices such as restocking, despite their well-known ecological drawbacks. Moving toward a more conservation-oriented framework, managers should instead aim to limit the expansion of non-native fish (e.g., through regulation and eradication where feasible, such as in protected areas; Tiberti et al., 2021), while maintaining systems capable of supporting recreational use without resorting to ecologically harmful practices (Ventura et al., 2017). The demonstrated vulnerability of these populations thus represents both a constraint and a management challenge, potentially requiring rigorous mitigation measures, including reduced harvest pressure, catch-and-release regulations, and temporary or permanent closures (Monk et al., 2021; Xiong et al., 2026).

Conclusions

Overall, rod angling emerges as a convenient and valuable complement to structured eradication methods, offering practical benefits without apparent negative effects, e.g., without protests regarding temporary exemptions to the fishing ban in the park. However, its educational role appears modest, and both its practical and educational outcomes are likely to be strongly context dependent. Accordingly, practitioners planning similar initiatives should carefully assess their specific operational contexts, avoid assuming that participation alone will yield educational outcomes, and instead invest explicitly in structured and sustained educational efforts.

At the same time, our results highlight how even limited recreational angling pressure can rapidly alter trout population structure and biomass in mountain lakes, with important implications for both conservation and fisheries management. These findings

reinforce the need for more precautionary and conservation-oriented management strategies.

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Data availability All relevant data are contained in the article.

Declarations

Competing interests No competing interests.

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