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Involvement of recreational anglers in the eradication of alien brook trout from high-altitude lakes

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ABSTRACT

Stocking programmes for recreational angling are primarily responsible for the spread and ecological impact of introduced fish in high-altitude, originally fishless lakes. In 2013, the Gran Paradiso National Park started an eradication campaign of brook trout by intensive gill-netting. Local anglers were invited to attend two angling sessions to start the eradication before gill-netting in an experimental lake, as part of an education action devoted to these critical stakeholders. The angling sessions turned out to be a valuable help for the eradication campaign and the aim of this study is to report on the outcomes of these angling sessions. Angling techniques were highly size-selective, removing a substantial part of the adult population and of the fish biomass, but their contribution to the eradication of small fish (<15cm) was irrelevant. Therefore, angling cannot completely eradicate age-structured populations. However, there is scope to use angling sessions as a support for eradication campaigns and as an emergency measure for recent fish introductions. Similar actions should be considered whenever a fish eradication programme is planned. These findings, however, do not imply a general endorsement for angling within protected areas.

Keywords: *Salvelinus fontinalis*, environmental education, fishery management, Gran Paradiso National Park, LIFE+ Bioaquae, protected areas

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1 INTRODUCTION

Institutional stocking programmes and fish translocation for recreational angling are largely responsible for the spread of introduced fish in high-altitude, once fishless lakes (Miró and Ventura, 2015). Usually, introduced fish exert a negative impact on native biota, leading to the extinction of many prey taxa and to a profound degeneration of the whole ecosystem (Knapp *et al.*, 2001; Tiberti *et al.*, 2014a). Recent studies suggest that a ban on angling and fish stocking is an effective strategy to control fish introductions and preserve biodiversity in high mountain lakes (Wiley, 2003; Miró and Ventura, 2013, 2015; Knapp *et al.*, 2016). Moreover, due to their relatively small size and to the regular presence of downstream ecological barriers preventing fish recolonization (Adams *et al.*, 2001), eradicating introduced fish is a realistic, well-documented conservation action in high-altitude lakes (Knapp and Matthews, 1998; Knapp *et al.*, 2001; Parker *et al.*, 2001; Vredenburg, 2004; Toro *et al.*, 2006; Pacas and Taylor, 2015; Tiberti *et al.*, 2017). These conservation measures can potentially produce a conflict between conservation interests and a part of the angling world. There is, therefore, an urgent need to direct educational and dissemination actions towards recreational anglers, to increase their awareness of the environmental threat represented by the introduction of alien species.

These considerations were clear to the Gran Paradiso National Park (GPNP, North-Western Italian Alps) Authority when an eradication campaign of introduced brook trout *Salvelinus fontinalis* (Mitchill, 1814) in four alpine lakes was started within the framework of the EU LIFE+ project BIOAQUAE (Biodiversity improvement of Aquatic Alpine Ecosystems, www.bioaquae.eu). Brook trout were introduced in GPNP in the 1960s and established reproductive populations in several of the stocked lakes. Introductions were stopped and a fishing ban was established in the 1970s, but the established brook trout populations still produced negative ecological consequences for the stocked lakes (Tiberti and von Hardenberg, 2012; Magnea *et al.*, 2013; Tiberti *et al.*, 2014a). Intensive gill-netting and electrofishing have been chosen as non-invasive eradication techniques (Knapp and Matthews, 1998) for the GPNP brook trout eradication plan. These methods provide sufficient guarantees for the conservation of non-target species (e.g. amphibians and aquatic invertebrates; Knapp and Matthews, 1998; Parker *et al.*, 2001; Vredenburg, 2004).

Due to the potential unpopularity of the project, the GPNP drafted a *Risk Management Plan* (included in GPNP, 2011) to avoid the risk of sabotage (e.g. vandalism on the capture devices, re-stocking of fish). One of the planned actions was to involve the local recreational anglers, to explain to these critical stakeholders the scientific and conservation value of the eradication action. Looking for an attractive and engaging way to disseminate these arguments, the local anglers were invited, through the involvement of their association, to help with the actual eradication action in an experimental lake (Lake Dres), using recreational angling techniques (fishing rods) before the nets were set in the lake.

This experience, initially designed as an education action, turned out to be a valuable help for the eradication campaign. The aim of this paper is to report on the outcomes of these two days of rod-angling sessions and on their impact on the eradication process. The importance of the local context when similar actions are taken into consideration is also discussed.

2 METHODS

2.1 Study lake

The experimental Lake Dres (latitude N 45°24′45″; longitude E 07°13′25″; altitude 2,087 m a.s.l.; surface: 2.6 ha; maximum depth: 7.4 m; Tiberti et al., 2010; Figure 1) lies at the edge of the GPNP. Lake Dres lies at the local timberline and is a typical alpine lake with low nutrient content (mean ± *SD* phosphorus concentration = 4.3 ± 2.5 µg L^{-1}; N = 22) and conductivity (mean ± *SD* conductivity at 20 °C = 24.9 ± 6.9 µS cm^{-1}; N = 22), and well oxygenated, transparent (light attenuation coefficient – k = 0.29 ± 0.08; N = 17), and circumneutral (pH = 7.0 ± 0.5; N = 22) waters (measures from a monitoring campaign from 2008 to 2016, *unpublished data*).

Due to the presence of several metres-high waterfalls along the outflowing stream, Lake Dres was completely isolated from the downstream fish populations and was originally fishless. Its stocking history is uncertain. The first brook trout introduction date back to the 1960s, but subsequent fish introductions have probably occurred before and after its inclusion in the GPNP territory (1979), because

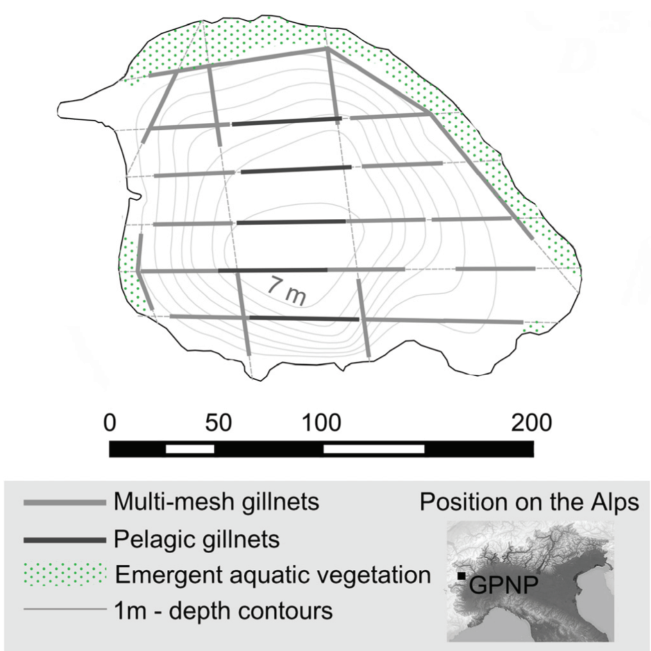

Figure 1 Lake Dres bathimetry and positioning scheme of the nets used to eradicate the introduced population of *S. fontinalis*.

of some disputes concerning the borders of the protected area, which were finally resolved in the early 2000s. Since then, fishing and stocking have been strictly prohibited. The fish community was dominated by *S. fontinalis* (>99.9%), but four marble trout (*Salmo marmoratus*, introduced in the early 2000s), one minnow (*Phoxinus* sp.), and one brown trout (*Salmo trutta*) were also found during the eradication campaign (2013–2016). The latter species were probably intentionally or incidentally introduced by poachers in the previous years. Prior to the eradication activities, the native community of the lake (e.g. crustacean zooplankton, aquatic invertebrates, and common frog *Rana temporaria*) was strongly impacted by the presence of introduced fish (Tiberti and von Hardenberg, 2012; Tiberti *et al.*, 2014a).

2.2 Angling sessions

In preparation for the angling sessions, a meeting with the local angler association "Associazione Pesca Sportiva Locana (Turin)" was organized on 21 May 2013 by the GPNP directorate and the scientific staff to meet the local anglers and to:

1. explain to them the impact of brook trout on alpine lake ecosystems (see Tiberti and von Hardenberg 2012; Magnea *et al.*, 2013; Tiberti *et al.*, 2014a);
2. explain in detail the conservation reasons and the expected results of the eradication action;
3. organize two experimental angling sessions at Lake Dres;
4. define some rules for the field work.

The use of live fish as bait was prohibited (while the use of invertebrate live baits and artificial baits was allowed, with no restrictions in hook size), the fishing area was limited to the lake's shores and tributaries (up to the cascade along the outflowing river), the anglers had to register themselves to obtain a nominal fishing permit exclusively for those two days, and they had to wear a harness with the GPNP symbol that would make them recognizable. Anglers were allowed to take away all the caught fish after the scientific staff completed the measurements of fish length and abundance. To prevent anglers restocking the lake in the hope of enjoying other special fishing permits after the eradication campaign, they were informed that not for any reason would the fishing sessions be repeated in Lake Dres.

A quantification of the educational efficacy of the preparatory meeting and of the angling sessions was not provided, but we are reasonably confident that the initiative has been helpful to educational purposes, or at least that it did not worsen the conflict with anglers.

Twenty-one and fourteen anglers took part in the angling sessions respectively on 22 and 23 June 2013. The fishing session lasted the same in both days (4.5 hours, from 11:00 to 15:30). The Park's wardens monitored the respect given to the agreed rules. The scientific staff measured the total length of all captured fish to the nearest millimetre (±1 mm) and the weight to the nearest gram (±1 g) of the 9% of captured trout.

2.3 Eradication methods

The eradication, undertaken with intensive gill-netting and electrofishing (Tiberti *et al.*, 2014b), started on 24 June, 2013, just after the two days angling sessions involving the local anglers. Twenty-five multi-mesh gill-nets (36 × 1.8 m, divided into 6 panels with increasing mesh size: 10.0, 12.5, 18.5, 25.0, 33.0, 38.0 mm) and 5 larger gill-nets (50 × 4 m, mesh size: 25 mm) were fixed to the shore with ropes, along nine transects each holding 1–6 nets (Figure 1), and were left in the lake for the whole duration of the project, including the ice-cover season (October–May). Seven additional multi-mesh gill-nets were used to increase the capture efforts in the littoral aquatic vegetation, which provided a refuge for a large number of brook trout (Tiberti *et al.*, 2017). During the 2013–2016 ice-free seasons, captured fish were regularly removed from the nets during 78 field surveys (38 in 2013, 20 in 2014, 15 in 2015, and 5 in 2016). Electrofishing (with an ELT62 II 160 GI backpack equipment) was used in the littoral area (e.g. littoral vegetation) and along the tributaries. Thirty-nine electrofishing sessions were performed (7 in 2013, 14 in 2014, 16 in 2015, and 2 in 2016). Following Knapp *et al.* (2001), one year without fish captures using all the capture devices was set as the minimum period of time that must pass in order to declare the end of the eradication process.

The brook trout population density was monitored along with the eradication process using Catch Per Unit Effort (CPUE) as an index of abundance (Radovich, 1976). CPUE was expressed as the number of fish captured per square metre of net per hour. For the calculation of the CPUE the fish catches from the nets placed in the littoral vegetation were excluded, since the reduced depth in this area (smaller than the height of the nets) did not allow us to control for the capture surface.

2.4 Assessment of the impact of the angling sessions on the fish population

To assess the impact of the anglers on the Lake Dres brook trout population, the maximum fish length was converted into five size-classes encompassing the values from <15 cm to ≥30 cm at 5-cm intervals. Then the percentage of fish belonging to each size-class and removed by anglers was compared to the total number of fish caught during the first field season of the eradication campaign (June–September, 2013). The data from the 2014–2016 field seasons were not included in this comparison due to fish growth from one season to the next, which would have required a back-calculation of the fish size at the dates of the angling sessions to assign them to a size-class. Indeed, in the absence of scalimetric/otholith rings measures (Panfili *et al.*, 2002), it was not even possible to know if the smaller fish caught in the following years were already born in the summer of 2013. However, the very large majority of larger >15 cm fish (98.5 %) – including the size-classes actually affected by anglers – was captured during the first field season; therefore, including the fish caught in 2014 and 2015 – almost exclusively <15 cm long fish (Figure 2c) – would be virtually irrelevant for the calculation of the contribution of the angling sessions to the overall eradication programme. The data from the second and third field season are however reported, to get a complete picture of the progress of the eradication.

The weight of each fish removed by anglers was calculated from their total length using the exponential length (L)–weight (W) relationship $W = 2.31e^{0.168L}$ estimated for the brook trout of Lake Dres (Tiberti *et al.*, 2017). Total biomass of fish removed by anglers was calculated by summing up all the individual weights. To assess the impact of the angling sessions on the biomass of the brook trout population, we compared the total biomass of the fish captured by anglers with the estimated total biomass of fish removed from Lake Dres at the end of the first year of the eradication campaign (361 kg) and at the end of the eradication campaign (476 kg; biomass estimates from Tiberti *et al.*, 2017).

3 RESULTS

During the angling sessions, a total of 1,672 fish were caught (Table 1). Angling was highly selective towards larger fish (mean size ± SD = 24.1 ± 2.9 cm; size range 12.0–32.6 cm; Figure 2c). During the second day, a reduction of the fishing efficiency was already observable, as well as a reduction of the mean size of captured fish (unpaired t-test, t = 8.26, df = 1,671, $p < 0.001$; Table 1). The angling sessions removed the 27.8 % of brook trout captured in the first field season (Table 2), accounting for the 60.5 % (218.5 kg) of their total biomass. These percentages decrease to 9.1 % and 45.9 % considering all the fish captured along the eradication campaign. The contribution of the anglers to the eradication efforts of the first field season was almost irrelevant (0.2 %) for the smallest size-class (<15 cm), but it increased up to 80.8% for the larger size-classes (Table 2).

By the end of June 2016, a total of 15,220 brook trout were captured in Lake Dres (Figure 2a and 2b). In addition to the 1,672 fish captured during the angling sessions, 6,758 fish (mean size ± SD = 13.2 ± 7.0) were captured with the nets, and

Table 1 Outcomes of the angling sessions at the Lake Dres. CPUE: capture per unit effort (number of fish (N) per hour (h) per angler (A)).

	22 June	23 June
Number of anglers (A)	21	14
Fishing time	4h 30′ (from 11:00 to 15:30)	4h 30′ (from 11:00 to 15:30)
Number of fish (N)	1,217	455
CPUE ($N \times h^{-1} \times A^{-1}$)	12.9	7.2
Mean total length ± SD (cm)	24.5 ± 2.8	23.1 ± 3.1
Total length range (cm)	12.0–32.6	14.4–31.2
Total biomass* (kg)	166.7	51.8

* Calculated from total length measures using the exponential length–weight relationship estimated by Tiberti *et al.* (2016a).

Table 2 Summary of the contribution of the angling sessions to the eradication of the brook trout from Lake Dres during the first field season (June–September 2013) in relation to fish maximum length (L) size-classes. N1: number of fish captured by anglers on 22–23 June 2013; N2: total number of fish captured during the 2013 field season (21 June–26 September 2013).

Size-classes	N1	N2	%
Class 1 (L ≤15cm)	6	3,074	0.2
Class 2 (L ≤15 to <20 cm)	120	797	15.1
Class 3 (L ≤20 to <25 cm)	874	1,311	66.7
Class 4 (L ≤25 to <30 cm)	651	806	80.8
Class 5 (L ≥30 cm)	21	35	60.0
TOTAL	**1,672**	**6,023**	**27.8**

6,790 (mean size ± SD = 8.4 ± 5.4 cm) during the electrofishing sessions (3,045 from the littoral area, 1,693 from the tributaries, while the capture point was not recorded for the remaining 2,052 fish). The CPUE (based on the gill-netting data) reached zero during the third field season (6 August 2015) (Figure 2a and 2b), but the last fish was captured on 11 August 2015 during an electrofishing session along the main tributary. After catching the last fish, all the tributaries were electrofished 9–11 times without catching any fish from August 2015 to September 2016. At the end of the fourth field season (October 2016), more than one year without fish captures had already passed. The nets will be kept in the lake until summer 2017, to ensure complete eradication and to detect any illegal fish re-stocking. The vast majority (99.5%) of the fish captured after the first field season were less than 15 cm long (Figure 2c).

4 DISCUSSION

4.1 Anglers' contribution to fish eradication

Angling was highly selective towards larger fish, but at the same time it was very efficient, with a high number of fish captures in a very short time. The number of fish captured by rod angling was high enough to represent a substantial help to eradication activities. However, there are a number of factors suggesting that, even if angling can represent a valuable support, it cannot replace other proven eradication techniques, such as gill-netting in high-altitude lakes. Indeed, eradication techniques have to be efficient and have a low degree of size selectivity (Knapp and Matthews, 1998). Angling shows only one of these characteristics (time efficiency) and also this feature is limited to the starting period of the eradication when densities of large fish are high. It is indeed impractical to maintain a high capture effort (many voluntary anglers) for a long time, especially when capture rates become low or near to zero. Therefore, the present study shows that angling

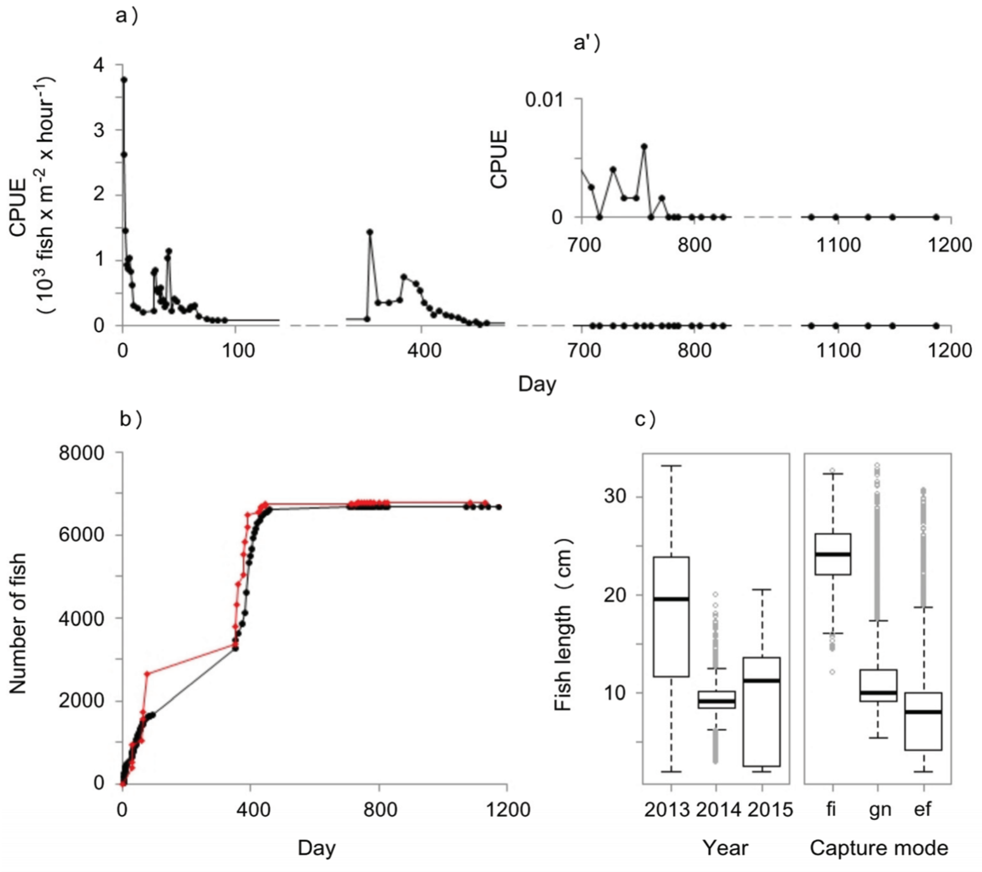

Figure 2 Progress of the brook trout eradication activities in Lake Dres. Panel a) Capture Per Unit Effort – CPUE trend from 24 June 2013 (Day 0) to 25 September 2016 (Day 1,187). The dashed parts of the x axis indicate the ice covered period, when it is impossible to carry out the surveys. Panel a') CPUE trend during the 2015–2016 field seasons: the y axis has been rescaled to highlight the trend approaching 0. Panel b) Cumulative number of gill-netted (black curve) and electrofished (red curve) fish along the eradication campaign. Panel c) Box plots showing median (solid line), first and third quartiles (box outlines), median ± 1.5 x Inter Quartile Range / √ sample size (wiskers), and outliers (empty circles) of the size distribution of the brook trout captured during the 2013–2015 field seasons and using different capture modes; fi: fished by anglers; gn: gill-netted; ef: electrofished.

can provide a useful initial support for eradication activities, but cannot be used as an eradication method by itself for age/size-structured fish populations in high-altitude lakes.

The high number of captured fish is a first prominent output of the angling sessions and it is certainly related to the high density of the population inhabiting Lake Dres and perhaps to the fact that the brook trout population had not experienced angling for more than a decade. The number of fish in Lake Dres was indeed exceptionally high (15,220 fish captured in total at the end of the 2016 season): for example it is higher than the total number of brook trout captured at the end of the eradication actions in similarly sized or even larger lakes [e.g. ≈3,500 brook trout captured in Lake Leynir (GPNP, Italy; 4.6 ha; 22.1 m maximum depth; *unpublished data*); ≈1,600 brook trout from both Lower (9.7 ha; 6 m maximum depth) and Middle (23.1 ha; 25 m maximum depth) Devon Lakes (Alberta, Canada; Pacas and Taylor, 2015); 261 brook trout from Bighorn Lake (Alberta, Canada; 2.1 ha; 9.2 m maximum depth; Parker *et al.*, 2001); 97 brook trout in Maul Lake (California, USA; 1.6 ha; 6 m maximum depth; Knapp and Matthews, 1998)].

A second point is that the captured fish represent a substantial fraction of the adult brook trout population inhabiting Lake Dres and of its total fish biomass. Moreover, angling was from the bank only, whereas netting was across the lake as well as from the shore, so perhaps, considering the fished area, the provided percentages could underestimate the capture efficiency of angling. Angling can strongly affect the density of larger fish and – only when larger size-classes are dominant – of the whole fish population. In Lake Dres, the angling sessions determined a rather limited fish density reduction, because the fish population was dominated by small fish. However, in some rare cases, large size-classes can strongly dominate the populations inhabiting high-altitude lakes (e.g. Lake Nero, GPNP; Tiberti *et al.*, 2017), due to the fact that annual population recruitment can completely or almost completely fail (in the presence of unfavourable climatic or hydrological conditions, or when the juvenile cohort are completely cannibalized by adult fish due to lack of adequate refugia (Hall, 1991). In these cases, angling sessions could reduce introduced fish populations to very low abundances, hypothetically, even below their minimum viable population size. The same finding could support the use of angling for eradicating/reducing the density of many non-reproductive populations of recently introduced fish, without waiting for their natural disappearance and avoiding a series of short-term, maybe irreversible impacts (e.g. the rapid disappearance of pedomorphic amphibians; Denoël *et al.*, 2009). Following along the same line, angling sessions could also be used as an emergency measure for very recent undesired introductions of potentially reproductive fish. For example, angling sessions might be used to break down the density of the founder population at very low levels, before the first successful reproductive event, and potentially affect its establishment in the lakes.

Altogether, the strong size selectivity of angling towards larger fish represent an important limit for using angling techniques against introduced fish populations. From the point of view of recreational anglers, there is no attraction to capture small fish, therefore anglers use relatively big hooks to target for big fish. Perhaps, if properly instructed, anglers could also target smaller fish using smaller hook sizes (for hooks size-selectivity, see Millar and Fryer, 1999; Lippolt *et al.*, 2011). However, even if using smaller hooks can increase the size range of captured fish, very small fish – feeding on microscopic preys such as zooplankton (Tiberti *et al.*, 2016) – would still remain unaffected, still requiring the use of more conventional eradication techniques (e.g. gill-netting and electrofishing).

When the high-altitude lakes host a well-established reproductive and age-structured fish population intended to be eradicated, the angling sessions can save considerable time and energy and increase the probability of a successful eradication. In Lake Dres, the eradication personnel (≈4 full-time technicians) would have needed several days to capture with gill-nets the same quantity of brook trout. In this sense, anglers' help could be more useful in the lakes with dense fish populations, where a lot of time can be saved by removing many fish, but the same initiative would represent just a little help in a lake containing just a small amount of fish.

The high number and proportion of adult brook trout captured within the few hours during the angling sessions indicate that angling has the potential for easily altering the population density and structure of introduced salmonids in high-altitude lakes, as reported in other study cases (Lewin *et al.*, 2006 and contained references). One could speculate that angling could reduce the density of introduced populations and therefore their ecological impact. However, the removal of larger size-classes does not necessarily involve an overall density reduction (Hall, 1991). On the contrary, the selective capture of large individuals could enhance the survival and thus increase the density of smaller size-classes (due to competitive release and to the reduction of cannibalism on younger fish; Hall, 1991). This is probably what happened in Lake Dres, where a recruitment spike probably produced the very high capture rates of small fish during the second year of eradication (Figure 2a and 2c). The potential of angling as a method for reducing the density of introduced fish populations and consequently their ecological impact in high-altitude lakes should be addressed in detail (e.g. comparing the ecological impact of introduced fish in lakes contrasting for their conservation regimes: angling prohibited vs. permitted) and the results of the present study do not provide any kind of indication in this sense.

4.2 Importance of the local context

The present case study shows that the involvement of local anglers in fish eradication programmes in high-altitude lakes is a valuable option worth considering. However, the local context plays a very important role in this delicate decision-making process. Indeed, conservation instances are often in contrast with recreational angling interests and management actions, and in particular with the common practice of fish introductions in once fishless freshwaters (e.g. mountain streams and lakes; Miró and Ventura, 2015). Therefore, if not well explained, the decision to involve anglers could be erroneously perceived as an endorsement for angling activities in stocked, naturally fishless water bodies, or, in very conflictive contexts, even as a provocation.

The Gran Paradiso National Park is an old protected area (established in 1922) and a restrictive fishing ban is guaranteed by a large number of wardens and the particularly severe regulation, at least since the 1970s. In this context, the decision to eradicate some populations of brook trout, apparently, did not meet a strong opposition. However, as usual in eradication projects (Carrion *et al.*, 2011), when the fish eradication was planned, beside the natural risk of failure, the *Risk Management Plan* (GPNP 2011) contained some indications to minimize the potential opposition of some parts of society (in particular of the anglers) and the connected risk of sabotage of the eradication actions. For this purpose, the four lakes chosen for eradication were at least an hour's walk from the nearest road (to discourage the transport of fish to restock the lakes), the GPNP wardens devoted special attention to the surveillance of the area surrounding the lakes, and a series of education actions, some of which were dedicated to the anglers, were planned. Overall, the level of conflict has always remained at very low levels. The little opposition that the GPNP encountered largely depends on this favourable local context. In other cases, it is essential that, whenever an eradication action is started, legislative constraints (including a fishing ban and the prohibition of fish stocking) are already in place and surveillance personnel should be in a position to enforce them. If these fundamental guarantees are absent or weak, it could be difficult to manage the risk of sabotage, and the local context might suggest deferring the project to future times. In all the other cases, education is probably the principal instrument to increase the public awareness of anglers and the organization of some angling sessions, under the strict control of the local conservation authorities, could also serve as a management tool.

However, in recently established protected areas (where the fishing bans are recent and not yet fully accepted by the anglers) and, in general, in other more conflictive contexts, the opportunity of involving anglers in eradication actions should be evaluated with care to avoid counterproductive effects on the project.

5 CONCLUSIONS

The involvement of local anglers can help with the eradication of introduced fish from high-altitude lakes. However, angling cannot be considered as an exclusive eradication method for well-established fish populations, but just as an accessory method supporting fish eradication and potentially saving a lot of time and energy in the first phases of the eradication programme. Potentially, however, there is scope to use rod-angling sessions as an emergency measure for very recent introductions. The organization of the angling sessions should be taken into account whenever a fish eradication action is planned, but the local context should be considered to avoid such an initiative being misperceived as an endorsement for angling in protected areas.

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