Journal of Mountain Ecology, 9 (Autumn 2013): 61–74

Preliminary studies on fish capture techniques in Gran Paradiso alpine lakes: towards an eradication plan

Rocco Tiberti*, Emanuele Acerbi and Rocco Iacobuzio

DSTA, Dipartimento di Scienze della Terra e dell'Ambiente, University of Pavia, Pavia, Italy

ABSTRACT

The Gran Paradiso National Park (GPNP) has recently approved an eradication plan, financed within the LIFE+ project BIOAQUAE (Biodiversity Improvement of Aquatic Alpine Ecosystems), to restore some mountain lakes impacted by the introduction of brook trout (*Salvelinus fontinalis*). This extensive eradication project involves the use of intensive gill netting as a non-invasive conservation measure. The aim of this study is to support, with technical data, the choice of the capture devices needed for the eradication program and to discuss some technical and practical aspects associated with the use of different nets. To this purpose we compared the efficiency, the size selectivity and the induced mortality of three kinds of nets: a trammel and two different multi-mesh gill nets, sampling brook trout in 7 alpine lakes in GPNP. The obtained results allowed us to better define the technical features of the capture devices needed to eradicate brook trout and provide several suggestions on how to conduct the eradication campaign.

Keywords: *Salvelinus fontinalis*, brook trout, Gran Paradiso National Park, intensive gillnetting, size selectivity, fishing efficiency

---

* *Corresponding Author:* Rocco Tiberti, DSTA, Dipartimento di Scienze della Terra e dell'Ambiente, University of Pavia, Via Ferrata 9, 27100, Pavia, Italy. Email: rocco.tiberti@gmail.com

Published by the Gran Paradiso National Park.

1. INTRODUCTION

Studies show that stocking fish into once fishless alpine lakes is a misguided practice exacting a heavy toll on fragile alpine aquatic ecosystems (Knapp *et al.*, 2001; Schabetsberger *et al.*, 2009). Introduced fish cause a series of detrimental direct and indirect effects (Eby *et al.*, 2006), which lead to the loss of native species and to the degeneration of the natural food-web structure (Knapp *et al.*, 2001; Eby *et al.*, 2006). Unaware of its ecological consequences, the practice of introducing fish in high altitude lakes is still present throughout the Alps. In the 1960s, some naturally fishless lakes of the Gran Paradiso National Park (GPNP; North-Western Italian Alps) underwent fish stocking with brook trout (*Salvelinus fontinalis*), an alien salmonid from North America. This species is well adapted to extremely cold environments (Hutchings, 1996) and thanks to its broad ecological valence, brook trout could survive and establish reproductive populations in the stocked lakes (Alessio *et al.*, 1987; Tiberti, 2012). Brook trout are now present in almost all the artificial reservoirs of the Park (lakes Serrù, Agnel, Teleccio and Valsoera), in some natural alpine lakes (Nivolet inferiore, Rosset, Leità, Leynir, Djouan, Nero, Miserino, Dres and Muanda) and in some stretches of mountain streams, including the main courses of the lower river segments. Despite fish introductions, fishing has been forbidden within the protected area since the 1970s and all fish populations, including brook trout populations, have not been affected by fishing activities since then. Recent studies confirmed that the presence of brook trout in the alpine lakes of GPNP have the same strong ecological impact as observed in other mountain regions (Eby *et al.*, 2006), with a dramatic impact on the macroinvertebrates and zooplankton communities (Tiberti, 2012) and on *Rana temporaria* (Tiberti and von Hardenberg, 2012).

To restore the lakes impacted by fish introduction, the Gran Paradiso National Park has recently approved an eradication plan, financed within the LIFE+ project BIOAQUAE (Biodiversity Improvement of Aquatic Alpine Ecosystems). This extensive eradication project involves four alpine lakes (Dres, Djouan, Nero and Leynir) using intensive gill netting as the main eradication technique. Intensive gill netting is considered an effective noninvasive practice, which has been successfully experimented in a few restoration programs (Knapp and Matthews, 1998; Parker *et al.*, 2001; Knapp *et al.*, 2007) without producing lethal effects for non-target species. The success of the eradication project will depend on the ability of nets to capture all the fish in the lakes. To this purpose the nets should be highly efficient and little selective, to catch all the fish independently of their size.

The aim of this study is to support with technical data the choice of the nets needed for the eradication program. To this purpose we compared the efficiency, the size selectivity and the induced mortality of three net types that are united by the fact of being little selective, a trammel (TR) and two different multi-mesh gill nets (MMG-1 and MMG-2), sampling brook trout in 7 alpine lakes in GPNP.

Considering that a gill net consists of a single wall of net, a multi-mesh gill net is just the result of many gill net panels with different mesh sizes put side by side and sewn together. On the other hand a trammel is composed of three panels of net: the inner panel is included into two outer panels with a larger mesh size. Both types of nets are held vertically and both can catch the fish in three different ways: fish can be gilled (held by the mesh around their gills), wedged (held by the mesh around their body), or tangled (held by teeth, spines or other protrusions without necessarily penetrating the mesh). However, only trammels can bag-fill the fish (a fish passing through the large meshed outer panel hits against the small meshed inner panel which carries through one of the large openings of the opposite large meshed outer wall). Both the net types are considered little selective: multi-mesh gill nets because they have all the mesh sizes needed to capture the entire dimensional spectrum of fish populations and trammels because they can capture every fish big enough not to pass through the inner panel (Hovgård and Lassen, 2000; Sutherland, 2006). For their little selectivity (Backiel and Welcomme, 1980; Fabi *et al.*, 2002; Karukalak and Erk, 2008) both trammels and multi-mesh gill nets were considered as potentially effective devices for a successful eradication plan and some technical, practical and economical aspects associated with the use of different capture devices are discussed in this article.

2. MATERIALS AND METHODS

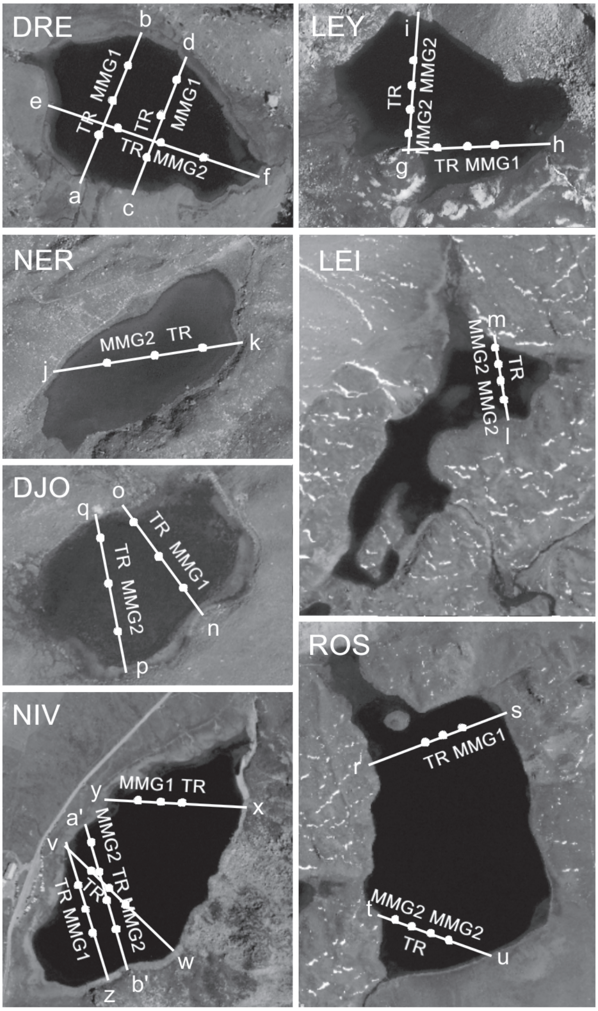
2.1. Study area

Gran Paradiso National Park (GPNP) is located between 45°25′ and 45°45′ N and between 7° and 7°30′ W in the Western Italian Alps. The protected area shows a large altitudinal extension (between 800 and 4061 m) and a typical alpine climate.

The studied lakes are all included in GPNP a.s.l. belonging to the catchments of rivers Orco and Dora di Savarenche. In this paper, toponyms of the lakes will be replaced by abbreviations: Nivolet inferiore – NIV, Leità – LEI, Leynir – LEY, Djouan – DJO, Nero – NER, Dres – DRE, Rosset – ROS. Main geographical, morphological, watershed and chemical data are reported in Table 1. The lakes are not affected by hydromorphological alterations, they are larger than 10,000 m^2 and are all located above 2,000 m a.s.l. Their watersheds belong to the Alpine and nival belts. They are placed in two geologically separated areas: the first is entirely dominated by acidic gneiss, while the second is dominated by a thick covering of calcareous schists variously metamorphosed (Compagnoni *et al.*, 1974). The geology affects the vegetation development in the watershed as well as the hydrochemistry of the lakes (Tiberti *et al.*, 2010). The studied lakes are well preserved by acidification risk and their conductivity is low because of the low ionic content. Phosphorus is the phytoplankton growth-limiting element assuming a leading role in shaping the biotic community and its concentration is an index of oligotrophy.

2.2. Sampling methods

During the summers of 2009 and 2012 we sampled the study lakes once (NER, LEI), twice (ROS, DJO, LEY), three times (DRES) or four times (NIV) to compare



DRE
a - b: 25 Jun 2009
c - d: 27 Jun 2009
e - f: 20 Aug 2012

LEY
g - h: 06 Sep 2009
g - i: 10 Jul 2012

NER
j - k: 19 Aug 2012

LEI
l - m: 07 Jul 2012

DJO
n - o: 23 Jun 2009
p - q: 18 Aug 2012

ROS
r - s: 07 Jul 2009
t - u: 08 Jul 2012

NIV
v - w: 11 Jul 2009
x - y: 27 Jul 2009
v - z: 19 Aug 2009
a' - b': 5 Jul 2012

Figure 1 Map of the sampled lakes showing the positioning of trammel (TR) and multi-mesh gill nets (MMG 1 and MMG 2) and the dates of sampling. LEY: Leynir; NIV: Nivolet inferiore; DJO: Djouan; DRE: Dres; ROS: Rosset; NER: Nero; LEI: Leità.

the efficiency, selectivity and mortality of MMG-1, MMG-2 and TR. MMG-1 was a multi-mesh gill net crafted by Retificio Moretti (Peschiera Maraglio, Italy) and made of mono-filament nylon, it was 30 m long and 1.5 m tall and was composed of 10 panels (each 3 m long) with standard mesh size for pelagic samples (55 mm, 45 mm, 40 mm, 30 mm, 24 mm, 19.5 mm, 15.5 mm, 12.5 mm, 10 mm, 8 mm; APAT, 2007). MMG-2 was a multi-mesh gill net specially produced by Oy Lindeman Ab (Raippaluoto, Finland) on the experience gained during the

Table 1 Geographic, morphometric and chemical data of the studied lakes from Gran Paradiso National Park; D: maximum depth; A: area; Geology-AG: cathment geology entirely composed by acidic gneiss; Geology-CS: catchment geology dominated by calcareous schists. C: conductivity at 20°C; Alk: total alkalinity; TP: total phosphorus; TN: total nitrogen; n: number of performed chemical analysis. Chemical analyses were performed at the Institute of Ecosystem Study (ISE-CNR), Pallanza, Italy, following Tartari and Mosello (1997); for each chemical variable we report the range of values measured in several dates between 2008 and 2012.

		NIV	LEI	LEY	DJO	NER	DRE	ROS
Latitude		45°29′10″	45°29′37″	45°30′28″	45°33′28″	45°33′06″	45°24′46″	45°29′47″
Longitude		07°08′45″	07°07′55″	07°09′06″	07°10′43″	07°10′07″	07°13′26″	07°08′17″
Altitude	(m)	2526	2701	2747	2515	2671	2087	2703
D	(m)	14.0	11.0	22.1	3.0	6.0	7.4	46.9
A	10^3 m^2	104.1	6.22	44.6	13.3	1.71	26.1	168.6
L	(m)	1445	1992	956	458	548	713	2116
B	10^3 m^2	1106	3156	1565	306	866	2919	1330
Geology		CS/AG	CS	CS	CS	CS	AG	CS
pH		7.44 ± 0.28	8.10 ± 0.17	8.02 ± 0.22	8.63 ± 0.45	8.03 ± 0.15	7.13 ± 0.30	7.76 ± 0.26
$C_{20°C}$	μS cm^{-1}	79.7 ± 2.2	118.0 ± 10.1	115.5 ± 3.8	130.1 ± 11.0	97.4 ± 14.0	25.1 ± 7.8	88.4 ± 5.0
Alk	meq L^{-1}	0.85 ± 0.02	1.12 ± 0.12	1.14 ± 0.04	1.18 ± 0.15	0.81 ± 0.10	0.19 ± 0.07	0.90 ± 0.05
TP	μg l^{-1}	10.0 ± 3.7	1.9 ± 1.0	2.9 ± 0.6	4.1 ± 1.1	2.9 ± 2.2	5.8 ± 3.5	3.8 ± 0.9
TN	mg l^{-1}	0.22 ± 0.16	0.21 ± 0.06	0.17 ± 0.05	0.17 ± 0.04	0.18 ± 0.04	0.28 ± 0.03	0.08 ± 0.02
n		4	8	14	8	8	8	8

eradication projects performed in Sierra Nevada, California (Knapp and Matthews, 1998; Knapp *et al.*, 2007). It was made of double-knotted monofilament (diameter: 0.15–0.20 mm), was 36 m long and 1.8 m tall, and contained six panels with different mesh sizes (38 mm, 33 mm, 25 mm, 18.5 mm, 12.5 mm, 10 mm). TR was made of nylon, it was 30 m long and 1.5 m high and the inner panel mesh size was 17 mm.

In 2009 we compared the efficiency, selectivity and induced mortality of TR and MMG-1, while in 2012 we compared TR with MMG-2. In 2012, we used two MMG-2 at the same time in DRE, DJO and NER. We fixed the nets to the shoreline with ropes and we stretched the nets side by side at the surface (Figure 1), where *Salvelinus fontinalis* stays in the summer time (Dawidowicz and Gliwicz, 1983). In Figure 1 we show the position of the nets during each date of sampling. In 2009, to avoid useless overfishing, TR, which was more efficient than MMG-1, was sometimes retreated before MMG-1. The nets were inspected from an inflatable dinghy every 1–2 hours during the diurnal sampling sessions to reduce mortality, but during the night the inspections of nets was suspended. Fishes were temporarily stocked in a bucket and the length of each fish was measured at the end of the inspection. Finally, limited to this preliminary study, fishes were released and considered alive when they were able to autonomously swim away.

2.3. Data analysis

Efficiency of TR and of the two kind of MMGs was compared using only the data collected when nets were in use at the same time. We first compared the efficiency of TR and MMG-1 with a Chi-square test. Having TR and MMG-1 in the same fishing area (45 m^2), the expected frequency of captured fish was equal for TR and MMG-1. Then we compared the efficiency of TR and MMG-2 with two additional Chi-square tests, the fist to compare the efficiency of TR and MMG-2 when a single MMG-2 was used (in DRE, DJO and NER) and the second when two MMG-2 were used (in NIV, LEI, LEY and ROS). Indeed, MMG-2 have a greater fishing area (64.8 m^2) than TR, thus the expected probabilities to catch brook trout was smaller in TR than in MMG-2 and was ~0.41 when a single MMG-2 was used and ~0.26 when two MMG-2 were used.

We thus compared the efficiency of each single panel of MMG-1 and MMG-2 with the efficiency of TR with a Chi-square test, but, when the expected frequencies were less than five, we calculated the cumulative binomial probability to obtain the observed results, considering that the expected probability to catch brook trout was ~0.91 (45 m^2/49.5 m^2 = 10/11) in TR, ~0.09 (4.5 m^2/49.5 m^2 = 1/11) in each panel of the MMG-1 and ~0.81(45 m^2/55.8 m^2) and ~0.19 (10.8 m^2/55.8 m^2) respectively for TR and for each panel of MMG-2.

To avoid pseudoreplication due to repeated sampling in the same lake at different times, the size selectivity of TR, MMG-1 and MMG-2 was compared using a Linear Mixed-Effects model implemented in the lme function of the package nlme of the R statistical software, version 2.12.1 (Pinheiro *et al.*, 2007; R Development Core Team, 2010) and fitted by Restricted Maximum Likelihood with the length of fishes as dependent variable. A factorial variable indicating the method of sampling and a factorial variable indicating each different sampling session were added to the model as fixed effects, while the sampled lakes were added as a random effect. The significance of fixed terms was assessed using conditional *F*-tests. We compared the selectivity of each mesh size both for MMG-1 and MMG-2 with an ANOVA and a Tukey test for multiple comparisons.

The mortality induced by TR, MMG-1 and MMG-2 was compared with a test for the equality of proportions. The data collected in 2012 with TR and MMG-2 was used to asses if the different ways in which fishes can be caught (bag-filled, gilled, wedged or tangled) could induce different mortality rates. To this purpose we used a generalized mixed effect linear model fitted by Laplace approximation and with an underlying binomial distribution (log link) implemented in the function glmer of the package lme4 of the statistical software R (R Development Core Team, 2010). The survival of each sampled fish ($0 = \text{dead}$, $1 = \text{alive}$) was added to the model as a binary dependent variable. We added as fixed effect a variable (Way) standing for the different ways in which fishes are caught (gilled, wedged, tangled and bag-filled) and the lake where we sampled the fish (Lake) as a random effect. Mortality data were obtained by counting the individuals died in the nets or during their extraction, handling or transport. The analysis did not include the mortality events that happened after the release of fishes and induced by stress or undetected damages.

3. RESULTS

378 fishes were sampled within 15 sampling sessions (Table 2, Figure 1). 184 fishes were collected within 56h 15′ of sampling with TR, 43 within 65h 40′ of sampling with MMG-1 and 151 within 22h 50′ of sampling with MMG-2. Fish length ranged from 15.5 cm to 34.5 cm and their average length ±SD depended on the sampling site: it was 23.0 ± 3.9 cm ($N = 77$) in DJO, 28.4 ± 2.2 cm ($N = 12$) in NER, 27.3 ± 4.0 cm ($N = 103$) in DRE, 30.2 ± 3.5 cm ($N = 80$) in NIV, 21.2 ± 1.4 cm ($N = 23$) in LEI, 22.4 ± 4.4 cm ($N = 77$) in LEY and 26.8 ± 3.9 ($N = 56$) in ROS (Figure 2).

TR was more efficient than MMG-1 ($\chi^2 = 69.48$, $df = 1$, $p < 0.0001$), but it was less efficient than MMG-2 ($\chi^2 = 27.50$, $df = 1$, $p < 0.0001$, for NIV, LEI, LEY and ROS; $\chi^2 = 0.53$, $df = 1$, $p = 0.47$ for DRE, DJO and NER). Only three panels of MMG-1, but all the panels of MMG-2, captured fishes during the sampling campaign. When we partitioned the efficiency analysis on each single panel, performing the analysis just on the fishing panels, the panels of MMG-1 with 24 and 40 mm mesh size did not show any significant difference with TR, but the panel with 30 mm mesh size of MMG-1was more efficient than TR in DRE and NIV ($p < 0.05$) and showed the same tendency in ROS ($p = 0.06$). We found coherent results also for some panels of MMG-2, with some mesh sizes which were more efficient than others and than TR. The panels with 10 and 12.5 mm mesh sizes proved to be more efficient than TR just in NIV ($p < 0.01$), the panel with 18.5 mesh size in NIV ($p < 0.01$) and LEI ($p < 0.0001$), the panel with 25 mm

Table 2 Summary table of the sampling campaign conducted in seven lakes in Gran Paradiso National Park; TR: trammel; MMG-1 and MMG 2: two different kind of multi-mesh gillnet; NF: number of caught fishes.

Lake	Date	Time – TR	Time – MMG-1	Time – MMG-2	NF-TR	NF-MMG-1/2
DJO	23 Jun, 2009	4 h 20′ (12:10 – 14:40)	20 h 50′ (12:10 – 9:00)–	–	23	5
	18 Aug, 2012	3 h 00′ (15:00 – 18:00)		3 h 00′ (15:00 – 18:00)	29	20
NER	19 Aug, 2012	3 h 00′ (12:00 – 15:00)	–	3 h 00′ (12:00 – 15:00)	2	10
DRE	25 Jun, 2009	0 h 30′ (13:00 – 13:30)	0 h 30′ (13:00 – 13:30)	–	16	2
	27 Jun, 2009	2 h 30′ (12:45 – 15:15)	2 h 30′ (12:45 – 15:15)	–	44	15
	20 Aug, 2012	1 h 50′ (13:45 – 15: 35)	–	1 h 50′ (13:45 – 15: 35)	9	17
NIV	11 Jul, 2009	3 h 30′ (16:45 – 20:15)	3 h 30′ (16:45 – 20:15)	–	16	0
	27 Jul, 2009	3 h 00′ (17:15 – 20:15)	2 h 45′ (17:30 – 20:15)	–	8	6
	19 Aug, 2009	5 h 35′ (10:15 – 15:50)	5 h 35′ (10:15 – 15:50)	–	6	3
	5 Jul, 2012	3 h 15′ (11:30 – 14:45)	–	3 h 15′ (11:30 – 14:45)	2	39
LEI	7 Jul, 2012	3 h 35′ (11:10 – 14:45)	–	3 h 35′ (11:10 – 14:45)	1	23
LEY	6 Sep, 2009	6 h 00′ (13:00 – 19:00)	22 h 00′ (13:00 – 11:00)	–	20	9
	10 Jul, 2012	4 h 00′ (12:20 – 16:20)	–	4 h 00′ (12:20 – 16:20)	1	27
ROS	7 Jul, 2009	8 h 00′ (11:15 – 19:15)	8 h 00′ (11:15 – 19:15)	–	7	3
	8 Jul, 2012	4 h 10′ (12:00 – 16:10)	–	4 h 10′ (12:00 – 16:10)	0	15
TOT		**56 h 15′**	**65 h 40′**	**22 h 50′**	**184**	**194**

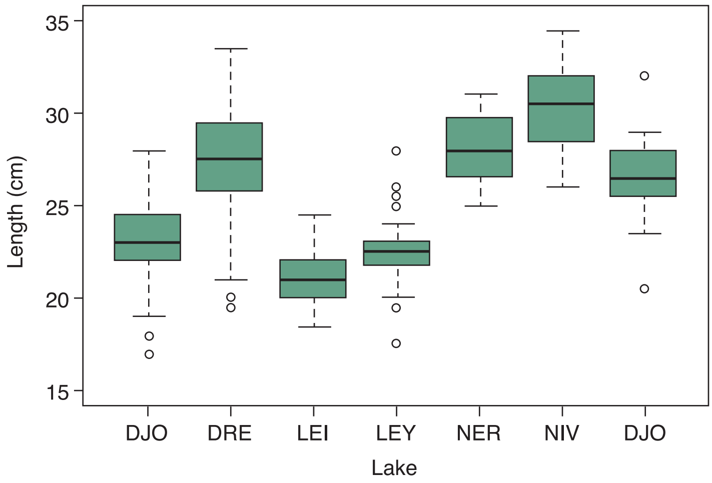


Figure 2 Length distribution of sampled fish divided by sampling site.

mesh size in NIV ($p < 0.01$), in LEI ($P < 0.05$), in ROS ($p < 0.0001$), in LEY ($p < 0.0001$) and NER ($p < 0.01$), the panel with 33 mm mesh size in none of the lakes and the panel with 38 mm mesh size just in NIV ($p < 0.01$). However some of the results from NIV are probably spurious due to the fact that MMG-2 was positioned too close to the shore.

We did not find a significant difference between the size selectivity of TR and MMG ($F_{2.366} = 2.56$, $p = 0.08$) (Figure 2) and in the size of fishes captured in different sampling sessions ($F_{1.366} = 0.02$, $p = 0.89$). After testing that the variance of the lengths of fish captured in each panel was homogeneous (Levene test: $F_{2.41} = 0.475$, $p = 0.63$), we found that the size of fish was significantly different among the fishing panels of MMG-1 ($F_{2.44} = 33.45$, $p < 0.001$). In Table 3 we show the results of the Tukey test for multiple comparison. The panel with 24 mm mesh size selected significantly smaller fish than the 29 and 35 mm mesh sizes in MMG-1. The size of fishes was significantly different also among the different panels of MMG-2 ($F_{5.145} = 8.26$, $p < 0.001$). The results of the Tukey test for multiple comparison are reported in Table 3.

Total mortality was 22.4% (20.7% in TR, 20.9% in MMG-1 and 25.0% in MMG-2) and the difference in the mortality induced by MMG-1, MMG-2 and TR was not significant ($\chi^2 = 0.97$, $df = 2$, $p = 0.62$). However, the different ways in which fishes can be caught induced different mortality rates, which were significantly lower when fish were tangled or wedged than when they were gilled (wedged vs. gilled: $beta = 1.61$, $z = 3.47$, $p < 0.001$; tangled vs. gilled: $beta = 2.24$, $z = 3.82$, $p < 0.001$) or bag-filled (wedged vs. bag-filled: $beta = 2.21$, $z = 3.58$, $p < 0.001$; tangled vs. bag-filled: $beta = 1.59$, $z = 3.14$, $p < 0.01$), while the induced mortality was not significantly different between gilled and bag-filled fish ($beta = -0.02$, $z = -0.06$, $p = 0.95$) and between tangled and wedged fish ($beta = -0.63$, $z = -0.97$, $p = 0.33$).

Table 3 Tukey test for multiple comparison of the selectivity of different mesh-sizes within multi-mesh gillnets MMG-1 and MMG-2. Data were collected in 7 alpine lakes in Gran Paradiso National Park.

Net	Mesh size	Mean difference	P	95% confidence intervals	
MMG-1	24 vs 29 mm	−4.72	<0.001	−6.18	−3.27
MMG-1	24 vs 35 mm	−4.53	<0.001	−6.65	−2.42
MMG-1	29 vs 35 mm	0.19	0.972	−1.82	2.20
MMG-2	10 vs 12.5 mm	1.73	0.860	−2.62	6.07
MMG-2	10 vs 18.5 mm	5.50	<0.001	1.64	9.37
MMG-2	10 vs 25 mm	3.57	0.071	−0.18	7.31
MMG-2	10 vs 33 mm	1.30	0.973	−3.63	6.23
MMG-2	10 vs 38 mm	−2.38	0.831	−8.07	3.30
MMG-2	12.5 vs 18.5 mm	3.77	<0.01	0.68	6.87
MMG-2	12.5 vs 25 mm	1.84	0.464	−1.10	4.78
MMG-2	12.5 vs 33 mm	−0.43	0.999	−4.77	3.92
MMG-2	12.5 vs 38 mm	−4.11	0.206	−9.30	1.08
MMG-2	18.5 vs 25 mm	−1.94	0.110	−4.11	0.24
MMG-2	18.5 vs 33 mm	−4.20	<0.05	−8.07	−0.34
MMG-2	18.5 vs 38 mm	−7.89	<0.0001	−12.68	−3.09
MMG-2	25 vs 33 mm	−2.27	0.50	−6.01	1.48
MMG-2	25 vs 38 mm	−5.95	<0.01	−10.65	−1.25
MMG-2	33 vs 38 mm	−3.68	0.42	−9.37	2.00

4. DISCUSSION

This study provides information supporting the choice of the capture devices to be used for the eradication program planned within the BIOAQUAE LIFE+ project. This information is very useful if we consider that the literature concerning fish eradication by gill netting in mountain lakes is still limited to a few examples from North America (Knapp and Matthews, 1998; Parker *et al.*, 2001; Knapp *et al.*, 2007).

Since the eradication process in high altitude lakes can take a long time (about two years of continuous gill netting; Knapp and Matthews, 1998; Knapp *et al.*, 2007), speeding up the capture rate is important. Thus, one of the most important characteristics of the nets needed for the eradication project is a high capture efficiency. This study shows that the efficiency of the capture devices depended both on the kind and on the quality of nets. TR showed a higher efficiency than MMG-1, which was manufactured without special features for fishing in high altitude lakes, but a lower efficiency than MMG-2, which was of the same kind as MMG-1, but with a clearly higher quality than MMG-1 (e.g. thinner monofilament diameter). Moreover, the panels with an appropriate mesh size of both MMG-1 and MMG-2 were often more efficient than TR. Considering these results, we suggest to use large gill nets with the most efficient mesh size to eradicate brook trout from the pelagic area. The technical features of gill nets (mesh size, length and height) should be decided on the basis of the dominant size of brook trout in the pelagic samples and considering the bathymetry of the lakes. Moreover, there are further practical reasons to prefer gill nets: the time required to remove fishes from gill nets is much shorter than that needed for the trammel. This latter feature is very important, especially in the early stages of eradication when there is expected a high number of captured fish, and the nets should be frequently and quickly inspected.

However, the efficiency of the nets is not the only important characteristic. For example, the most efficient nets are probably highly selective for the dominant size classes, but they may completely miss the smaller size classes. The length distribution of captured fish indicates that the pelagic area of the lakes is populated only by adult fish and that young individuals are excluded from this area, probably due to the cannibalistic behavior of adult brook trout (Scott and Crossman, 1973; Griffith, 1974). Direct observations indicate that smaller size classes of brook trout used to stay in the littoral area: near the shorelines, in the littoral vegetation or in the first segment of inlets and outlets. To successfully complete the eradication, all the fish should be captured, including the ones not belonging to the dominant size classes sampled in the pelagic area. Thus, in the littoral area it would be better to use a less efficient, but also less selective net to also catch the smaller individuals and the possibility to support the eradication with other capture devices should be evaluated (e.g. electrofishing along the colonized segments of the inlets and outlets, where it is not possible to stretch a net). Previous successful experiments (Knapp and Matthews, 1998; Parker *et al.*, 2001; Knapp *et al.*, 2007) suggest to set MMGs perpendicular to the lake shoreline, with one end of the nets containing the smallest mesh size anchored to the shore and the other end of the net containing the largest mesh size anchored in deep water.

The number of nets needed to eradicate brook trout is a function of lake surface area (Knapp *et al.*, 2007) and probably also of its depth. Considering a 36 m long and 1.8 m tall MMG, with six 6 m long panels with bar mesh sizes of 10, 12.5, 18.5, 25, 33, and 38 mm (MMG-2, standard net features from Knapp and Matthews, 1998; Knapp *et al.*, 2007) it is common to use as many as 10 nets per hectare of lake surface area. Indeed, the effort needed to complete the eradication provides the continuous use of many gill nets over a period of several months.

The mortality induced by fishing with nets is not a problem from a conservation point of view, since the caught fish are non-native and are intended to be eliminated. However there are ethical reasons which are imposed to minimize the pain of the captured animals and further practical reasons to prevent the death of fish in the nets. Indeed, still-alive fish can be temporarily stocked in tanks or submerged closed nets and taken away when it is possible or more convenient, while dead fish should be rapidly taken away and eliminated. The observed mortality rates are rather high (20–25%) and it is predictable that many nets used at the same time during the eradication process will be more difficult to be frequently inspected to reduce mortality. We did not find any significant difference between the mortality induced by MMG-1, MMG-2 and TR, but we are aware that gilled and bag-filled fish are subject to higher mortality rates, because nets close their gills and prevent breathing. Unfortunately, fishes are efficiently captured when they are gilled by the appropriate mesh size and many gill nets with these mesh sizes will likely be used in the pelagic area during the eradication process. The use of highly efficient and highly lethal gill nets and the predicted decrease of the frequency of inspections to the nets due to the huge number of nets in the water at the same time – at least 10 per hectar according to Knapp *et al.* (2007) – will probably result in an increase of the mortality rates during the eradication process, that will probably be higher than 20–25%. For this reason it is important to well organize a frequent downstream transport of dead fish during the eradication. We are also aware that the weather is one of the main factors inducing mortality: fish manipulation with windy and cold weather can kill a fish in a few seconds (e.g. the mortality rate during the first sampling in DJO was 71% due to the extremely harsh weather conditions). We therefore suggest maximizing the efforts for the inspection of nets during the early stages of the eradication project, when catch rates are high, and to consider the weather forecast before starting with the eradication.

ACKNOWLEDGMENTS

We thank Achaz von Hardenberg, Bruno Bassano and Giuseppe Bogliani. Logistic support and funding for this research was provided by the Gran Paradiso National Park within the framework of the FP7 ACQWA Project (Assessment of Climatic change and impacts on the Quantity and quality of WAter), Grant Agreement No. 212250.

REFERENCES

Alessio G., Forneris G. and Confortini I. (1987) Indagini preliminari su accrescimento, biologia e ambientamento del salmerino di fontana, *Salvelinus fontinalis* Mitch., in un ecosistema lacustre di alta quota. *Atti della Società italiana di Scienze naturali e del Museo civico di Storia naturale di Milano* 128: 138–152.

APAT (2007) Protocollo di campionamento della fauna ittica dei laghi italiani. In *APAT. Metodi biologici per le acque I*. Rome.

Compagnoni R., Elter G. and Lombardo B. (1974) Eterogeneità stratigrafica del complesso degli 'Gneiss Minuti' nel massiccio cristallino del Gran Paradiso. *Societá Geologica Italaliona*. 13: 227–239.

Dawidowicz P. and Gliwicz Z. M. (1983) Food of brook charr in extreme oligotrophic conditions of an alpine lake. *Environmental Biology of Fishes* 8: 55–60.

Eby L. A., Roach W. J., Crowder L. B. and Stanford J. A. (2006) Effects of stocking-up freshwater food webs. *Trends in Ecology and Evolution* 21: 576–584.

Fabi G., Sbrana M., Biagi F., Grati F., Leonori I., Sartor P (2002) Trammel net and gill net selectivity for *Lithognathus mormyrus* (L., 1758), *Diplodus annularis* (L., 1758) and *Mullus barbatus* (L., 1758) in the Adriatic and Ligurian seas. *Fisheries Research* 54: 375–388

Griffith J. J. S. (1974) Utilization of invertebrate drift by brook trout (*Salvelinus fontinalis*) and cutthroat trout (*Salmo clarki*) in small streams in Idaho. *Transactions of the American Fisheries Society* 103: 440–447.

Hutchings J.A. (1996) Adaptive phenotypic plasticity in brook trout, *Salvelinus fontinalis*, life histories. *Ecoscience* 3: 25–32.

Hovgård H. and Lassen H. (2000) Manual on estimation of selectivity for gillnet and longline gears in abundance surveys. *FAO Fisheries Technical Paper 397*. Rome.

Karakulak F.S. and Erk H. (2008) Gill net and trammel net selectivity in the northern Aegean Sea, Turkey. *Scientia Marina* 72: 527–540

Knapp R. A. and Matthews K. R. (1998) Eradication of nonnative fish by gill netting from a small mountain lake in California. *Restoration Ecology* 6: 207–213.

Knapp R. A., Matthews K. R. and Sarnelle O. (2001) Resistance and resilience of alpine lake fauna to fish introductions. *Ecological Monographs* 71: 401–421.

Knapp R. A., Boiano D. M. and Vredenburg V. T. (2007) Removal of nonnative fish results in population expansion of a declining amphibian (mountain yellow-legged frog, *Rana muscosa*). *Biological Conservation* 135: 11–20.

Magnea U., Sciascia R., Paparella F., Tiberti R., Provenzale A. (2013) A model for high-altitude alpine lake ecosystems and the effect of introduced fish. *Ecological Modelling* 254: 211–220.

Parker B.R., Schindler D.W., Donald D.B. and Anderson R.S. (2001) The effects of stocking and removal of a nonnative salmonid on the plankton of an alpine lake. *Ecosystems* 4: 334–345.

Pinheiro J., Bates D., Debroy S. and Sarkar D. (2007) Linear and Nonlinear Mixed Effects Models 'nlme' package in R. Available at http://cran.r-project.org/web/packages/nlme/index.html

Schabetsberger R., Luger M., Drozdowski G. and Jagsch A. (2009) Only the small survive: monitoring long-term changes in the zooplankton community of an Alpine lake after fish introduction. *Biological Invasions* 11: 1335–1345.

Scott W.B. and Crossman E.J. (1973) *Freshwater Fishes of Canada*. Fisheries Research Board of Canada, Winnipeg.

Sutherland W.J. (2006) *Ecological Census Techniques – a handbook*. Second edition, Cambridge University Press.

Tartari G. and Mosello R. (1997) Metodologie analitiche e controlli di qualità nel laboratorio chimico dell'Istituto Italiano di Idrobiologia del Consiglio Nazionale delle Ricerche. *Documenta dell'Istituto Italiano di Idrobiologica* 60: 1–160.

Tiberti R., Tartari G.A. and Marchetto A. (2010) Geomorphology and hydrochemistry of 12 Alpine lakes in the Gran Paradiso National Park, Italy. *Journal of Limnology* 69: 242–256.

Tiberti R. (2012) Ecology of alpine lakes in Gran Paradiso National Park. Ph.D thesis, University of Pavia, Pavia.

Tiberti R. and von Hardenberg A. (2012) Impact of introduced fish on Common frog (*Rana temporaria*) close to its altitudinal limit in alpine lakes. *Amphibia Reptilia* 33: 303–307.