

Online Resource 1: Study lakes

Article title: Recovery of high mountain Alpine lakes after the eradication of introduced brook trout *Salvelinus fontinalis* using non-chemical methods

Journal name: Biological Invasions

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Gran Paradiso National Park (GPNP) is a large protected area (710 km²) located between 45° 25' and 45° 45' N and between 7° and 7° 30' W in the Western Italian Alps (Fig. OR1.1). The protected area shows a large altitudinal extension (between 800 and 4,061 m) and a typical alpine climate. GPNP was founded in 1922 and is one of the oldest protected areas in Italy and Europe.

The present study involves a total of 18 natural (not dammed) lakes of the GPNP (Fig. OR1.1; Table OR1.1): 4 lakes treated for fish eradication and 14 naturally fishless lakes. Control lakes represent virtually all the fishless lakes of the GPNP placed between 2000 and 3000 m a.s.l. (i.e. above or at the local tree line) and larger than 1.0 ha. In Table OA1 we provide a summary of their main environmental features. The studied lakes are oligotrophic or ultraoligotrophic, but nutrient input from livestock grazing can produce a nutrient increase in a few lakes (i.e. Djouan and Dres; Tiberti et al., 2014). All studied lakes are placed in two geologically separated areas: the first is entirely dominated by acidic gneiss, while the second is dominated by thick coverings of variously metamorphosed calcareous schists (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). Direct thermal stratification occurs only in the late summer and only in the deepest lakes. The ice-covered season lasts for 7–10 months per year (Tiberti et al., 2010).

Some fishless lakes (N=4) larger than 1.0 ha were excluded from the study because they were affected by huge input of glacial sediments. Compared to clear lakes, glacier-fed turbid lakes (usually in direct connection with the glaciers) present peculiar ecological features (Koenings et al., 1990; Sommaruga and Kandolf, 2014) affecting some of the ecosystems components considered in the present study, independent by the impact of introduced fish.

Fish-removal lakes contrast for their morphology, habitat complexity, and ecological connection with other lentic habitats. These factors may influence the effectiveness of the eradication methods, the efforts needed to get the complete eradication, and the resilience potential of the lakes.

- *Morphology*. DJO, DRE and NER are considerably smaller than LEY (Table OR1.1), where fish eradication was therefore expected to be harder (Pacas and Tylor, 2015).
- *Habitat complexity*. LEY and NER are without aquatic vegetation, but DJO and DRE have abundant aquatic vegetation, which can serve as a refuge for aquatic preys against fish predation (potentially mitigating fish impact and favoring post-eradication resilience; Knapp et al., 2001) and for fish against eradication (potentially complicating the eradication attempts; Tiberti et al., 2017). Lake DRE have 380 m of permanent tributaries colonized by brook trout; the tributaries of DJO, LEY and NER were not colonized by fish or were intermittent.
- *Ecological connection*. DRE have two fishless ponds upstream (favoring the re-colonization by drifting aquatic organisms, e.g. zooplankton); DJO have a very close (≈ 80 m) pond outside its catchment (favoring the re-colonization of semiaquatic organisms, e.g. frogs and aquatic insects with aerial dispersion); LEY and NER have not upstream or close (within ≈ 0.5 km) lentic habitats.

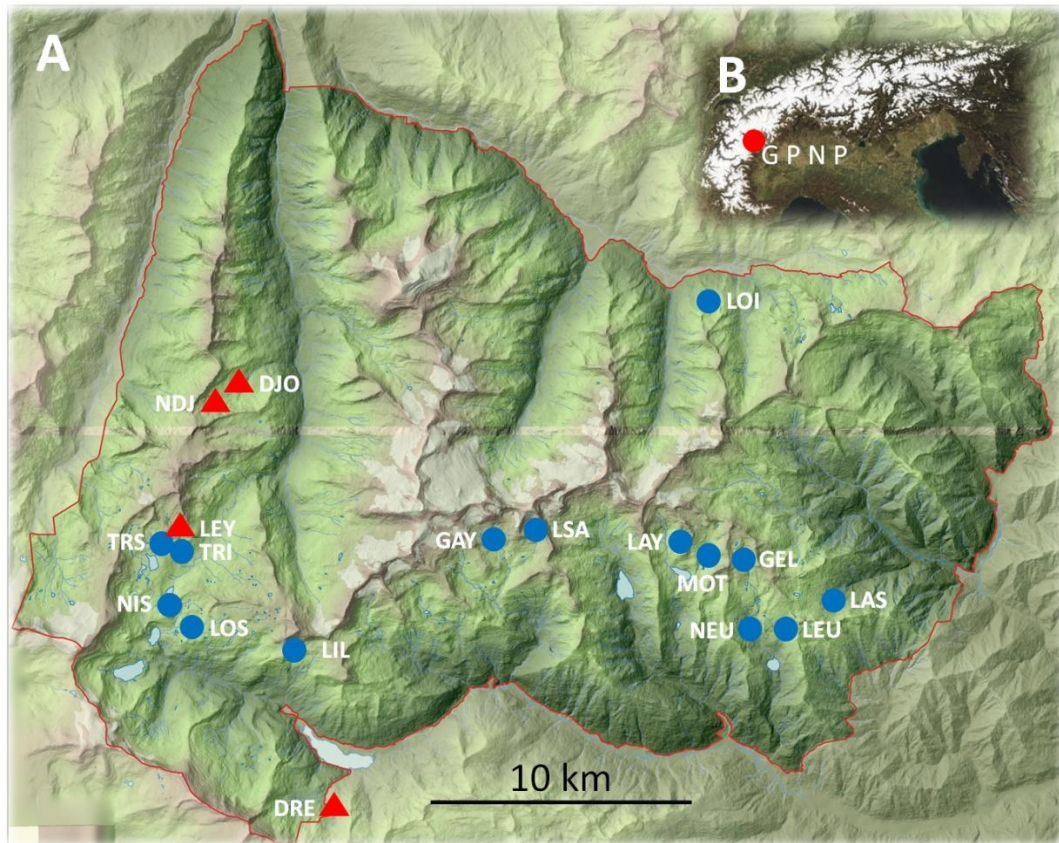


Fig. OR1.1 Gran Paradiso National Park area (A) and its position in the Alps (B). Red triangles: fish-removal lakes; blue circles: fishless control lakes.

Table OR1.1 Main Geographic, morphometric, chemical and catchment characteristics of the study lakes. Lat: latitude N; Long: longitude E; Alt: altitude; A: lake area; D_{max} : maximum depth; TP: Total phosphorus; B: catchment area; Geology-AG: acidic gneiss; Geology-CS: calcareous shists. Chemical features are based on 1-36 repeated measures collected between 2008 and 2017.

Lakes	Geography			Morphometry		Chemistry		Catchment		Land cover				
	Lat UTM Zone	Long 32T	Alt m a.s.l.	A ha	D_{max} m	pH	TP $\mu\text{g L}^{-1}$	B ha	Geology	Water %	Ice %	Rocks %	Meadows %	Shrubs %
<i>Eradication lakes</i>														
DJO – Djouan	357860	5046523	2515	1.43	3	8.6 ± 0.4	3.9 ± 1.5	47	CS	3	-	77	20	-
DRE – Dres	361033	5030342	2088	2.51	7.4	7.0 ± 0.4	4.7 ± 3.7	289	AG	1	-	87	8	4
LEY – Leynir	355629	5041013	2747	4.56	22.1	7.9 ± 0.4	3.4 ± 1.4	155	CS	3	-	75	22	-
NDJ – Nero, Djouan	357064	5045896	2667	1.45	6	8.0 ± 0.3	2.6 ± 1.5	89	CS	2	-	88	10	-
<i>Fishless lakes</i>														
GAY – Gay	367650	5040583	2978	1.89	13.5	7.2	4	22	AG	8	-	92	-	-
GEL – Gelato	377141	5039559	2848	18.65	50	6.7 ± 0.2	3.0 ± 0.0	129	AG	15	-	85	-	-
LAS – Lasin	380556	5037822	2104	8.4	38	6.0 ± 0.6	2.0 ± 0.0	350	AG	3	-	95	1	1
LAY – Layet	374738	5040175	2787	1.53	8.4	6.7 ± 0.2	3.0 ± 0.0	22	AG	7	-	93	-	-
LOI – Loie	378409	5036637	2316	2.31	11.8	8.1	4	92	CS	2	-	98	-	-
LOS – Losere, Orco	359898	5036351	2578	2.04	7.2	7.0 ± 0.4	4.0 ± 1.9	49	AG	4	-	96	-	-
LEU – Losere, Eugio	376073	5049310	2351	1.47	8.9	6.1 ± 0.1	5.0 ± 1.0	84	AG	2	-	72	18	8
LIL – Lillet	355949	5037448	2767	3.67	13.1	7.5 ± 0.3	2.7 ± 1.1	92	AG	4	-	96	-	-
LSA – Losa	369119	5040677	2987	6.64	44.3	7.3 ± 0.1	2.5 ± 0.7	64	AG	11	7	82	-	-
MOT – Motta	375593	5039599	2657	12.65	51	6.8 ± 0.1	3.3 ± 0.5	316	AG	4	-	96	-	-
NEU – Nero, Eugio	377335	5036837	2061	5.8	21.8	6.7 ± 0.1	3.7 ± 0.6	572	AG	5	-	90	4	1
NIS – Nivolet sup.	355021	5038211	2538	3.55	16.1	7.1 ± 0.3	5.8 ± 3.4	37	AG	1-	-	66	24	-
TRI – Trebecchi inf.	355210	5040410	2723	1.62	8.1	8.0 ± 0.4	3.3 ± 1.8	25	CS	8	-	18	74	-
TRS – Trebecchi sup.	355029	5040390	2729	1.4	7.5	7.9 ± 0.4	2.7 ± 0.8	21	CS	8	-	20	72	-

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