INRAE

i SERV

Relationship between intraspecific diversity and ecosystem services: role of fish stocking practices

Métaprogramme BIOSEFAIR

Project report: 2024 – 2026

March 2026

Intraspecific diversity is important for ecosystem functioning. However, it is strongly affected by human activities. For example, freshwater fish are subject to pressure from climate change, fishing, pollution and management practices such as restocking. These species support major ecosystem services, such as fish production, nutrient cycling and water quality. Changes in their intraspecific diversity could therefore have significant ecological and socio-economic consequences.

This project investigated the effects of Arctic char (*Salvelinus umbla*) restocking practices in peri-alpine lakes on the links between intraspecific diversity and ecosystem services. Restocking can alter intraspecific diversity, indirectly affecting fish biomass and nutrient cycling, which are important services for fisheries and water quality. Nonetheless, the links between fish management practices and ecosystem services remain largely unexplored.

The iSERV project aimed to (1) link intraspecific diversity resulting from restocking to the nutrient cycle (regulatory service) at the individual and ecosystem scales using a mesocosm approach; (2) quantify in situ the effects of restocking on genetic diversity and fish biomass production (production service); (3) quantify the local population's preference for char conservation strategies.

Studies conducted in Lake Annecy show that the current Arctic char population is highly dependent on stocking, as naturally reproduced individuals are very scarce. Fish from local fish farms and naturally occurring individuals had very similar genetic structures, growth rates and phenotypic traits, suggesting a close relationship between these origins. In contrast, fish from Lake Geneva fish farms were slightly genetically differentiated and showed higher growth rates. Despite contrasting stocking intensities, individuals from both fish farms contributed comparably to the population, indicating that the origin of stocked fish may influence their survival and contribution to total biomass, a key service for fisheries.

A common garden experiment revealed that functional differences depended on the origin and date of spawning of the fish, particularly in terms of zooplankton consumption and ammonium excretion, with contrasting thermal responses. These variations suggested that restocking could alter the nutrient cycle and trophic functioning of the lake, particularly in a context of global warming.

Finally, a mesocosm experiment showed that Arctic char influence the structure of aquatic communities through top-down effects on zooplankton and that differences between origins could alter the abundance of certain taxa present in the community. The overall effects on ecosystem functioning were moderate. Overall, the project highlights that restocking practices affect intraspecific diversity and, possibly, associated ecosystem services.

The socio-economic component of the iSERV project aims to analyse public preferences regarding the management of recreational use and fish stocks in Lake Annecy. The research combined a stakeholder workshop with a large-scale survey of the general public across seven neighbouring departments (n = 984 valid responses).

The workshop, organised in cooperation with local stakeholders, helped to identify the main management issues and inform the design of the questionnaire. The survey incorporated a Discrete Choice Experiment (DCE) to estimate marginal preferences and willingness to pay for various management strategies, including the regulation of motorboats, the control of recreational uses, information campaigns, restocking strategies and nature-based solutions.

The results highlight a significant willingness to pay for tighter controls on lake use and, in particular, for restocking strategies based on local genetic resources. Preferences for nature-based solutions are positive but more moderate. On average, restrictions on motorboats do not enjoy strong support; however, there appears to be substantial heterogeneity in preferences.

In particular, fishermen and non-fishermen have significantly different preferences, highlighting potential conflicts between user groups in the management of the lake – a point also raised during discussions with stakeholders. Information processing also influences choices, suggesting that perceptions of the native or iconic nature of species affect support for conservation measures.

The ongoing analyses will examine in greater depth the systematic and random heterogeneity of preferences and assess the robustness of the results across different econometric specifications. Furthermore, the data collected on travel distances and transport costs will enable us to estimate the overall recreational value of Lake Annecy, in order to place the willingness-to-pay estimates within a broader economic valuation framework.

Detailed results

The main objective of the iSERV project was to assess the effects of Arctic char restocking practices on intraspecific diversity and associated ecosystem services, combining genetic, functional, experimental and socio-economic approaches. Overall, the work carried out is consistent with the initial objectives and has produced robust results, although the effects observed are generally small in magnitude but statistically significant.

Genetic and phenotypic analyses conducted in Lake Annecy showed that the current Arctic char population is mainly based on restocking practices, with individuals from natural reproduction being scarce. Fish from local fish farms and naturally occurring individuals were similar in their genetic diversity and phenotypic traits, suggesting that these practices have not led to a marked disruption of local intraspecific diversity. Fish from Lake Geneva were slightly genetically differentiated and distinguished themselves by slightly higher growth rates, which could influence their contribution to total biomass and fisheries production.

Laboratory experiments testing functional differences revealed variations in temperature responses depending on the fish's origin and spawning date, particularly in terms of zooplankton consumption and ammonium excretion. Fish from the Annecy fish farm exhibited greater functional plasticity to temperature than those from Lake Geneva. Specifically, the Annecy fish consumed more resources and excreted more nutrients at high temperatures than the Lake Geneva fish. Consequently, we demonstrated using a dynamic model that, in the event of global warming, restocking with Lake Geneva fish could increase fish biomass production (confirming the empirical results above). These results suggest that, in a context of global warming, the choice of the origin of the fish used for restocking could modulate certain ecosystem processes, in particular prey abundance and the biomass of the char population in Lake Annecy. This approach is novel in understanding the effects of restocking. Indeed, most studies have focused on genetic and phenotypic effects. We have shown here that functional changes are worth considering as they open up new avenues of research, particularly in terms of ecological predictions (population density, prey density).

Building on this, we conducted a mesocosm study to test the effects of fish used for restocking on community structure and ecosystem functioning. We demonstrated that Arctic char exerts marked effects on the structure of aquatic communities via top-down mechanisms acting on zooplankton. The composition of zooplankton differed depending on the origin of the char populations. This suggests that the origin of the stocked fish influences their trophic selectivity. However, the overall consequences for ecosystem functioning (productivity, decomposition, physico-chemical parameters) remained relatively limited, confirming that the effects of intraspecific diversity, whilst

real, were relatively weak at the ecosystem scale.The key findings of the socio-economic component highlight a significant willingness to pay for certain lake management measures, notably the strengthening of controls on recreational use and the use of local genetic resources for restocking. However, the analysis reveals significant heterogeneity in preferences, particularly between anglers and non-anglers. These two groups express different expectations regarding the regulation of uses and management strategies, which confirms the potential existence of tensions between user categories and highlights the importance of incorporating this diversity of preferences into public decision-making.

Furthermore, the results suggest that management strategies based on the introduction or use of genetic resources from other lakes — for example, Lake Geneva — which might offer advantages in terms of biomass production, may not align with the preferences of a significant proportion of the general non-fishing population. This highlights a potential trade-off between ecological and productive objectives and social acceptability.

Finally, the information analyses show that the way in which ecological characteristics (such as whether a species is native or emblematic) are presented significantly influences stated choices. This finding highlights the importance of providing accurate and rigorous information in survey instruments in order to obtain estimates of willingness to pay that best reflect individuals' actual preferences.

The iSERV project shows that, even when the effects of restocking on intraspecific diversity and ecosystem functioning are small, they can be significant, particularly on char population density and the structure of prey communities. The results highlight the importance of considering the origin of stocked fish, favouring sources genetically close to local populations to limit the risk of altering intraspecific diversity. The research also provides scientific evidence to adapt restocking strategies in the context of climate change, taking into account differences in functional responses between populations. For example, if no consideration of genetic heritage preservation is required, restocking with fish better adapted to higher temperatures may be beneficial for the future of char populations. Finally, incorporating the perceptions and preferences of local stakeholders provides a solid foundation for improving dialogue between scientists, managers and users, and for developing more sustainable and socially acceptable management strategies.

Scientific perspectives.

Several major scientific perspectives are emerging from this project. First and foremost, it appears necessary to conduct further research into the effects of restocking in high-altitude lakes, which are particularly fragile ecosystems, by carefully characterising the genetic and functional diversity of the introduced Arctic char populations and their evolutionary trajectories. In addition, the project has raised new questions about interactions between introduced species, particularly between salmonids and minnows, and their consequences for ecosystems. This research could build on the approaches developed in iSERV, combining functional responses, experiments and ecological modelling to better anticipate the medium- and long-term impacts of fish introductions.