museu de ciències naturals de Barcelona

Arxius de Miscel·lània Zoològica 23(2025): 95-102
DOI: https://doi.org/10.32800/amz.2025.23.0095

What can I eat before being eaten? Notes about the diet of *Phoxinus* spp. in a high mountain lake (Monviso group, NW Italy)

M. Abbà[1,2]*, S. Fenoglio[1,2], T. Bo[1,2]

[1] DBIOS, University of Turin, Via Accademia Albertina, 13, 10123 Turin, Italy
[2] ALPSTREAM–Alpine Stream Research Center, 12030 Ostana, Italy
* Corresponding author: margherita.abba@unito.it

Abbà M, Fenoglio S, Bo T, 2025. What can I eat before being eaten? Notes about the diet of *Phoxinus* spp. in a high mountain lake (Monviso group, NW Italy). *Arxius de Miscel·lània Zoològica* 23, 95-102. DOI: https://doi.org/10.32800/amz.2025.23.0095

Abstract

What can I eat before being eaten? Notes about the diet of *Phoxinus* spp. in a high mountain lake (Monviso group, NW Italy)
high mountain lakes are naturally fishless and therefore particularly vulnerable to the introduction of non-native fish. In addition to salmonids, minnows *Phoxinus* spp. have recently been introduced into these environments. While the impact of salmonid introductions on biodiversity has been extensively studied, including analyses of their diet, information on the impact and diet of introduced minnows in these environments remains scarce. This study analyzes the stomach contents of minnows in a high mountain lake, demonstrating how their diet reflects the low diversity of aquatic fauna typical of these oligotrophic environments, as well as the overexploitation of natural communities resulting from the unnatural presence of fish. This information can be useful for better understanding the complex ecological dynamics that arise when multiple predators are introduced into sensitive and unique environments such as high mountain lakes.

Key words: High mountain lakes, Fish introductions, Fish diet, Minnow, Predation

Resumen

¿Qué puedo comer antes de ser comido? Notas sobre la dieta de *Phoxinus* spp. en un lago de alta montaña (grupo Monviso, noroeste de Italia)
Los lagos de alta montaña carecen de ictiofauna por naturaleza y, por lo tanto, son particularmente vulnerables a la introducción de peces al*óctonos.* Además de los salmónidos, recientemente se han introducido piscardos *Phoxinus* spp. en estos entornos. Si bien el impacto de la introducción de salmónidos en la biodiversidad se ha estudiado ampliamente, incluyendo análisis de su dieta, la información sobre el impacto y la dieta de los piscardos introducidos en estos entornos sigue siendo escasa. Este estudio analiza el contenido estomacal de piscardos en un lago de alta montaña, demostrando cómo su dieta refleja la baja diversidad de fauna acuática típica de estos entornos oligotróficos, así como la sobreexplotación de las comunidades naturales resultante de la presencia no natural de peces. Esta información puede ser útil para comprender mejor la compleja dinámica ecológica que surge cuando se introducen múltiples depredadores en entornos sensibles y únicos como los lagos de alta montaña.

Palabras clave: Lagos de alta montaña, Introducción de peces, Dieta de los peces, Piscardo, Depredación

Resumen

Què puc menjar abans que em mengin? Notes sobre la dieta de *Phoxinus* spp. en un llac d'alta muntanya (grup Monviso, nord-oest d'Itàlia)
Els llacs d'alta muntanya no tenen peixos de manera natural i, per tant, són particularment vulnerables a la introducció de peixos no autòctons. A més dels salmònids, recentment s'han introduït piscards *Phoxinus* spp. en aquests ambients. Tot i que l'impacte de les introduccions de salmònids en la biodiversitat s'ha estudiat àmpliament, incloent-hi anàlisis de la seva dieta, la informació sobre l'impacte i la dieta dels peixos petits introduïts en aquests ambients continua sent escassa. Aquest estudi analitza el contingut estomacal dels piscards en un llac d'alta muntanya, demostrant com la seva dieta reflecteix la baixa diversitat de fauna aquàtica típica d'aquests ambients oligotròfics, així com la sobreexplotació de les comunitats naturals resultant de la presència no natural de peixos. Aquesta informació pot ser útil per comprendre millor les dinàmiques ecològiques complexes que sorgeixen quan s'introdueixen múltiples depredadors en ambients sensibles i únics com els llacs d'alta muntanya.

Paraules clau: Llacs d'alta muntanya, Introducció de peixos, Dieta de peixos, Piscards, Depredació

Received: 12/11/2024; Conditional acceptance: 27/05/2025; Final acceptance: 19/06/2025; Published: 03/07/2025

Introduction

Alpine, and in general, high mountain lakes are remote ecosystems considered extreme for life due to their harsh environmental characteristics (Catalan et al 2006). These include low temperatures and highly diluted, oligotrophic waters, as well as a marked seasonal alternation between the extended winter period, characterized by snow and ice cover and limited light conditions, and the short summer period, typified by extremely high solar radiation (Sommaruga 2001, Catalan et al 2006, Füreder et al 2006). These conditions result in high mountain lakes hosting a few dominant, well-adapted organisms that support relatively simple communities, making these environments unique and distinctive (Sommaruga 2001, Füreder et al 2006). Despite their remoteness from more populated areas, these ecosystems are so sensitive and vulnerable to external and anthropogenic pressures that they are considered sentinels of environmental change (Pastorino and Prearo 2020, Pastorino et al 2024).

The isolation of high mountain lakes has resulted in a natural absence of fish, and one of the main threats to these environments is the introduction of non-native species for angling, mainly salmonids (Pastorino and Prearo 2020, Pastorino et al 2024). The impacts of introduced salmonids on faunal assemblages in high mountain lakes are well documented and relate to predatory pressure and consequent ecological effects on zooplankton, macroinvertebrates, and amphibians (Knapp et al 2001, Parker et al 2001, Perilli et al 2020, Tiberti et al 2014, Tiberti and von Hardenberg 2012, Miró and Ventura 2020). More recently, minnows (for example, *Phoxinus* spp.) have also been introduced into high mountain lakes. They have been introduced accidentally as surviving live bait for salmonids, as a result of contamination of released salmonid stocks, or intentionally to provide forage fish for trout or char (Museth et al 2007). Minnows have an omnivorous and unspecialized diet, feeding mainly on aquatic insect larvae and benthic crustaceans, and occasionally on the larvae and eggs of other fish. In lacustrine environments, they also feed on zooplankton (Zerunian 2004). The effects of minnows on biodiversity in high mountain lakes have been less studied than those of salmonids, but some authors have pointed out that they also prey on zooplankton, amphibians, and benthic macroinvertebrates (Miró et al 2018, Miró and Ventura 2020, Næstad and Brittain 2010), with negative effects on the latter even greater than those of trout (Osorio et al 2022). Moreover, despite minnows being part of trout diets (Museth et al 2003), they can cause the decline (Museth et al 2007, Tiberti et al 2022) or disappearance (Miró and Ventura 2015, 2020) of previously introduced salmonids, mainly through competition for common trophic resources (Museth et al 2007) and predation on salmonid eggs (Miró and Ventura 2020). Some authors have investigated the diet of salmonids introduced to high mountain lakes in northern and southern Europe (Cavalli et al 1998, Hesthagen et al 1992, Museth et al 2010, Tiberti et al 2016). To our knowledge, information on the diet of minnows in these environments is only available for northern Europe, particularly Norway (Hesthagen et al 1992, Museth et al 2010). The aim of this study was to analyze the diet of introduced minnows in sympatry with introduced salmonids in an Italian high mountain lake, to increase our understanding of their feeding habits in these peculiar environments.

Materials and methods

Study area

Lake Fiorenza (fig. 1) is a small high mountain (2,113 m a.s.l.) oligotrophic lake of glacial origin located in the Po Valley (NW Italy), within the Monviso Natural Park (44.6971ºN, 7.0927ºE; WGS84). It has a surface area of 2.3 ha and a maximum depth of 15 m. During summer, the average surface temperature is 12.5 ºC. From a depth of 6 m downward, the temperature gradually drops to 6 ºC. This temperature decrease is also accompanied by a slight decline in pH and oxygen levels from the surface to the bottom, along with a slight increase in conductivity (Gentili et al 2002, Conseil Supérieur de la Pêche 2006).

Originally, this lake was fishless and has undergone a series of fish introductions, dating back to the 1960s. Most of these introductions were carried out by individual fishermen or local fishing societies, resulting in a lack of a clear historical record.

Today, the fish community in the lake includes brown trout *Salmo trutta* Linnaeus, 1758, minnow *Phoxinus* spp., and occasional rainbow trout *Oncorhynchus mykiss* Walbaum, 1792 (Gentili et al 2002, Fenoglio 2010). Recent genetic analyses indicate that *Phoxinus lumaireul* (Schinz, 1840), native to the Central Balkans, co-occurs in Lake Fiorenza with *Phoxinus csikii* (Hankó, 1992) (De Santis et al 2021). Since minnow species show minimal morphological differences and phenotypic plasticity (Rampler et al 2016), and no genetic analysis was conducted in this study, we refer to all minnows as *Phoxinus* spp.

Fish sampling and analysis of stomach contents

On August 19, 2019, 46 minnows were collected via electrofishing using a Scubla IG200/2 device. The fish were euthanized with an overdose of clove oil and preserved in 80 % ethanol.

In the laboratory, each fish was measured to an accuracy of 0.1 mm (total length). The digestive tracts were then extracted, and their contents analyzed using a Nikon SMZ 1500 light microscope (magnification 60-100 x) coupled with

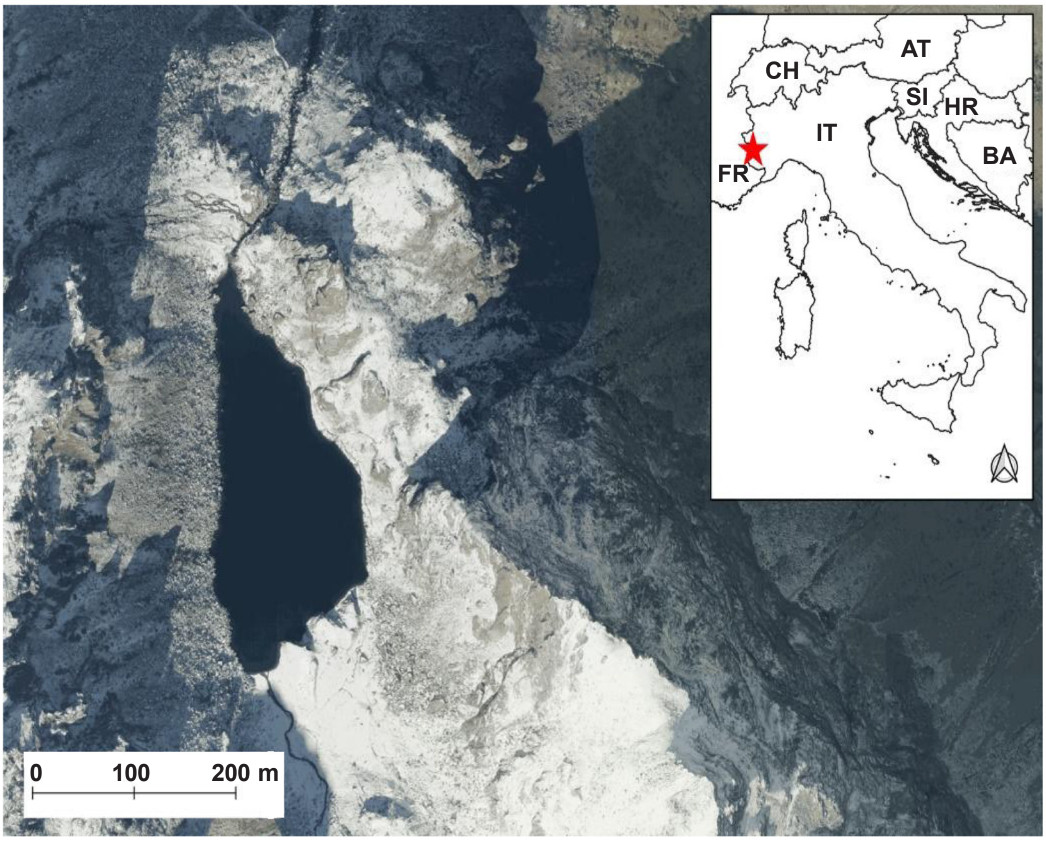

Fig. 1. Study area and location of Lake Fiorenza (NW Italy, 44.6971ºN, 7.0927ºE; WGS84).

***Fig. 1**. Área de estudio y ubicación del Lago Fiorenza (noroeste de Italia, 44.6971ºN, 7.0927ºE; WGS84).*

a Sony HD video camera and a Samsung LCD monitor. Prey identification and counting were based on sclerotized body parts, such as head capsules, mouth parts, wings, and leg fragments. According to Stewart and Stark (2002), counting sclerotized fragments (e.g., head capsules or legs) can provide a reasonably accurate estimate of prey consumed. This method has been employed in various scientific studies on the diets of both vertebrates (e.g., Bo et al 2012) and invertebrates (e.g., Fenoglio et al 2007, 2008).

Prey were categorized into groups and subgroups at different taxonomic levels. Insects were divided into orders ('groups') and, where possible, into suborders or families ('subgroups'). Other prey items were identified at the most reliable taxonomic level available. For each prey, the life stage (larva, nymph, pupa, or adult) and environment (terrestrial or aquatic) were recorded. For each group, subgroup, and variable (life stage and environment), a percentage frequency was calculated as the ratio between the number of fish containing that prey and the total number of fish examined. Since the life stage of insects is closely related to their environment, and the results for these two variables were redundant, we focused on and presented the results for the environment variable (terrestrial/aquatic).

Results

In total, 46 minnows were analyzed. Their mean length was 6.15 ± 0.41 cm (range: 5.3-7.0 cm). All stomachs contained prey. Mites (subclass Acarina), bivalves (class Bivalvia) of the genus *Pisidium*, and several orders of insects (Coleoptera, Diptera, Heteroptera, Homoptera, Hymenoptera, Plecoptera, Thysanoptera, Trichoptera) were identified. On average, there were 34.3 ± 22.2 (range: 9-112) prey items per minnow (fig. 2). Additionally, 0.85 ± 1.09 (range: 0-5) prey items per minnow could not be identified. No plant material or zooplankton specimens were found or identified. The table showing the stomach contents of each minnow can be found in the supplementary material (table 1s).

Diptera were the most frequent prey, present in 100 % of the fish. They were followed by Coleoptera, Homoptera, Hymenoptera, and Thysanoptera. Diptera were also the most abundant prey, with a total of 1,204 individuals counted, followed by Homoptera with 107 individuals. Among Diptera, Brachycera were the most frequent prey (95.7 %), followed by Chironomidae (80.4 %). However, Chironomidae were the most abundant subgroup, with 843 individuals counted.

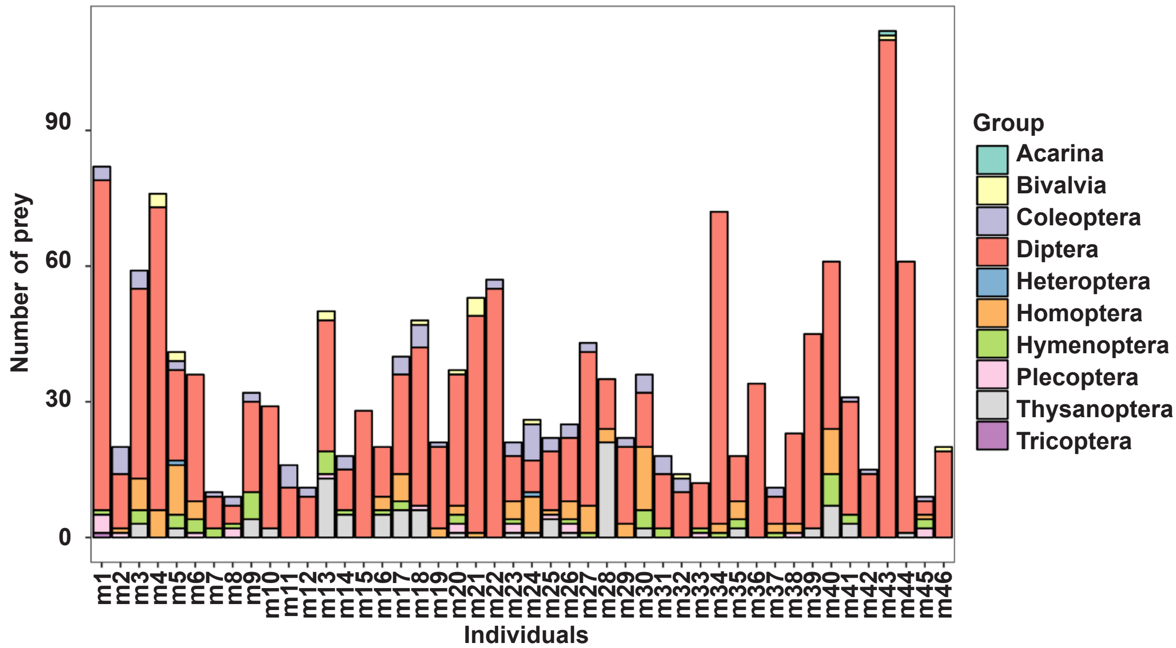

Fig. 2. Number of prey items divided by group identified in each minnow.

Fig. 2. *Número de presas clasificados por grupo, identificados en cada piscardo.*

All minnows had fed on prey of terrestrial origin (remains of which were present in 100 % of the stomachs examined), while 82 % of the fish had consumed aquatic prey. Of the subgroups identified, 12 are terrestrial and six are aquatic. The most frequent terrestrial prey were winged forms of Brachycera (Diptera), Nematocera (Diptera), Coleoptera, Homoptera, Hymenoptera, and Thysanoptera (fig. 3). Among aquatic prey, Chironomidae larval stages were the most common, followed by *Pisidium* bivalves (fig. 3). In terms of abundance, a total of 727 terrestrial prey and 852 aquatic prey items were counted. Aquatic Chironomidae dominated with 829 individuals, while the most abundant terrestrial prey were adults of Brachycera and Nematocera (fig. 4).

Discussion

The introduction of non-native species always causes changes and disruptions to local biological communities, and this is particularly true for freshwater fish, which are probably the most displaced and introduced group of animals by humans (Britton 2023). Examples of introductions between catchment areas (e.g., Welsh catfish in Southern Europe, Mancini et al 2022) or even between continents (e.g., brown trout in New Zealand, Jones and Closs 2017) are well documented. However, within-catchment introductions –such as those in high mountain lakes– are perhaps less studied. In these naturally fishless environments, there is a long history of salmonid introductions for angling purposes (Miró and Ventura 2020, Tiberti et al 2014). The subsequent introduction of small cyprinids (mainly *Phoxinus* spp.) is linked, on one hand, to live bait fishing and, on the other, to the need to provide food for salmonids (Museth et al 2007). While studies on the diet of trout in high mountain lakes are available (e.g., Cavalli et al 1998, Tiberti et al 2016), research on the diet of minnows in these environments remains scarce.

One of the main findings of our work is that the analyzed minnows exploit a broader range of non-aquatic than aquatic trophic resources, particularly winged insects that fall onto the lake's surface. In fact, the diversity of terrestrial prey is twice that of aquatic prey. Moreover, terrestrial prey are consumed more frequently than aquatic prey, to the extent that some specimens had only terrestrial prey in their stomachs. Another significant finding is the low diversity of aquatic prey, with chironomids dominating the minnows' diet in terms of both frequency and abundance among the aquatic component. Several factors may explain these results. First, high mountain lakes are oligotrophic environments where the scarcity of nutrients such as phosphates and nitrates limits phytoplankton presence, thereby preventing the development of rich and abundant aquatic communities (Füreder et al 2006). This results in chironomids, which are well adapted to challenging environments, becoming the most abundant and available component of the macrobenthos in these lakes (Čiamporová-Zaťovičová et al 2010, Fjellheim et al 2009, Füreder et al 2006, Gabetti et al 2024). Consequently, minnows in Lake Fiorenza likely feed mainly on *Chironomidae* larvae because they are the most abundant and accessible part of

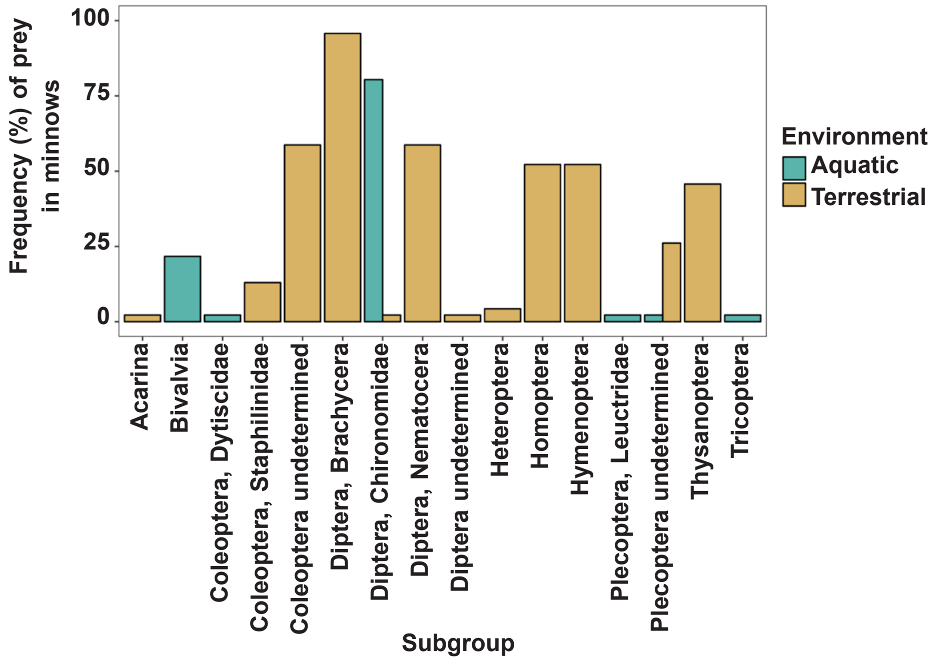

Fig. 3. Frequency (%) of prey in minnows by type of environment (aquatic/terrestrial).

Fig. 3*. Frecuencia (%) de presas en piscardos según el tipo de entorno (acuático/terrestre).*

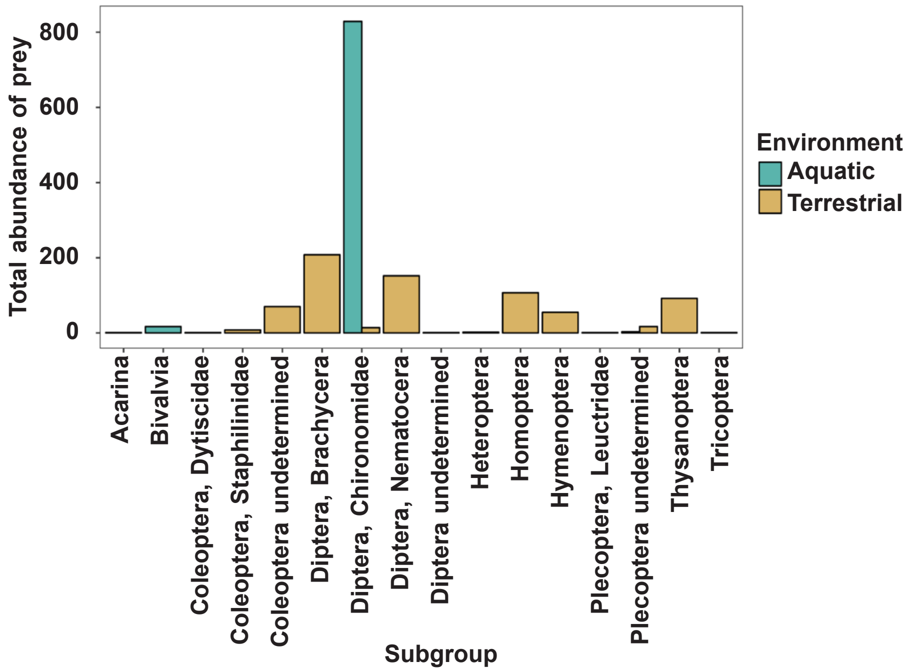

Fig. 4. Total abundance of prey by type of environment (aquatic/terrestrial).

Fig. 4*. Abundancia total de presas según el tipo de entorno (acuático/terrestre).*

the macrobenthic community, rather than due to a specific preference. This aligns with findings by Museth et al (2010), who observed in a Norwegian lake where *Phoxinus* spp. and *Salmo trutta* coexisted that both species showed a marked preference for feeding on chironomid larvae.

Another important factor to consider is that the long-term presence of non-native fish has led to a decline in the lake's natural biodiversity (Osorio et al 2022, Schabetsberger and Jersabek 1995), which is likely reflected in the minnows' diet. This could explain the low diversity of aquatic prey, which is directly influenced by predation pressure from aquatic predators. In contrast, terrestrial prey reach the lake surface incidentally from the surrounding environment, and their overall diversity is not directly affected by minnow predation.

Finally, it should be noted that the sample analyzed in this study was collected during a single sampling event. Therefore, while the results provide valuable insights into the diet of introduced minnows in high mountain lakes, some aspects of their trophic habits may have gone undetected. For example, the absence of zooplankton and plant material in the sample may reflect this limitation; it is possible that the minnows were collected at a time when these components were not part of their diet.

In conclusion, although the data are limited to a single high mountain lake, they contribute to the growing body of knowledge in trophic ecology, which has become a central element in freshwater sciences. There is a crucial need to expand our understanding of the foraging behavior of aquatic organisms, as this is essential for describing ecological interactions, analyzing trophic webs, investigating the impacts of invasive species, and better understanding the functional dynamics of inland water ecosystems.

References

Bo T, Cammarata M, Candiotto A, Fenoglio S, 2012. Trophic preferences of three allochthonous fishes in Bormida River (Alessandria, NW Italy). *Hidrobiológica* 22(3), 195-200. https://hidrobiologica.izt.uam.mx/index.php/revHidro/article/view/713

Britton JR, 2023. Contemporary perspectives on the ecological impacts of invasive freshwater fishes. *Journal of Fish Biology* 103(4), 752-764. DOI: 10.1111/jfb.15240

Catalan J, Camarero L, Felip M, Pla S, Ventura M, Buchaca T, Bartumeus F, De Mendoza G, Miró A, 2006. High mountain lakes: extreme habitats and witnesses of environmental changes. *Limnetica* 25(1-2), 551-584. DOI: 10.23818/limn.25.38

Cavalli L, Chappaz R, Gilles A, 1998. Diet of Arctic charr (*Salvelinus alpinus* (L.)) and brown trout (*Salmo trutta* L.) in sympatry in two high altitude alpine lakes. *Hydrobiologia* 386(1), 9-17. DOI: 10.1023/A:1003466725314

Čiamporová-Zaťovičová Z, Hamerlík L, Šporka F, Bitušík P, 2010. Littoral benthic macroinvertebrates of alpine lakes (Tatra Mts) along an altitudinal gradient: a basis for climate change assessment. *Hydrobiologia* 648, 19-34. DOI: 10.1007/s10750-010-0139-5

Conseil Supérieur de la Pêche, 2006. *Lago Fiorenza: Approche écologique et toxicologique*. Rapport Interreg III A-Aqua, Regione Piemonte, Italy.

De Santis V, Delmastro GB, Vanetti I, Britton JR, Zaccara S, 2021. Species composition of introduced and natural minnow populations of the Phoxinus cryptic complex in the westernmost part of the Po River Basin (north Italy). *Biological Invasions* 23, 657-668. DOI: 10.1007/s10530-020-02406-2

Fenoglio S, 2010. *Alla scoperta della natura in Valle Po. Parco del Po Cuneese, Regione Piemonte*. Ed. NuovaStampa. Available online at: https://www.piemonteparchi.it/cms/index.php/news/itemlist/tag/Parco%20del%20Po%20cuneese?start=12

Fenoglio S, Bo T, Tierno de Figueroa JM, Cucco M, 2008. Nymphal growth, life cycle, and feeding habits of *Potamanthus luteus* (Linnaeus, 1767) (Insecta: Ephemeroptera) in the Bormida River, Northwestern Italy. *Zoological Studies* 47(2), 185-190.

Fenoglio S, Bo T, Pessino M, Malacarne G, 2007. Feeding of *Perla grandis* nymphs (Plecoptera: Perlidae) in an Apennine first order stream (Rio Berga, NW Italy). *Annales de la Société entomologique de France (N.S.)* 43, 221-224.

Fjellheim A, Raddum GG, Vandvik V, Cogălniceanu D, Boggero A, Brancelj A, Galas J, Sporka F, Vidinova Y, Bitusik P, Dumnicka E, Galdean N, Kownacki A, Krno I, Preda E, Rîşnoveanu G, Stuchlik E, 2009. Diversity and distribution patterns of benthic invertebrates along alpine gradients. A study of remote European freshwater lakes. *Advances in Oceanography and Limnology* 62, 167-190.

Füreder L, Ettinger R, Boggero A, Thaler B, Thies H, 2006. Macroinvertebrate diversity in Alpine lakes: effects of altitude and catchment properties. *Hydrobiologia* 562, 123-144. DOI: 10.1007/s10750-005-1808-7

Gabetti A, Maganza A, Mossotto C, Rizzioli B, Esposito G, Bertoli M, Pizzul E, Bozzetta E, Prearo M, Pastorino P, 2024. Macrobenthic assemblages and the influence of microhabitat in a high-mountain lake (Northwest Italy). *Diversity* 16(6), 329. DOI: 10.3390/d16060329

Gentili G, Romanò A, Puzzi C, Bardazzi M, Jacovino M, Bucchini A, Compare S, 2002. *Studio sull'ecologia dei laghi alpini della Provincia di Cuneo*. Settore tutela fauna e pesca, Provincia di Cuneo, Italy.

Hesthagen T, Hegge O, Skurdal J, 1992. Food choice and vertical distribution of European minnow, *Phoxinus phoxinus*, and young native and stocked brown trout, *Salmo trutta*, in the littoral zone of a subalpine lake. *Nordic Journal of Freshwater Research* 67, 72-76.

Jones P, Closs G, 2017. The introduction of brown trout to New Zealand and their impact on native fish communities. In: *Brown Trout: Bioology, Ecology and Management*: 545-567 (L Lobón-Cerviá, N Sanz, Eds). John Wiley & Sons, Ltd, Hoboken, New Jersey.

Knapp RA, Matthews KR, Sarnelle O, 2001. Resistance and resilience of alpine lake fauna to fish introductions. *Ecological Monographs* 71, 401-421. DOI: 10.1890/0012-9615(2001)071[0401:RAROAL]2.0.CO;2

Mancini E, Tiralongo F, Collepardo Coccia F, Pieracci D, Tentoni E, Ceci M, Cerioni S, 2022. The wels catfish *Silurus glanis* Linnaeus, 1758 (Actinopterygii Siluriformes) in Italian waters: a review with first report in the Bolsena lake (Italy). *Biodiversity Journal* 13(6), 673-684. DOI: 10.31396/Biodiv.Jour.2022.13.3.673.684

Miró A, Sabás I, Ventura M, 2018. Large negative effect of non-native trout and minnows on Pyrenean lake amphibians. *Biological Conservation* 218, 144-153. DOI: 10.1016/j.biocon.2017.12.030

Miró A, Ventura M, 2020. Introduced fish in Pyrenean high mountain lakes: impact on amphibians and other organisms, and conservation implications. *Limnetica* 39(1), 283-297. DOI: 10.23818/limn.39.19

Miró A, Ventura M, 2015. Evidence of exotic trout mediated minnow invasion in Pyrenean high mountain lakes. *Biological Invasions* 17, 791-803.

Museth J, Borgstrøm R, Brittain JE, 2010. Diet overlap between introduced European minnow (*Phoxinus phoxinus*) and young brown trout (*Salmo trutta*) in the lake, Øvre Heimdalsvatn: a result of abundant resources or forced niche overlap? *Hydrobiologia* 642, 93-100. DOI: 10.1007/978-90-481-9388-2_9

Museth J, BorgstrØm R, Hame T, Holen LÅ, 2003. Predation by brown trout: a major mortality factor for sexually mature European minnows. *Journal of Fish Biology* 62(3), 692-705. DOI: 10.1046/j.1095-8649.2003.00059.x

Museth J, Hesthagen T, Sandlund OT, Thorstad EB, Ugedal O, 2007. The history of the minnow *Phoxinus phoxinus* (L.) in Norway: from harmless species to pest. *Journal of Fish Biology* 71, 184-195. DOI: 10.1111/j.1095-8649.2007.01673.x

Næstad F, Brittain JE, 2010. Long-term changes in the littoral benthos of a Norwegian subalpine lake following the introduction of the European minnow (*Phoxinus phoxinus*). *Hydrobiologia* 642(1), 71-79. DOI: 10.1007/s10750-010-0160-8

Osorio V, Puig MÁ, Buchaca T, Sabas I, Miró A, Lucati F, Suh J, Pou-Rovira Q, Ventura M, 2022. Non-native minnows cause much larger negative effects than trout on littoral macroinvertebrates of high mountain lakes. *Biological Conservation* 272, 109637. DOI: 10.1016/j.biocon.2022.109637

Parker BR, Schindler DW, Donald DB, Anderson RS, 2001. The effects of stocking and removal of a nonnative salmonid on the plankton of an Alpine lake. *Ecosystems* 4, 334-345. DOI: 10.1007/s10021-001-0015-2

Pastorino P, Elia AC, Pizzul E, Bertoli M, Renzi M, Prearo M, 2024. The old and the new on threats to high-mountain lakes in the Alps: A comprehensive examination with future research directions. *Ecological Indicators* 160, 111812. DOI: 10.1016/j.ecolind.2024.111812

Pastorino P, Prearo M, 2020. High-mountain lakes, indicators of global change: ecological characterization and environmental pressures. *Diversity* 12(6), 260. DOI: 10.3390/d12060260

Perilli S, Pastorino P, Bertoli M, Salvi G, Franz F, Prearo M, Pizzul E, 2020. Changes in midge assemblages (Diptera Chironomidae) in an alpine lake from the Italian Western Alps: the role and importance of fish introduction. *Hydrobiologia* 847, 2393-2415. DOI: 10.1007/s10750-020-04257-3

Ramler D, Palandačić A, Delmastro GB, Wanzenböck J, Ahnelt H, 2017. Morphological divergence of lake and stream *Phoxinus* of Northern Italy and the Danube basin based on geometric morphometric analysis. *Ecology and Evolution* 7(2), 572-584. DOI: 10.1002/ece3.2648

Sommaruga R, 2001. The role of solar UV radiation in the ecology of alpine lakes. *Journal of Photochemistry and Photobiology B: Biology* 62(1-2), 35-42. DOI: 10.1016/S1011-1344(01)00154-3

Schabetsberger R, Jersabek C, 1995. The impact of alpine newts (*Triturus alpestris*) and minnows (*Phoxinus phoxinus*) on the micro-crustacean communities of two high altitude karst lakes. *Alytes* (12), 183-189.

Stewart K, Stark B, 2002. *Nymphs of the North American Stonefly Genera*. Caddis Press, Columbus.

Tiberti R, Brighenti S, Canedoli C, Iacobuzio R, Pasquini G, Rolla M, 2016. The diet of introduced brook trout (*Salvelinus fontinalis*; Mitchill, 1814) in an alpine area and a literature review on its feeding ecology. *Journal of Limnology* 75(3), 488-507. DOI: https://doi.org/10.4081/jlimnol.2016.1366

Tiberti R, Buchaca T, Cruset Tonietti E, Iacobelli L, Maini Ribelli F, Pou-Rovira Q, Ventura M, 2022. Minnow introductions in mountain lakes result in lower salmonid densities. *Biological Invasions* 24, 2285-2289. DOI: 10.1007/s10530-022-02783-w

Tiberti R, 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. DOI: 10.1163/156853812X634044

Tiberti R, Von Hardenberg A, Bogliani G, 2014. Ecological impact of introduced fish in high altitude lakes: a case of study from the European Alps. *Hydrobiologia* 724, 1-19. DOI: 10.1007/s10750-013-1696-1

Zerunian S, 2004. Pesci delle acque interne d'Italia. *Quaderni di Conservazioni della Natura*, 20. Ministero dell'Ambiente e della Tutela del Territorio, Istituto Nazionale per la Fauna Selvatica, Italy.

Acknowledgements
We would thank M. Cammarata and A. Candiotto for help during sampling activities.

Author's contributions
All authors contributed to the observations and study conception.

Conflicts of interest
No conflicts declared.

Complete affiliations
Margherita Abbà, Stefano Fenoglio, Tiziano Bo, DBIOS, University of Turin, Via Accademia Albertina, 13, 10123 Turin, Italy and ALPSTREAM–Alpine Stream Research Center, 12030 Ostana, Italy.

Suplemmentary material

Table 1s. Stomach contents of each minnow classified by group, subgroup and type of environment.

***Table 1s**. Contenido estomacal de cada piscardo clasificado según grupo, subgrupo y tipo de ambiente.*

		Group / Subgroup / Type																			
		Plecoptera	Plecoptera	Plecoptera	Tricoptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Coleoptera	Coleoptera	Coleoptera	Heteroptera	Homoptera	Thysanoptera	Hymenoptera	Bivalvia	Acarina	Undetermined
		Undetermined	Undetermined	Leuctridae	Undetermined	Brachicera	Nematocera	Chironomidae	Chironomidae	Chironomidae	Undetermined	Staphilinidae	Undetermined	Dytiscidae	Undetermined	Undetermined	Undetermined	Undetermined	Undetermined	Undetermined	Undetermined
Minnow	Size (cm)	Terrestrial	Aquatic	Aquatic	Aquatic	Terrestrial	Terrestrial	Aquatic	Aquatic	Terrestrial	Terrestrial	Terrestrial	Terrestrial	Aquatic	Terrestrial	Terrestrial	Terrestrial	Terrestrial	Aquatic	Terrestrial	NA
m1	5.8	0	3	1	1	2	15	56	0	0	0	2	1	0	0	0	0	1	0	0	0
m2	5.9	1	0	0	0	12	0	0	0	0	0	0	6	0	0	1	0	0	0	0	0
m3	5.7	0	0	0	0	9	0	19	0	14	0	0	4	0	0	7	3	3	0	0	0
m4	6.6	0	0	0	0	2	0	65	0	0	0	0	0	0	0	6	0	0	3	0	0
m5	5.9	0	0	0	0	3	0	16	1	0	0	1	1	0	1	11	2	3	2	0	2
m6	6.3	1	0	0	0	6	4	18	0	0	0	0	0	0	0	4	0	3	0	0	0
m7	5.8	0	0	0	0	5	0	0	2	0	0	0	1	0	0	0	0	2	0	0	2
m8	6.6	2	0	0	0	4	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0
m9	6.7	0	0	0	0	11	0	6	3	0	0	0	2	0	0	0	4	6	0	0	3
m10	6.2	0	0	0	0	1	0	22	4	0	0	0	0	0	0	0	2	0	0	0	1
m11	6.7	0	0	0	0	6	0	4	1	0	0	0	5	0	0	0	0	0	0	0	1
m12	6.3	0	0	0	0	5	0	4	0	0	0	0	2	0	0	0	0	0	0	0	2
m13	6.5	1	0	0	0	3	6	20	0	0	0	0	0	0	0	0	13	5	2	0	1
m14	6.2	0	0	0	0	6	3	0	0	0	0	0	3	0	0	0	5	1	0	0	0
m15	5.8	0	0	0	0	8	0	17	3	0	0	0	0	0	0	0	0	0	0	0	1
m16	5.7	0	0	0	0	2	5	4	0	0	0	0	0	0	0	3	5	1	0	0	1
m17	6.7	0	0	0	0	3	3	16	0	0	0	0	4	0	0	6	6	2	0	0	1
m18	6.7	1	0	0	0	8	3	24	0	0	0	0	5	0	0	0	6	0	1	0	0
m19	5.8	0	0	0	0	3	9	6	0	0	0	0	1	0	0	2	0	0	0	0	0
m20	5.5	2	0	0	0	12	10	7	0	0	0	0	0	0	0	2	1	2	1	0	2
m21	6.8	0	0	0	0	1	0	46	1	0	0	0	0	0	0	1	0	0	4	0	1
m22	5.7	0	0	0	0	2	1	45	7	0	0	1	1	0	0	0	0	0	0	0	0
m23	6.4	2	0	0	0	5	5	0	0	0	0	1	2	0	0	4	1	1	0	0	0
m24	6.5	0	0	0	0	3	4	0	0	0	0	0	8	0	1	8	1	0	1	0	0
m25	5.9	1	0	0	0	4	4	5	0	0	0	1	2	0	0	1	4	0	0	0	5
m26	6.1	2	0	0	0	8	5	0	1	0	0	0	3	0	0	4	1	1	0	0	2
m27	6.3	0	0	0	0	6	9	19	0	0	0	0	2	0	0	6	0	1	0	0	1
m28	5.5	0	0	0	0	3	4	3	1	0	0	0	0	0	0	3	21	0	0	0	0
m29	6.3	0	0	0	0	2	0	11	4	0	0	0	2	0	0	3	0	0	0	0	2
m30	5.8	0	0	0	0	1	11	0	0	0	0	2	2	0	0	14	2	4	0	0	2
m31	6	0	0	0	0	5	7	0	0	0	0	0	4	0	0	0	0	2	0	0	2
m32	6.4	0	0	0	0	2	0	6	2	0	0	0	2	1	0	0	0	0	1	0	0
m33	6.2	1	0	0	0	4	0	0	6	0	0	0	0	0	0	0	0	1	0	0	0
m34	6.3	0	0	0	0	7	6	47	9	0	0	0	0	0	0	2	0	1	0	0	0
m35	5.9	0	0	0	0	2	7	1	0	0	0	0	0	0	0	4	2	2	0	0	0
m36	6	0	0	0	0	2	0	31	1	0	0	0	0	0	0	0	0	0	0	0	0
m37	5.9	0	0	0	0	4	2	0	0	0	0	0	2	0	0	2	0	1	0	0	0
m38	6.6	1	0	0	0	5	0	15	0	0	0	0	0	0	0	2	0	0	0	0	0
m39	7	0	0	0	0	6	2	27	8	0	0	0	0	0	0	0	2	0	0	0	0
m40	6.1	0	0	0	0	6	17	5	9	0	0	0	0	0	0	10	7	7	0	0	0
m41	5.9	0	0	0	0	10	4	8	3	0	0	0	1	0	0	0	3	2	0	0	0
m42	5.4	0	0	0	0	0	0	12	1	0	1	0	1	0	0	0	0	0	0	0	2
m43	5.3	0	0	0	0	3	0	93	14	0	0	0	0	0	0	0	0	0	1	1	0
m44	6.5	0	0	0	0	0	1	55	4	0	0	0	0	0	0	0	1	0	0	0	1
m45	6.7	2	0	0	0	1	2	0	0	0	0	0	1	0	0	1	0	2	0	0	2
m46	6.3	0	0	0	0	5	3	9	2	0	0	0	0	0	0	0	0	0	1	0	2