

Atti del convegno BioDiv Verbania Pallanza 2025



La riqualificazione degli ecosistemi: tra cambiamento globale e politiche pubbliche

6 - 7 novembre 2025



Convivere con la biodiversità nell'interfaccia terra-mare

Atti del convegno BioDiv Verbania Pallanza 2025

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a cura di

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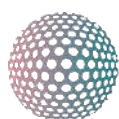
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Prefazione

Il fatto che la qualità della nostra vita dipenda dalla qualità dell'ambiente in cui viviamo è talmente evidente che non se ne dovrebbe nemmeno discutere. Invece, il confronto politico intorno al ripristino della funzionalità degli ecosistemi è ancora un aspetto chiave delle normative ambientali europee tanto che la "Nature Restoration Law", entrata in vigore nell'Agosto 2024 in tutti i paesi membri dell'Unione Europea, è passata attraverso una travagliata serie di problemi dovuti alla mancanza di consensi e ha più volte rischiato di non vedere la luce.

Il riconoscimento dell'importanza della biodiversità e degli ecosistemi sta prendendo piede anche in Italia, con un'accelerazione evidente negli ultimi anni: nel 2022 questi termini sono entrati nella nostra costituzione e uno dei cinque Centri Nazionali istituiti nel nostro paese e finanziati dal 2022 al 2025 grazie ai fondi PNRR, il National Biodiversity Future Center, è relativo alla biodiversità.

Proprio per questi motivi, BioDiv2025, il momento di incontro tra giovani esponenti della comunità scientifica italiana in campo ambientale, quest'anno arrivato al suo sesto appuntamento, ha avuto come tema "La riqualificazione degli ecosistemi: tra cambiamento globale e politiche pubbliche". L'incontro si è svolto in due giornate, il 6 e 7 novembre, sulle sponde del Lago Maggiore a Verbania. Grazie al patrocinio del Comune di Verbania, l'incontro è stato organizzato nelle sale di Villa Giulia, elegante palazzina legata alle vicende della famiglia Branca, famosa per il Fernet. L'incontro è stato supportato dal "Biodiversity Gateway" del "National Biodiversity Future Center", con lo scopo di discutere di argomenti relativi alla biodiversità. L'organizzazione ha cercato di attirare interventi e partecipanti che aggiungessero approcci interdisciplinari alla biodiversità, proprio per riflettere anche sul fatto che nel momento in cui il termine "biodiversità" diventa di dominio pubblico e non rimane più ristretto solo ad una piccola cerchia di esperti ecologi, anche il significato del termine stesso si allarga ed include una maggiore varietà di argomenti e idee, con cui è doveroso confrontarsi. Come CNR-IRSA di Verbania siamo stati contenti ed orgogliosi di essere riusciti ad aiutare Successione Ecologica a continuare la tradizione degli incontri BioDiv: è stato davvero bello vedere così tante interazioni formali ed informali tra studentesse/studenti, dottorandæ e giovani ricercatrici/ricercatori entusiastæ di lavorare sulla biodiversità. La partecipazione è infatti andata ben oltre le aspettative degli organizzatori, per il gran numero di relazioni e poster, ma soprattutto per l'altissima partecipazione di iscrittæ anche solo per osservare le novità italiane e per discutere insieme di biodiversità ed ecologia.

Vi auguro una buona lettura dei testi prodotti per questo volume, che rappresentano un sunto degli argomenti discussi durante BioDiv2025.

Diego Fontaneto

PRESENTAZIONI ORALI

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Dalla ricerca all'azione: selezione dei siti per il ripristino dell'habitat di una farfalla in pericolo critico

Abstract. *Insect diversity is undergoing a rapid global decline. Numerous endemic European butterflies are currently threatened with extinction. This study focuses on *Polyommatus humedasaе*, a butterfly species restricted to a small area in northwestern Italy, threatened by forest encroachment. We developed an operational approach based on high-resolution distribution models, combining information available from a previous capture–mark–recapture study with vegetation indices derived from remote sensing. The resulting suitability map made it possible to assess connectivity and to identify priority areas for restoration, selecting 0.6 hectares that were recently subjected to forest thinning, with the aim of primarily facilitating the movements of the species.*

Negli ultimi decenni si assiste ad un declino globale della diversità di insetti, con numerose farfalle europee minacciate da perdita e degradazione dell'habitat, inquinamento e cambiamenti climatici (Warren *et al.*, 2021). I cambiamenti nell'uso del suolo e l'aumento delle temperature stanno modificato le comunità di farfalle alpine, favorendo specie mobili e tolleranti, mentre le specie stanziali e specialiste rimangono particolarmente vulnerabili (Bonelli *et al.*, 2022, Maes *et al.*, 2022). In Europa, circa il 25% delle specie endemiche valutate è attualmente minacciato, in particolare quelle associate ad habitat aperti e semi-aperti (IUCN, 2025). *Polyommatus humedasaе* (Toso & Balletto, 1976), farfalla monofaga e monovoltina endemica del nord-ovest Italia, dove occupa una porzione ristretta e frammentata della Valle d'Aosta, principalmente all'interno del SIC Pont'Ael. Si riproduce su *Onobrychis arenaria* in praterie aride e parzialmente ombreggiate. La specie, classificata recentemente come Critically Endangered (Piccini *et al.*, 2024), è minacciata dalla progressiva invasione arborea dovuta all'abbandono del territorio, una problematica già segnalata oltre vent'anni fa per questa specie (van Swaay and Warren, 1999). Interventi gestionali mirati erano quindi necessari per ripristinare gli habitat della specie nell'Area Protetta, pur preservando l'eterogeneità del paesaggio e altri elementi di interesse conservazionistico presenti.

I dati di presenza di sono stati raccolti da Piccini *et al.* (2024) in uno studio di cattura marcatura-ricattura (MRR) condotto nell'estate 2022 (468 osservazioni su 341 individui). L'elevata concentrazione spaziale delle occorrenze indicava aree chiave e i dati di ricattura suggerivano l'esistenza di limitazioni negli

spostamenti. Dopo un rigoroso filtraggio per ridurre bias e autocorrelazione, sono state utilizzate 28 presenze per la modellizzazione.

Sono stati selezionati dati ambientali ad alta risoluzione (10 m), comprendenti variabili topografiche e indici di vegetazione da Sentinel-2, utili a descrivere l'habitat della specie e delle piante ospiti. Un'analisi delle Componenti Principali (PCA) esplorativa ha permesso di ridurre il numero di predittori, eliminando variabili ridondanti o poco informative. Tramite una seconda PCA eseguita su questi, sono stati selezionati due predittori non altamente correlati che riassumevano il 95% della varianza totale.

Per predire la distribuzione della specie è stato costruito un modello *ensemble* basato su due algoritmi: MaxEnt e GLM. MaxEnt ha utilizzato solo dati di presenza confrontati con un campione di background (Phillips *et al.*, 2006), mentre GLM ha impiegato anche pseudo-assenze generate attorno alle presenze MRR. I dati sono stati suddivisi in blocchi spaziali per la validazione incrociata e i modelli calibrati con ottimizzazione dei parametri. L'ensemble finale ha prodotto una mappa di idoneità, utilizzata per individuare aree idonee e non idonee. Queste informazioni sono state utilizzate per valutare la connettività nell'area, sulla base della teoria dei circuiti elettronici (McRae *et al.* 2008). Dai risultati, è stato possibile individuare aree che fungono da barriera ai movimenti, aree maggiormente permeabili e aree formanti colli di bottiglia.

Sono stati eseguiti rilievi in campo per stimare la copertura arborea ottimale per la specie, individuando la relazione tra questa e l'idoneità calcolata.

Infine, le superfici da destinare a ripristino sono state selezionate privilegiando aree con priorità basata sul miglioramento della connettività. La scelta finale è stata definita tramite sopralluoghi sul campo, valutando l'impatto su altri elementi di importanza conservazionistica, accessibilità e risorse disponibili (Figs 1-2).

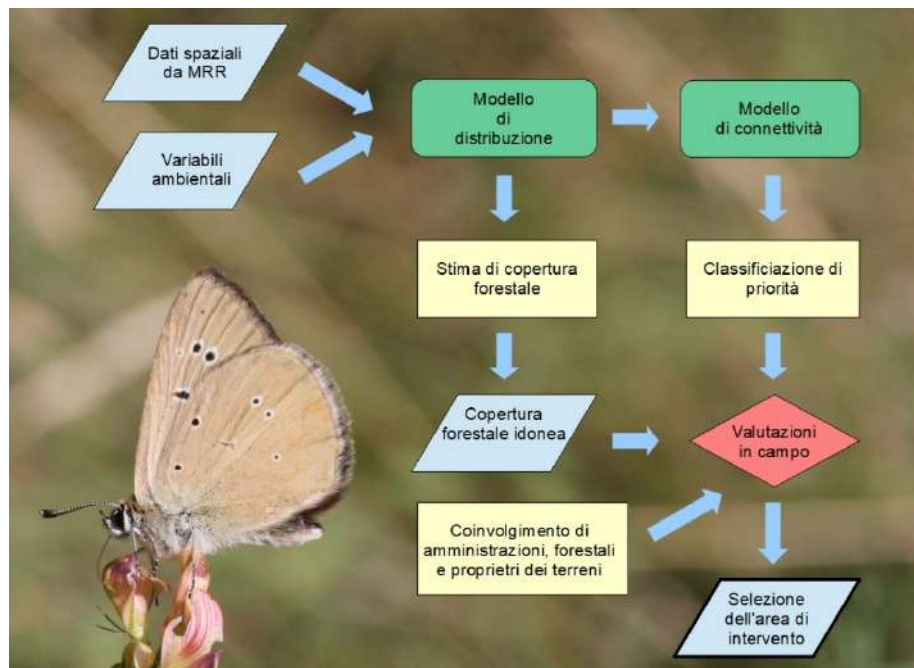


Figura 1 - Rappresentazione schematica del workflow implementato per selezionare l'area destinata al primo intervento di ripristino dell'habitat di *P. humedasa*



Figura 2 - A) Mappa raffigurante la classificazione della priorità di intervento. In nero il perimetro dell'area selezionata. B) Operatori forestali intenti ad effettuare il diradamento nell'inverno 2024

L'ensemble model ha mostrato buona capacità predittiva ($AUC = 0.75$, $TSS = 0.53$). La probabilità di presenza della farfalla è principalmente determinata dalla copertura arborea, ottimale tra 23% e 80%. Oltre metà dell'area iniziale non è risultata idonea per copertura troppo alta ($>80\%$) e solo una piccola parte rientra nella priorità massima. Dopo le valutazioni in campo, è stata selezionata un'area da destinare a diradamento di circa 6'382 m². L'intervento, effettuato nell'inverno 2024, ha ridotto la copertura arborea al 25%, prestando attenzione a non intaccare habitat e microhabitat rilevanti per altri elementi conservazionistici.

Il modello di distribuzione della specie è stato costruito con variabili derivate da indici vegetazionali, ottimizzando le informazioni derivanti da uno studio intensivo di MRR. Le mappe di idoneità e i rilievi in campo hanno confermato che *P. humedasae* predilige zone transitorie con copertura arborea moderata, dove probabilmente larve e adulti trovano microclimi e risorse adeguate. La densità degli alberi eccessiva ($>80\%$) rende le aree inadatte e pertanto suscettibili ad interventi di ripristino; quelle con copertura troppo bassa non richiedono interventi, poiché il rimboschimento naturale è atteso. La selezione dei siti di ripristino ha privilegiato piccole aree strategiche per la connettività, individuando 0.6 ha sottoposti a diradamento forestale nel dicembre 2024. I sopralluoghi hanno escluso zone inaccessibili o ospitanti altri elementi di interesse conservazionistico. L'intervento, a basso costo e rapido, ha cercato di migliorare la disponibilità di habitat idoneo con particolare attenzione al miglioramento della connettività.

Lo studio ha dimostrato come l'approccio modellistico a scala fine basato su dati derivanti da monitoraggio intensivo possa guidare le scelte mirate alla conservazione di specie endemiche minacciate di aree semi-aperte, come nel caso di *P. humedasae*.

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Towards the eradication of *Senecio pterophorus*: techniques and strategies for effective control

Abstract. *Questo studio rientra nel progetto franco-italiano Interreg ALIEM VIGIL volto a preservare gli ecosistemi mediterranei dalle specie invasive. La specie oggetto dello studio è *Senecio pterophorus*, arbusto sudafricano invasivo in Australia e, da circa 35–40 anni, anche in Spagna e Italia. In un'area fluviale della Liguria di ponente infestata dalla specie vengono testati tre trattamenti: taglio mensile, pacciamatura con semina di erbacee autoctone e piantumazione di arbusti autoctoni. I risultati preliminari mostrano differenze tra i trattamenti, ma servirà un monitoraggio più lungo. Questo protocollo potrà costituire un modello per la gestione di altre specie invasive e l'area selezionata permetterà di approfondire la biologia e l'ecologia della specie in ambiente mediterraneo.*

This work is part of the Interreg ALIEM VIGIL project, a French Italian initiative aimed at preserving Mediterranean biodiversity and ecosystems from the threat of invasive alien species (IAS). Within the framework of the ALIEM VIGIL project, the University of Genova was tasked with developing an eradication protocol for a particularly relevant invasive plant species. *Senecio pterophorus* DC. is a perennial shrub belonging to the Asteraceae family and native to South Africa. It spread in the Western Cape Province and was introduced in Australia about 100 years ago, while in Europe (Spain and Italy) it appeared approximately 35–40 years ago (Vilatersana *et al.*, 2016). The species has a self-incompatibility system (Lawrence 1985; Caño *et al.* 2008), is insect-pollinated, and shows very high seed production (Lawrence 1985; Parsons and Cuthbertson 2001). Its dispersal ability is ensured by the easily deciduous pappus, which is adapted for both wind and water transport. Moreover, the species exhibits a high germination rate (around 80%) (Lawrence 1985). All these characteristics are typical of successful invasive species and make it a serious threat to natural habitats. This species was selected not only for its global relevance as an invasive plant, but also because its first occurrence in Italy was recorded in western Liguria. The aim of this study is to test different control and eradication techniques for *S. pterophorus* in order to define guidelines for large-scale management and control. The experimental design is based on the approach proposed by Minuto *et al.* (2020) for *Senecio deltoideus*: square plots of 3 × 3 m were established to assess the effectiveness of (1) monthly cutting, (2) planting of native shrub species (*Spartium junceum* and *Pistacia lentiscus*, one

individual of each species per m²), and (3) mulching with biodegradable jute sheets, addition of soil, and sowing of native herbaceous species. The study area is located along the Centa River, on the left bank. The land was made available for the experiment after authorization by the Liguria Region. The area is entirely flat, with soils of variable composition but mainly consisting of riverbank fill. In the past, a major part of the area was used for agriculture, but after years of abandonment it has become an ideal example of disturbed land, now densely invaded by *S. pterophorus*. In addition, the area is highly representative of disturbed habitats where invasive plants in general tend to proliferate. This makes the site particularly suitable for testing management strategies that could later be applied to similar ecosystems across the Mediterranean Basin. Each treatment was preceded by an initial cut, with manual uprooting of the most vigorous and woody shrub individuals. In addition, each 3 × 3 m plot was set up within a 5 × 5 m area, creating a buffer zone to prevent external contamination of the experiment. To evaluate treatment effectiveness, each plot was subdivided into 1 m² sub-plots. Among these, the three plots located along the diagonal (the same in each survey) were photographed from above using a wooden frame of standard size (1 m²), in order to estimate the percentage cover of *S. pterophorus*. Photographic surveys were conducted monthly, and the temporal trend of the data made it possible to verify the effectiveness of the different treatments. Data analysis was carried out using linear regression, considering the percentage cover of *S. pterophorus* as the dependent variable and time (months of monitoring) as the independent variable. In the future, alternative models, such as non-linear approaches, may also be tested. Preliminary results suggest different trends among treatments, which will require a longer monitoring period to be confirmed. This initial experimental design represents the first step of a study that could be further extended to the biology, ecology, and invasion process of *S. pterophorus* as a whole. To our knowledge, no comprehensive studies have addressed the management of *S. pterophorus* in the Mediterranean Basin, which makes this work both innovative and relevant. Once concluded, this study could greatly contribute to the understanding of invasion processes in alien plants and provide important tools for the effective control and management of *S. pterophorus*. Furthermore, the approach developed here besides limiting the potential spread in other areas could serve as a model for testing the effectiveness of control and eradication techniques on other invasive species.

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Effects on the pollination network of reintroducing an endemic species: case study of *Campanula sabatia*

Abstract. *Questo lavoro mira a comprendere il ruolo di una specie rara all'interno del pollination network per sviluppare un approccio basato sulla comunità nelle azioni di reintroduzione di singole specie a scopo di conservazione. Su 10 plot di 1 m², dei quali 5 interessati da reintroduzione di *Campanula sabatia* De Not. e 5 usati come controllo, sono stati osservati gli impollinatori prima e dopo l'introduzione. Le differenze osservate in termini di diversità degli impollinatori non sono attribuibili a *C. sabatia*, ma l'abbondanza dei diversi impollinatori varia tra i plot con e senza *C. sabatia*. Benché il ruolo della specie oggetto non sia centrale, è la terza più visitata e questo fa supporre che la specie modifichi l'abbondanza degli impollinatori attirando quelli adatti alla sua riproduzione.*

Conservation actions, particularly those relating to rare plant species, are often species-based, both in terms of planning and post-introduction monitoring, that usually focus on survival, flowering and fruiting (Godefroid *et al.*, 2011). However, all organisms in ecosystems are mutually connected in interactions that can be negative, such as competition, predation, parasitism, or positive, such as facilitation or mutualism (Bertness & Callaway, 1994). The 87.5% of angiosperms (Ollerton *et al.*, 2011) rely on animal pollinators and so they are part of pollination networks, in which plants and pollinators are linked by positive interactions, which constitute a reproductive benefit for plants and a trophic benefit for animals. In a changing world, understanding the relationships, even positive ones, between species becomes crucial for conservation. Our work was therefore focused on the investigation of what role a “new” species plays in the ecosystem. In particular, with regard to the plant-pollinator relationship, we questioned what are the effects of reintroducing a rare species on a) the biodiversity of pollinators at various levels, b) their abundance, and c) the connections within the pollination network that would be established or modified.

The target species of the current study is *Campanula sabatia* De Not., endemic to the Ligurian Alps and listed in Annex II of the EU Habitats Directive, which is being reintroduced by the “SeedForce” Life project in selected areas. Ten 1 m² plots were set up within SAC IT 1324896 Lerrone-Valloni of Natura 2000 network, at a distance of at least 2 m from each other, within an area of approximately 500 m². Flower

visitors were recorded with observation periods of 15 minutes, between 10:00 a.m. and 18:00 p.m. between June and July (flowering period of *C. sabatia*) before (summer 2023) and after (summer 2024) the reintroduction of the species. The reintroduction was carried out at the end of 2023, with five individuals of *C. sabatia* being introduced into five plots, while the other five plots were designated as controls. Observations were organized so that each plot was observed in each time slot. Each insect observed was recorded along with the flowering plant it visited, and some specimens were collected for identification in the laboratory. To answer the above questions, we: a) calculated and correlated the alpha, beta, and gamma diversity indices, b) performed a partial least square discriminant analysis (PLS-DA), and c) performed a network analysis with the bipartite R package.

We totally achieved 95 hours of observation time and detected 2,056 individuals belonging to 152 taxonomical entities. The reintroduction of *C. sabatia* does not account for the observed differences in terms of visitors' alpha, beta and gamma diversity, that are rather attributable to a variation in the number of flowering species. However, in terms of pollinators' composition, PLS-DA shows a clear differentiation between plots with and without *C. sabatia*. As regards connections, although *C. sabatia* does not play a central role, is the fifth most visited plant considering visitors at the family level with 14 families, and the third, with 25 links, considering a species identification level.

The effects of introducing *C. sabatia* are not visible locally in biodiversity index values, which is consistent with the results of other studies on the reintroduction/introduction of a single species (LaBar *et al.* 2014). However, the distribution of visitor abundance discriminates between plots with and without the species under study. The reintroduced species has established several links with pollinator species, both those already present at the site and new ones (not detected in the previous year). The pool of species observed on *C. sabatia* is practically the same as that observed in previous studies on the reproductive biology of the species (yet to be published). This evidence suggests that *C. sabatia* plays a role in its community and is able to rebuild the pollination network necessary for its survival around itself.

In conclusion, the changes made to the pollination network since the introduction of *C. sabatia* are not visible in species richness, but in species composition, and represent minor adjustments that highlight a good ability to fit into the community into which the species was introduced. These results suggest that there are good grounds for the successful reintroduction of the species and its maintenance in the future.

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From wildlife-vehicle collisions prevention to habitat connectivity restoration

Abstract. *Gli incidenti stradali con la fauna rappresentano una minaccia crescente per la sicurezza stradale e la conservazione della biodiversità. L'analisi di 693 investimenti avvenuti in provincia di Parma tra il 2013 e il 2018 ha evidenziato come fattori di rischio la vicinanza a zone agricole, fiumi, zone antropiche e aree protette. Le strade principali non recintate sono le più pericolose, le autostrade e le tangenziali sembrano inibire l'attraversamento. Data l'efficacia di strutture ecologiche come sottopassi e sovrappassi nel ridurre la mortalità animale, un ecodotto in costruzione lungo la S.S. 62 Strada della Cisa mira a ristabilire la connettività tra due siti Natura 2000, insieme ad interventi di ripristino ambientale e un sistema predittivo basato sull'intelligenza artificiale.*

Wildlife-vehicle collisions (WVCs) are an increasingly pressing issue concerning road safety and biodiversity conservation. In Italy, WVCs events and the species involved are largely underestimated and a national system for systematic monitoring is lacking. As a result, the actual risk - both to drivers and to wildlife species, many of which are protected or declining - is significantly downplayed (Guccione *et al.*, 2008; Dinetti, 2010).

We identified high-risk zones for wildlife-vehicle collisions in the Province of Parma (Castagnoli, 2024). In this area, from 2013 to 2018, a total of 693 roadkill records were reported, almost entirely involving ungulates, and especially roe deer *Capreolus capreolus* Linnaeus, 1758 and wild boar *Sus scrofa* Linnaeus, 1758. The spatial patterns of collisions were investigated aiming to identify the landscape and road characteristics that could increase or decrease the risk of WVCs and to spot the locations where preventive measures are most needed. To evaluate the relative risk of roadkill in the area, a set of randomly located points along road sections where collisions were not observed was generated to act as control points, in contrast to the collisions observed. Both sets of points were used as response variables (1 = collision, 0 = non-collision) inside a non-linear binomial logistic Generalized Additive Model (GAM). Predictive variables such as land covers, altimetry, road categories, road sinuosity, road density, distance from protected areas and traffic volumes were used.

The analysis revealed that proximity to croplands and to river basins, usually visited by ungulates, seems to be a significant risk factor, especially near cities or urbanised areas. The probability of collision with a

wild animal further increases near two neighbouring protected areas, the Boschi di Carrega Park and the Taro Regional Park. Our results showed that the busiest unfenced main roads are the most prone to roadkill. WVC counts decrease on less travelled secondary roads (< 5000 vehicles/day) where average speed is lower (< 50 km/h). Instead, they drop to zero on highways and expressways, typically fenced and characterized by heavy traffic volumes (> 22000 vehicles/day) and a higher average vehicles speed (> 80 km/h).

The province's ecological network is strongly shaped by natural river corridors running north to south. These corridors serve as key movement routes for various species but are aligned with and often interrupted by road infrastructures that act as ecological barriers. In particular, the highly travelled *S.S. 9 Via Emilia* forms a major east-west barrier, further fragmenting the landscape and increasing the risk of collisions. As expected, from 2013 to 2018 the *S.S. 9 Via Emilia* was the most affected by WVCs with an average of one collision per km, followed by the *S.S. 62 Strada della Cisa* with an average of one collision every 3 km.

European initiatives have shown that ecological crossing structures - such as wildlife overpasses and underpasses - can significantly reduce animal mortality and improve ecological connectivity. In the Netherlands, monitoring programs assessed that these structures are frequently used by a relatively broad range of species, positively influencing the long-term habitat potential for supporting viable population sizes of targeted species (Sijtsma *et al.*, 2020). Thanks to the LIFE SAFE-CROSSING project in Italy, Spain, Greece and Romania the adaptation of already existing underpasses as crossing structures for wildlife, together with the installation of innovative prevention systems and the raise of driver awareness, significantly decreased roadkills among priority species like the brown bear, Iberian lynx, and wolf. In monitored areas, the observed percentage of reduction was up to 100% in several cases, highlighting the system's strong potential for protecting fauna and facilitating fauna crossings (LIFE SAFE-CROSSING, 2023).

An example of local implementation of crossing structure is the ecoduct that is going to be built in Province of Parma, along the *S.S. 62 Strada della Cisa* in a high-risk location between two protected areas, the Taro Regional Park and the Boschi di Carrega Park, thanks to the winning of a public regional tender. These two Natura 2000 sites—ZSC-ZPS IT4020001 “Boschi di Carrega” and ZSC-ZPS IT4020021 “Medio Taro”—are nearly contiguous and aligned along a north-south axis, consistent with most ecological corridors in the region. However, east-west connections remain scarce and ineffective, making this project particularly strategic. Moreover, this zone is currently under pressure from intensive agriculture, which has been flagged as a critical threat requiring mitigation. To counteract this pressure, the project includes habitat restoration measures: converting intensively farmed land into forested areas on the eastern side and creating a mosaic of wetlands, scrubland, and woodland on the western side. These restored habitats not only will guide wildlife toward the crossing structure but will also provide refuge, breeding grounds, and foraging sites for small and medium-sized species.

Ecological crossings are not mere accessories but essential tools for ensuring coexistence between human mobility and biodiversity conservation. Public policy, both locally and nationally, must recognize the

strategic value of these interventions and promote integrated territorial planning based on scientific data, to improve both human and wildlife safety, and to reduce the impact of global change on wildlife and restore continuity to our fragmented ecosystems.

We are planning to develop a predictive system based on artificial intelligence to analyse the movement of wildlife species in relation to environmental and anthropogenic factors in order to implement WVCs prevention and ecological land planning.

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Remote sensing and GPS tracking reveal year-round movement ecology of rock ptarmigan (*Lagopus muta*) in the European Alps in an era of climate change

Abstract. *Gli ambienti alpini sono tra i più suscettibili ai cambiamenti climatici e specie altamente adattate come la pernice bianca *Lagopus muta* Montin, 1758, risultano maggiormente esposte a tali pressioni. Abbiamo analizzato dati raccolti tra il 2021 e 2024 da quattro individui dotati di GPS nelle Alpi slovene, considerando i movimenti annuali e la selezione dell'habitat in relazione a sesso, variabili climatiche e topografiche. Sono stati combinati dati di telemetria con mappe ambientali derivate da immagini satellitari (Sentinel-2 ed ESA WorldCover). I risultati mostrano forti differenze stagionali nello spostamento e selezione dell'habitat tra i sessi. Lo studio conferma osservazioni fatte su altre specie alpine e sottolinea la necessità di ulteriori ricerche per orientare strategie di conservazione in scenari climatici futuri.*

High-altitude environments are particularly vulnerable to climate change-related pressures (Bettega *et al.*, 2025), driving many mountain bird species towards higher elevations in search of suitable habitats, as warmer temperatures render lower altitudes less hospitable (Freeman *et al.*, 2018; Scridel *et al.*, 2018; Alba & Chamberlain, 2025). Species inhabiting these ecosystems, such as the rock ptarmigan *Lagopus muta* Montin, 1758, display remarkable adaptations that enable them to thrive in high-elevation habitats, yet they remain particularly vulnerable to ongoing climatic alterations (Nilsen *et al.*, 2020). However, because of the challenges associated with working in such topographically complex systems, studies that investigate the behaviour of high-mountain biota in fine detail, such as at the individual level using GPS telemetry, are extremely scarce, yet pivotal for improving predictions of their potential responses and for guiding conservational efforts to prevent population decline.

Using data collected over a four-year period (2021–2024) from four GPS-tagged rock ptarmigan in the Slovenian Alps, we investigated how sex, weather (e.g., temperature, snow cover), topography (e.g., slope, aspect, Topographic Position Index), and habitat, shape their circannual movement, ecology and habitat selection. We combined home-range analyses and movement metrics (e.g., daily and seasonal distance travelled, consecutive distance) with habitat mapping derived from Sentinel-2 and ESA WorldCover

database imagery, allowing us to describe rock ptarmigan behaviour at an unprecedented spatio-temporal resolution.

Our results indicate great differences in seasonal movements with rock ptarmigan travelling less during the breeding period with males covering larger distances during the breeding period compared to females. Activity (i.e. distance travelled between fixes) declined with increasing external temperature in most seasons but were more evident in the warmest months of the year. By comparing temperatures recorded by GPS devices with external ambient temperatures from remote sensing, we assessed how birds regulate their body-to-air temperature gap under varying environmental conditions. This gap was large in cold conditions ($>10^{\circ}\text{C}$ at -20°C) but declined at moderate and high temperatures. In winter, birds reduced heat loss by sheltering in burrows or on warm aspects and by moving to lower elevations. In summer, they shifted to higher elevations to avoid overheating, yet evidence of heat stress was still apparent with birds avoiding areas with exceeding 20°C temperatures. Home range analyses indicated substantial overlap across years and seasons, reflecting the strong fidelity to both breeding and non-breeding sites. Remarkably, habitat selection greatly varied by sex and especially during the breeding period. Females consistently selected alpine grasslands areas, likely due to proximity to food resources for offspring, whereas males preferentially selected rocky and snow habitats, presumably to deal with heat stress.

Our findings are the first to reveal, with such detail, the habitat selection patterns and behaviour of one of the highest-altitude breeding bird species in the world, as well as their partial capacity to cope with ongoing climate change. The results indicate strong sex-specific responses to potential climate impacts, with females likely more vulnerable due to reproductive constraints. These findings are consistent with previous research (Strinella *et al.*, 2020) on other alpine birds (i.e. white-winged snowfinch *Montifringilla nivalis*) and underscore the urgent need for further studies on alpine avian ecology to guide effective conservation strategies under future climate scenarios.

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***Two decades of change in land cover and landscape pattern (2004-2024)
across protected areas in the Mozambique - Zimbabwe
transboundary region***

Abstract. *Le attività umane e i cambiamenti d'uso del suolo sono tra i principali fattori di perdita di biodiversità, favorendo frammentazione e riduzione della connettività ecologica. Questo studio ha analizzato la copertura del suolo in un'area transfrontaliera caratterizzata dalla presenza di varie aree protette tra Mozambico e Zimbabwe dal 2004 al 2024 tramite classificazioni Random Forest su immagini Landsat e Sentinel-2 (accuratezza delle classificazioni tra 79% e 84%). I risultati mostrano una riduzione delle foreste e un aumento di suolo nudo e aree antropizzate, soprattutto dopo il 2014, dovuti ad agricoltura e degrado. Le metriche di paesaggio evidenziano maggiore frammentazione nelle zone di buffer, mentre la persistenza di ampie foreste conferma il ruolo centrale delle aree protette.*

Human activities and land-use changes are major drivers of biodiversity loss, causing habitat degradation, fragmentation, and reduced ecological connectivity (Turner, 2010). Even small-scale human pressures, particularly in developing regions, can disproportionately affect ecosystem integrity, threatening species and ecological processes (Anderson & Mammides, 2020). Protected areas (PAs) are essential tools for conservation, limiting habitat loss, maintaining connectivity, and providing refuges for species, yet their effectiveness varies, especially in tropical regions with high biodiversity. Socio-economic pressures, weak governance, and inadequate funding often compromise management, while expanding settlements and infrastructure further fragment landscapes (Naughton-Treves *et al.*, 2005). Maintaining ecological connectivity is crucial to support species movement, gene flow, and resilience to climate change. Remote sensing and landscape metrics provide powerful tools to monitor land cover changes, quantify fragmentation, and guide conservation strategies, enabling evidence-based management to protect ecosystems and prioritize restoration in human impacted landscapes.

The study was conducted in three phases. The first phase developed detailed land cover maps to analyze habitat distribution within the study area, across the border between Mozambique and Zimbabwe, characterized by different PAs such as the Chimanimani National Parks of Mozambique and Zimbabwe. Sentinel-2 imagery (2024) and a Random Forest algorithm in R (R Core Team, 2024) were used for high-resolution classification, adapted to local ecological and spectral conditions (Pafumi *et al.*, 2023). For the

second phase, historical classification for 2004, 2014 and 2024 were produced using Landsat-5 TM and Landsat-8 OLI imagery, maintaining consistent methods and selecting dry-season images (May and June) to reduce cloud and phenology effects. In the third phase, these maps were used to assess structural connectivity and fragmentation, with particular focus on the forested areas; via landscape metrics at class, and landscape levels using the landscapemetrics R package (Hesselbarth *et al.*, 2019). Comparative analysis across 2004, 2014 and 2024 identified temporal changes in habitat distribution, fragmentation, and connectivity, providing insights into landscape transformations that may affect ecological processes and guide conservation priorities (Yuan *et al.*, 2024).

Land cover classification for 2024 using Sentinel-2 imagery achieved an overall accuracy of 84%, while the Random Forest-based classifications using Landsat-8 OLI images for 2004, 2014, and 2024 achieved overall accuracy of 82.02%. Forested areas represent the predominant land cover throughout the study period, ranging from 69.84% in 2004 to 66.82% in 2024, with mixed, evergreen, and deciduous forest forming the largest proportion. Analysis of macro categories indicates a decline in forest, grassland, and shrublands over the twenty-year period, with forest cover slightly increasing by 2 km² between 2004-2014 but sharply decreasing by 91 km² between 2004-2024. Grassland showed a similar contrasting trend, increasing by 7 km² in the first decade and decreasing by 72 km² in the second. Shrubland decreased by 33 km² between 2004-2014 and remained stable thereafter. Anthropized areas and bare soil experienced substantial increases, with bare soil expanding by 183 km² (164.9%) and total anthropized areas increasing by 19 km² overall. These changes are concentrated in the north-western and eastern buffer zones of Chimanimani National Park in Mozambique and adjacent PAs of IUCN categories IV and VI, reflecting growing human pressures, agricultural expansion, and land degradation. The results indicate a marked increase in habitat fragmentation and reduction in landscape connectivity.

Land cover dynamics in Chimanimani between 2004 and 2024 illustrate gradual shifts in habitat composition and distribution. Forests continue to represent the dominant class, though with some reduction, while bare soil and cropland have become more prominent in certain zones. These trends are more evident in the buffer areas, where human presence is stronger (Mapaura *et al.*, 2016). Landscape metrics point to increasing fragmentation, which may affect ecological connectivity. The persistence of large forest patches suggest that the park still plays a central role in maintaining biodiversity. At the same time, socio-economic activities such as agriculture and gold mining remain important drivers of land cover change, while opportunities linked to sustainable tourism and non-timber forest products are still underdeveloped. Together, these findings highlight both the pressure and the potential pathways for balancing conservation and local development.

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Exploring the wild bee (Hymenoptera: Anthophila) diversity in the Canary Islands through DNA barcoding

Abstract. *Le api selvatiche delle Isole Canarie costituiscono un gruppo altamente diversificato e vulnerabile, caratterizzato da un elevato tasso di endemismo. È stata realizzata una libreria di DNA barcode basata su oltre 800 sequenze, rappresentative della maggior parte delle specie dell'arcipelago. L'uso integrato di diversi metodi di delimitazione delle specie ha confermato in gran parte la tassonomia tradizionale, ma ha anche rivelato la presenza di numerosi taxa criptici e nuove linee evolutive, aumentando la stima complessiva della diversità. I risultati indicano processi di speciazione insulare, individuano specie esotiche finora non segnalate e dimostrano il valore del DNA barcoding per la conservazione e lo studio della biodiversità insulare.*

Wild bees are one of the most diverse and heterogeneous groups of pollinators, whose ecosystem services play a key role in both natural and agricultural environments (Potts *et al.*, 2016). On oceanic islands, these groups are especially vulnerable to anthropogenic pressures due to their small territory and isolation, making them highly susceptible to extinction (Wood *et al.*, 2017). In this context, the Canary Islands are a recognized hotspot of bee endemism, with almost half of their species being endemic and more than 17% representing all European endemics (Nieto *et al.*, 2014). Although the bee fauna of the archipelago has received considerable taxonomic attention in recent decades, recent molecular and morphological studies have revealed several overlooked cryptic species (Kratochwil *et al.*, 2022). Therefore, an accurate characterization of biodiversity is urgently needed to establish appropriate conservation measures.

To this end, more than one thousand samples were collected across the seven main islands and islets. A DNA barcode library of Canary Island bees was constructed, including over 800 sequences from 122 species and 34 genera. This dataset represents 86% of the bee diversity and 73% of the described endemic species of the archipelago. To explore patterns of diversification and detect potential cryptic species, three species delimitation methods (ASAP, ABGD, and GMYC) were applied. The first one the Assemble Species by Automatic Partition (ASAP) is a fast and reliable method that use hierarchical clustering with pairwise genetic distance, avoiding phylogenetic reconstructions (Puillandre *et al.*, 2021), in other way the second method Automatic Barcode Gap Discovery (ABGD) works different, employing a coalescent model to

identify the most likely position of the barcode gap, based on maximal genetic intraspecific distances defined (Puillandre *et al.*, 2012), finally the General Mixed Yule Coalescent model (GMYC) use a reconstructed phylogenetic tree with Bayesian inferences analysing the timing of branching events, seeking for significant switches between a Yule (interspecific) and a coalescent (intraspecific) branching structure (Pons *et al.*, 2006). Additionally, we use a parsimony approach (TCS) to draw haplotypes networks of the species populations, this method uses pairwise distances matrix, and collapse populations in haplotypes groups looking into the minimal divergence or parsimony changes (Clement *et al.*, 2002).

Species delimitation results were largely congruent with traditional taxonomy. However, evidence of cryptic taxa and distinct evolutionary lineages was found in more than 15% of the species, increasing the species in more than 140 species. Our results suggest separate speciation events across islands, related to specific functional traits and the detection of four unnoticed exotic species. This work highlights the usefulness of DNA barcoding for characterizing bee diversity in an oceanic archipelago, identifying previously unnoticed exotic taxa, resolving colonization origins, and revealing processes of island colonization and speciation.

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HIGH-PBS: a standardized dataset of vascular plants, beetles, and spiders from Alpine/Apennine high-elevation landforms (Italy)

Abstract. *Il dataset HIGH-PBS fornisce dati standardizzati su 395 taxa di piante vascolari, coleotteri carabidi e ragni campionati in 768 siti d'alta quota delle Alpi e dell'Appennino (1875--3120 m) utilizzando protocolli standardizzati per rilievi vegetazionali, faunistici e di analisi del suolo. Questo dataset multi-taxa, quantitativo, colma un vuoto nella documentazione della biodiversità alpina d'alta quota, consentendo analisi riproducibili dei gradienti ecologici e supportando il monitoraggio degli ecosistemi glaciali e periglaciali nel contesto del cambiamento climatico e uso del suolo.*

High-elevation environments represent some of the most sensitive ecosystems on Earth and provide unique opportunities to study biodiversity responses to rapid climate change. Mountain regions are experiencing accelerated warming compared with global averages, leading to pronounced shifts in species distributions, changes in community composition, and the progressive loss of cold-adapted organisms (IPCC, 2021; Rahbek *et al.*, 2019). The European Alps and Apennines, in particular, are recognized as biodiversity hotspots, yet they are also among the most vulnerable ecosystems due to their exposure to glacier retreat, permafrost degradation, and changing snow dynamics. A persistent challenge in understanding these environments is the lack of large-scale, standardized datasets: existing surveys are often taxon-specific, spatially restricted, or methodologically heterogeneous, limiting opportunities for comparison and synthesis (Lortie *et al.*, 2015).

The HIGH-PBS dataset was developed to address this gap by implementing a unified, multi-taxon sampling protocol across 7686 high-elevation sampling points ranging from 1875 to 3120 m a.s.l. in the

Italian Alps and Apennines. These sampling points were carefully selected to represent the geomorphological and ecological heterogeneity of high mountain landscapes, including stable slopes, debris-covered glaciers, glacier forelands, rock glaciers, snowfields, and active scree slopes. Such a classification captures gradients in substrate stability, successional stage, and ice influence, which are known to drive species assembly and persistence (Scherrer and Körner, 2011; Lembrechts *et al.*, 2018). By spanning both ice-related and ice-free landforms, the dataset provides a robust framework for testing hypotheses on how abiotic conditions shape alpine biodiversity.

The dataset comprises 395 species in total: 183 vascular plants (93 genera), 71 carabid beetle species (19 genera), and 141 spider species (65 genera). For vascular plants, surveys were conducted in standardized 25 m² plots where all species were recorded and ground cover estimated following a harmonized scale. This approach provides data on species richness, abundance, and vegetation structure, while also allowing the quantification of bare substrate, debris, and non-vascular cover. Carabid beetles and spiders, two groups widely recognized as sensitive bioindicators (Gottfried *et al.*, 2012; Losapio *et al.*, 2021), were sampled using pitfall traps placed directly within the vegetation plots (Gobbi, 2020). Traps remained active throughout the snow-free season, ensuring comparable effort across sites, and specimens were subsequently identified to species level by expert taxonomists using updated checklists (Casale *et al.*, 2021; Pantini and Isaia, 2019). Soil samples were collected for physical and chemical analyses, including grain size distribution, pH, organic carbon, and carbonate content. These environmental data are crucial to interpret biodiversity patterns in relation to substrate stability, soil development, and nutrient availability (Tampucci *et al.*, 2017).

A defining strength of the HIGH-PBS dataset is its integration of biological and environmental data. Each sampling point is associated with precise geographic coordinates and metadata on landform type, elevation, and soil conditions, enabling reproducible analyses across spatial and ecological gradients. The dataset is organized into openly accessible CSV files deposited in the PANGAEA repository (DOI pending) under a CC0 license. Data are complemented by structured metadata in Darwin Core format, ensuring interoperability and long-term reuse. This open-access approach not only enhances transparency but also facilitates comparative research across mountain systems worldwide.

The dataset underwent rigorous quality control procedures. Field campaigns followed a standardized protocol across all sites, supervised by the project leaders to ensure consistency. Species identifications were validated with the support of experts and reference collections housed at the MUSE--Science Museum of Trento and the Civic Museum of Natural Sciences "E. Caffi" of Bergamo. Soil analyses were carried out in accredited laboratories following standardized methods. Data were harmonized across sites, with careful documentation of cases where different formats (e.g. activity density vs. presence/absence data for arthropods) were used. These procedures guarantee high reliability and usability of the dataset (Gobbi *et al.*, 2017; Rosero *et al.*, 2021).

The potential applications of HIGH-PBS are manifold. From a scientific perspective, it enables investigations into species richness, evenness, and community turnover across diverse alpine landforms. For

example, by comparing communities on recently deglaciated forelands with those on stable slopes, it is possible to quantify colonization dynamics and successional trajectories (Pauli *et al.*, 2007). By contrasting ice-related and non-ice-related landforms, the dataset supports analyses of how cryospheric processes influence biotic communities. And which landforms is acting as warm-stage refugia in the current interglacial period. These insights are critical for forecasting biodiversity responses under scenarios of continued glacier retreat and changing snow cover (Gobbi *et al.*, 2017; Gottfried *et al.*, 2012).

From an applied perspective, the dataset provides a baseline for long-term biodiversity monitoring in European mountain regions. Its standardized approach allows integration into continental-scale initiatives such as GLORIA and other monitoring networks (Pauli *et al.*, 2007; Freeman *et al.*, 2018). Moreover, the dataset supports conservation management by identifying vulnerable habitats and taxa, informing strategies to protect biodiversity in the face of climate change. The explicit link between biological and environmental data also facilitates modeling approaches, enabling predictions of species distribution shifts and community reassembly under different climate scenarios.

In summary, the HIGH-PBS dataset represents the most comprehensive standardized multi-taxa dataset currently available for high-elevation ecosystems in the Italian Alps and Apennines. By combining vascular plant, beetle, and spider assemblages with detailed environmental data, it provides a unique platform for reproducible and cross-taxon ecological analyses. Beyond its immediate value for research, it offers a critical resource for conservation planning and policy-making in a period of rapid and unprecedented environmental change.

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Revenant forests: life thrives after bark beetle outbreaks, insights on vegetation and soil-arthropod biodiversity

Abstract. *Le foreste delle Alpi italiane hanno visto la diffusione di un'epidemia senza precedenti di Ips typographus. L'epidemia ha interessato le peccete delle Alpi Centro-Orientali, modificandone la fisionomia. Il fenomeno implica degli evidenti danni al paesaggio, ma dal punto di vista della funzionalità ecosistemica e dell'ecologia forestale può risultare una grande opportunità. In questo studio abbiamo utilizzato la vegetazione e gli artropodi del suolo come bioindicatori di questo cambiamento, cercando in questo modo di valutare se il bosco di alberi morti in piedi che rimane dopo il passaggio del bostrico ha una qualità ambientale maggiore, inferiore o uguale alle condizioni preesistenti.*

Natural disturbances are known to affect ecosystems and their study is becoming increasingly urgent in the context of climate change. Indeed, climate change has already led to an increase in frequency, intensity and spatial extent of disturbances such as windstorms, wildfires and insect outbreaks. In the Alps, forests are rapidly changing their physiognomy in response to new disturbance regimes and also other factors such as management decisions (e.g., close-to-nature forestry, abandonment, rewilding). Seeing how these forests represent a core component of Alpine landscapes and play a key role in ecosystem regulation and services – including timber production, biodiversity conservation, water supply, protection from landslides, tourism and also cultural heritage – it is of the uttermost importance to understand the processes that regulate them and how they are being impacted by new disturbance regimes. In this context, large-scale spruce bark beetle, *Ips typographus* (Coleoptera: Scolytinae) outbreaks are being observed more and more often in Europe, also in the Alps. The Italian Alps are experiencing a major outbreak in the central-eastern sector, where spruce stands are far more common than elsewhere in Italy. This outbreak started in 2015 but was dramatically intensified by the extreme weather event “Vaia” in 2018, a windstorm of unprecedented strength that damaged 42,525 hectares of forests and offered the perfect conditions for *I. typographus* to develop and go from the endemic phase to the epidemic phase typical of this beetle under suitable conditions. Since then, vast portions of spruce forests have been destroyed by the bark beetle, leaving behind patches of standing dead trees and snags (snag forests, *sensu* Swanson *et al.*, 2011), which are no more of interest to the bark

beetle, but represent biological legacies that probably play a central role in the ecological succession that follows this kind of disturbance. What is unprecedented is the scale of the current dieback of spruce forests, which has never been documented before in these areas. Very little is known about the successional trajectories these forests will follow in the coming years, or about which management practices will be most appropriate to implement in order to foster forest recovery, taking into account projected climate scenarios and potential shifts in the ways these forests are used.

To better understand the ecological consequences of this major bark beetle outbreak, we focused our attention on vegetation succession and soil biodiversity. The main question we asked ourselves was: how does soil biodiversity respond to bark beetle disturbance? In fact, we expect that the standing dead trees and snags will be part of a new transient habitat type (snag forest) with different microclimatic conditions and resource availability, and that might translate into a community turnover. The dieback of spruces represents the first vegetation change that initiates all subsequent successional processes, primarily driven by the increased availability of light at the forest floor and by greater daily temperature fluctuations following canopy thinning. Whether this succession is relevant for other organisms or represents a more neutral factor remains an open question. We investigated the vegetation trajectory of snag forests created by *Ips typographus* through phytosociological relevés and α - and β -diversity patterns of soil-arthropod communities, focusing our efforts on taxa considered most informative for environmental quality (e.g., Carabidae). We sampled epigeic arthropod taxa using pitfall traps, and also assessed soil biological quality by measuring QBS-ar index values based on microarthropods extracted from soil samples. All ecological parameters were recorded along transects spanning from “healthy” forest stands to adjacent “disturbed” snag forest patches (Fig. 1). Transects were established in areas where snag forests were already 3–5 years old, corresponding to the period since the “red phase” of bark beetle infestation, when spruce trees had died. Two sites were investigated each with three separate transects.

Vegetation rapidly shifts in snag forests, with more eliophilous taxa replacing shade-tolerant species. Interestingly, broadleaf trees are establishing instead of spruce renewal, reflecting the potential vegetation of the investigated sites. Our data suggest that when dead spruces are not removed, succession progresses faster, facilitating the growth of other tree species and shortening the herbaceous and shrub phases of the succession. Plant α -diversity seems higher in the transition zone between healthy and disturbed forests, probably because this ecotonal strip provides multiple conditions that allow for forest species to persist while also enabling pioneer species to colonize.

Epigeic arthropods represent the bulk of the dataset and are still being sorted, yet preliminary data suggest an increasing carabid beetle diversity moving towards the disturbed condition. The overall abundance of epigeic arthropods is much higher in the transition zone; however, this pattern is entirely driven by springtails (Hexapoda: Collembola). After removing springtails from the analysis, we observed an increase in the overall abundance moving towards the disturbed condition. Endogeic microarthropods are still being

sorted to obtain QBS-ar values obtained along our transect, but preliminary data suggest that there are no clear differences in soil biotic quality across the disturbance gradient.

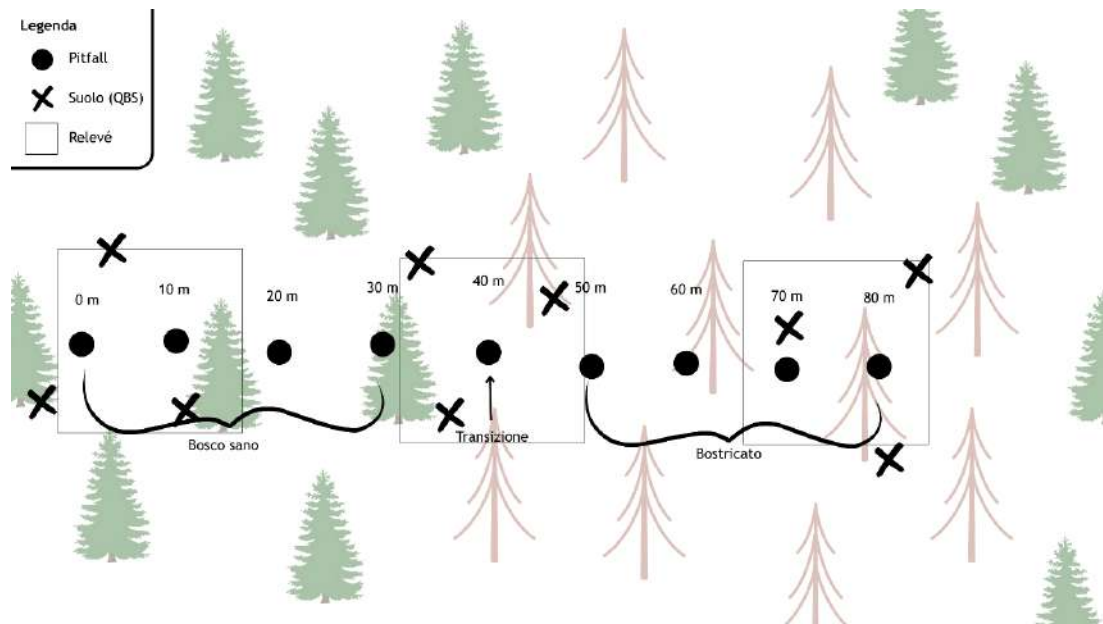


Figure 1. Sampling design we used. Points represent pitfall traps, crosses are soil samples extracted with the Berlese-Tullgren method for QBS-ar measures, squares are sample areas for relevés.

After removing springtails from the analysis, we observed an increase in the overall abundance moving towards the disturbed condition. Endogeic microarthropods are still being sorted to obtain QBS-ar values obtained along our transect, but preliminary data suggest that there are no clear differences in soil biotic quality across the disturbance gradient.

Early results indicate that soil arthropods do respond to bark beetle disturbance, but the signal is subtler compared to the dramatic response of vegetation. This might signify that additional analysis, such as the study of functional traits, might be needed or that animal communities are remarkably resilient to bark beetle disturbance compared to other forest disturbances such as windstorms, which can become very impactful especially when salvage logging is done. Leaving standing dead trees in place, when possible, could therefore be a sensible and cost-efficient management option, provided that no other priorities are present (e.g., infrastructures safety). Such an approach would help maintain forest conditions and foster biodiversity while allowing natural forest dynamics to unfold.

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Valutazione della vulnerabilità degli impollinatori selvatici ai pesticidi tramite tratti funzionali: verso un approccio inclusivo e sistemico alla valutazione del rischio ecologico

Abstract. Pesticide risk for pollinators is the result of complex interactions between environmental contamination and species-specific characteristics. While regulatory frameworks typically rely on data from *Apis mellifera* Linnaeus 1758, wild pollinators exhibit a wide range of ecological and physiological traits that can strongly influence their exposure to, and sensitivity toward, pesticides. To address this gap, we propose a trait-based framework to assess pesticide vulnerability across pollinator taxa considering exposure via five environmental matrices. This framework aims to support more inclusive and representative risk assessment approaches and to develop quantitative tools that estimate community-level risk by integrating trait-based vulnerability scores with empirical data on environmental contamination and pollinator occurrence.

La vulnerabilità degli impollinatori ai pesticidi è il risultato dell'interazione tra fattori ambientali esterni - come il tipo, la concentrazione e la persistenza delle sostanze chimiche - e caratteristiche intrinseche delle specie, che modulano l'esposizione e la sensibilità alle sostanze tossiche.

È ormai ampiamente documentato che i pesticidi determinano una contaminazione diffusa e persistente nell'ambiente, con conseguente rischio di esposizione sia per gli impollinatori gestiti che per quelli selvatici (Tosi *et al.*, 2018). Nelle valutazioni del rischio da pesticidi, l'ape mellifera *Apis mellifera* Linnaeus, 1758 viene comunemente utilizzata come specie modello per la presenza di una grande quantità di dati disponibili sulla loro biologia, ecologia ed ecotossicologia (Boyle *et al.*, 2019; Tosi *et al.*, 2022). Tuttavia, esistono differenze sostanziali nella storia evolutiva e nelle caratteristiche biologiche tra le api mellifere e altri impollinatori selvatici, che possono limitare la rappresentatività di questa specie rispetto alla sensibilità, ai tratti ecologici e alle vie di esposizione rilevanti per altre specie (Boyle *et al.*, 2019; Franklin & Raine, 2019; Raine & Rundlöf, 2024). Negli ultimi anni, si è cercato di ampliare la gamma di specie considerate nelle valutazioni includendo il bombo *Bombus terrestris* Linnaeus, 1758 e api solitarie come quelle del genere *Osmia* spp. (Panzer, 1806), al fine di riflettere meglio la diversità degli impollinatori (EFSA, 2023). Tuttavia, la sola inclusione di queste poche specie non è sufficiente a ridurre l'incertezza complessiva nella valutazione del rischio. In Europa, infatti, sono state registrate oltre 12.000 specie di impollinatori selvatici

tra api, sirfidi e lepidotteri, molte delle quali in declino sia in abbondanza che in diversità (Goulson *et al.*, 2015; Sanchez-Bayo & Goka, 2014; Zattara & Aizen, 2021). Considerato il loro ruolo chiave nella riproduzione delle piante, anche oltre le colture gestite (Rader *et al.*, 2020), vi è un bisogno urgente di estendere e diversificare i modelli utilizzati nelle valutazioni del rischio da pesticidi. Questo studio propone lo sviluppo di un approccio integrato e multi-specie basato sull'analisi dei tratti funzionali, per valutare in modo sistematico la vulnerabilità di un'ampia gamma di impollinatori selvatici ai pesticidi. Gli obiettivi principali sono: (1) valutare la vulnerabilità ai pesticidi di impollinatori oltre le api mellifere, considerando esposizione tramite diverse matrici ambientali; (2) supportare la valutazione del rischio ambientale individuando le specie, i gruppi tassonomici e le matrici ambientali più vulnerabili; (3) sviluppare strumenti quantitativi per stimare il rischio a livello di comunità integrando indici di vulnerabilità derivati dai tratti con dati empirici di contaminazione ambientale e presenza degli impollinatori.

I tratti selezionati sono organizzati in tre categorie principali: esposizione esterna, sensibilità intrinseca e resilienza della popolazione. Queste categorie sono riconosciute come i fattori chiave che influenzano la vulnerabilità complessiva di una specie a uno specifico fattore di stress (De Lange *et al.*, 2010; Schmolke *et al.*, 2021; Van Straalen, 1994). La metodologia prevede una prima fase di selezione dei tratti, guidata dalla letteratura scientifica sull'ecologia degli impollinatori e sulla tossicologia dei pesticidi, e dalla presenza di ipotesi meccanicistiche o di evidenze empiriche che collegano tali tratti ai processi rilevanti. In una fase successiva, l'importanza relativa dei tratti viene valutata da esperti con riferimento alle diverse matrici ambientali. I valori dei tratti vengono poi utilizzati per costruire indicatori sintetici di vulnerabilità, che permettono di confrontare specie e gruppi tassonomici e di evidenziare le matrici più critiche per l'esposizione. Infine, questi indicatori verranno messi in relazione con dati di contaminazione e di presenza degli impollinatori nei siti di studio, al fine di esplorare i legami tra pressione chimica e stato delle comunità e di individuare soglie di rischio ecologicamente rilevanti. I risultati attesi includono l'identificazione di specie sentinella ad alto rischio, la classificazione delle matrici ambientali più critiche, e lo sviluppo di indicatori sintetici di rischio da poter integrare nelle future valutazioni del rischio e nella gestione dei pesticidi.

Questo lavoro mira a fornire informazioni utili sia per la prioritizzazione degli studi su specie chiave, sia per colmare l'attuale lacuna metodologica nella valutazione del rischio ambientale, ampliando lo spettro tassonomico considerato e proponendo un metodo replicabile, fondato su caratteristiche funzionali condivise tra le specie. L'approccio proposto può supportare l'integrazione della biodiversità degli impollinatori nelle strategie di gestione del rischio chimico, contribuendo alla protezione di specie meno studiate ma fondamentali per il funzionamento degli ecosistemi terrestri.

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Life and Ice: Ground Beetle Communities along a Cryospheric Continuum in the Alps

Abstract. *In contesti d'alta quota, la fusione dei ghiacciai è una delle conseguenze più evidenti del riscaldamento globale. Tuttavia, anche la degradazione del permafrost è un fenomeno sempre più rilevante. Questi eventi non comportano solo rischi per le popolazioni umane (risorse idriche, infrastrutture, eventi gravitativi), ma rappresentano anche una minaccia per la biodiversità criofila. Per comprendere meglio le conseguenze di questi fenomeni, abbiamo analizzato i cambiamenti nella comunità di artropodi lungo un gradiente criosferico d'alta quota (Conca del Breuil, Valle d'Aosta, Italia). I risultati hanno evidenziato l'importanza dei rock glacier intatti come aree di rifugio per la biodiversità criofila durante i periodi interglaciali, ma anche le attuali carenze conoscitive.*

Glaciers and permafrost are key elements of the mountain cryosphere, supporting human communities in mountain regions and lowland areas (Jones *et al.*, 2019; Gaudio & Gobbi, 2022; Zhang *et al.*, 2022). Despite being overlooked as ecosystems for a long period, they harbor life (Laybourn-Parry *et al.*, 2012; Crosta *et al.*, 2024) and represent pivotal habitats for many alpine organisms (Stibal *et al.*, 2020; Gobbi *et al.*, 2021). However, due to the ongoing climate crisis, they are rapidly shrinking and degrading, with severe consequences for human safety and biodiversity. Changes in the cryosphere alter water quality and availability, increase the occurrence of natural hazards (landslides, avalanches, rockfalls, floods), and compromise infrastructure instability (Hock *et al.*, 2019). At the same time, cold-adapted and cryophilic species are losing suitable habitat, with local extinctions already reported in the Ecuadorian Andes and in the European Alps (Gobbi, 2020).

To assess the ecological consequences of the cryosphere degradation on alpine arthropods, we investigated ground beetle (Coleoptera, Carabidae) communities across a gradient of cryospheric and non-cryospheric habitats, including a glacier front, a glacier foreland, two rock glaciers (one active and one relict), and an alpine grassland which was not glaciated during the Little Ice Age (LIA; 14th to mid-19th century). For the first time ever, a “cryospheric continuum” perspective (i.e., the cryospheric gradient) was adopted. The study was carried out in the Breuil Basin (Aosta Valley, Italy) during the summers of 2022 and 2023. Ten plots were selected along the continuum, spanning from 2400 to 3120 m a.s.l.: Valtournanche Glacier front - Valtournanche Glacier foreland - active rock glacier - relict rock glacier - mature alpine

grassland. At each plot, three sampling points were randomly established, each located 10 m apart from the others. In each plot, ground beetles were sampled by pitfall trapping, using soft plastic cups (diameter 7 cm, height 10 cm) baited with a water-vinegar-salt-soap solution (Gobbi, 2020). Traps were checked every 10-15 days, emptied and refilled with the solution. Specimens were identified at the specific level, and preserved in 70% ethanol, at the Science Museum of Trento (Trento, Italy).

Additionally, for each plot, ground surface temperature and humidity were recorded continuously for two years with hourly resolution, using Tinytag TGP-4500 data loggers placed 10 cm below the ground surface. An additional 500 g of soil was collected at each sampling point for physical (soil texture) and chemical (carbon and nitrogen concentration, soil pH) analysis.

Our results showed environmental similarities between the plots freed by the glacier less than 100 years ago and the active rock glacier, and between the alpine grassland and the relict rock glacier. Sites of the glacier foreland deglaciated more than 200 years ago exhibited intermediate characteristics, reflecting transitional environmental conditions. Species data (abundance and distribution) revealed that, even above 2400 m a.s.l., active rock glaciers can already function as a warm-stage refugium for some cold-adapted species.

These findings emphasise the importance of adopting a broader geomorphological and ecological approach when studying biodiversity responses to climate change. Indeed, such an approach allows not only to detect ecological processes that would otherwise remain overlooked, but also to refine our understanding of species' ecological needs and distributional limits, which are pivotal information when assessing extinction risk and forecasting biodiversity trajectories under the ongoing climate change.

Furthermore, the present study revealed three urgent research priorities:

1. Establishing a clear distinction between cold-adapted and cryophilic species, as the terms are often used interchangeably in literature.
2. Assessing the extinction risk of cold-adapted and cryophilic species, many of which are endemic to restricted Alpine areas but remain poorly studied in terms of conservation status.
3. Resampling glacier forelands previously investigated to determine whether climate change is altering colonization dynamics at high elevations, and to test the validity of the widely used space-for-time substitution approach in this research field.

We are currently pursuing these directions to better understand the consequences of cryosphere degradation and to improve predictions on the persistence of alpine biodiversity under climate change.

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Mining the Cosmos: Sphingomonas desiccabilis and Acidithiobacillus ferrooxidans in Microbial Metal Extraction

Abstract. *Esplorare lo spazio significa anche ripensare al nostro rapporto con la Terra. Attraverso l'uso di microrganismi capaci di estrarre metalli da rocce extraterrestri, come Acidithiobacillus ferrooxidans e Sphingomonas desiccabilis, il biomineraggio apre nuove vie per missioni spaziali sostenibili. Gli stessi processi microbici permettono anche il recupero di elementi rari e la bonifica di ambienti contaminati sul nostro pianeta. Tecnologie pensate per altri mondi possono così contribuire alla conservazione degli ecosistemi terrestri.*

The growing need for sustainable strategies in space exploration is driving innovation at the intersection of microbiology, planetary science, and environmental engineering (Santomartino *et al.*, 2022). Long-term human presence on the Moon, Mars, and other celestial bodies requires access to essential resources such as metals, oxygen, water, and structural materials. Given the prohibitive costs and environmental burden of transporting these from Earth, *In-Situ* Resource Utilization (ISRU) is emerging as a cornerstone of extraterrestrial colonization strategies (Linne *et al.*, 2017). Within this context, biomineraggio *i.e.*, microbial extraction of metals from rocks, offers a promising, energy-efficient, and scalable solution (Chaerun *et al.*, 2017). This technology is well-established on Earth in the biohydrometallurgical industry and involves microorganisms capable of dissolving and mobilizing metals from mineral matrices (Habibi *et al.*, 2020). Its low-energy demand and minimal environmental impact make it particularly attractive for off-Earth

applications, where logistical constraints and sustainability are paramount. Our research focuses on adapting this technology to space environments, using two extremophilic bacterial species: i) *Acidithiobacillus ferrooxidans* and ii) *Sphingomonas desiccabilis*.

To simulate space-relevant conditions, we conducted biomining experiments using terrestrial analogs of Martian and icy moon substrates. These included: hydrothermal vent deposits (active/inactive chimneys, basaltic seabed, pyritic samples) from the East Pacific Rise to model Martian paleolake environments such as Eridania Planitia; cryoconite powders from the Forni Glacier (Italy), representing analogs of the icy surfaces of Europa or Enceladus; Sulfide-rich mine tailings and meteorite samples, including material from asteroid 4Vesta, used to assess microbial growth and bioleaching on planetary crust analogs.

Experimental protocols were designed to replicate the pH, temperature, and nutrient availability expected in these extraterrestrial environments. Media were modified to simulate acidic conditions suitable for *A. ferrooxidans* and normal rock-rich conditions for *S. desiccabilis*. Growth was monitored via optical density, colony-forming units, and biofilm formation. Elemental mobilization was quantified using Inductively Coupled Plasma–Mass Spectrometry (ICP-MS) and optical emission spectroscopy (ICP-OES), while Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) were used to study microbe-substrate interactions.

Our findings show that *A. ferrooxidans*, an acidophilic chemolithoautotroph, was highly effective in mobilizing a wide array of elements under simulated Martian conditions. Key extractions included Fe, Cu, Mn, Ga, As, and W from hydrothermal vent analogs. Notably, pyrite-rich samples showed particularly high yields, reinforcing the relevance of sulfide-rich Martian deposits. In cryoconite-based experiments, *A. ferrooxidans* was also able to extract REEs and several radionuclides, indicating potential applications for resource recovery from icy celestial bodies.

S. desiccabilis, a desiccation-tolerant bacterium capable of biofilm production on rock surfaces, demonstrated robust growth on both terrestrial and extraterrestrial substrates. This organism was tested on samples from Canadian REE-rich mines, meteorite fragments, and BioRock reference materials previously flown to the International Space Station. Over 30-day incubation periods, *S. desiccabilis* successfully mobilized Fe, Ni, V, Ge, Pd, and actinides. It also produced dense, structured biofilms, which appeared to enhance metal solubilization, particularly in igneous and sulfide-rich contexts. These results not only validate the feasibility of microbial metal extraction in analog space environments, but also underscore the dual-use potential of biomining technologies. The same metabolic mechanisms used to extract strategic elements in space can be applied to terrestrial challenges, such as the recovery of critical materials from electronic waste, and the bioremediation of polluted soils and water systems. For instance, both microbial systems tested were able to mobilize radionuclides and heavy metals, indicating potential applications in contaminated mining regions or post-industrial landscapes. This synergy between space biotechnology and Earth-based ecological restoration is central to our vision of sustainable exploration. The deployment of biomining and biorecovery processes supports closed-loop systems for future habitats, where waste is recycled, resources are recovered

locally, and minimal external input is required. These principles align closely with the goals of ecosystem conservation and circular economy frameworks being developed on Earth.

Furthermore, by working at the interface of microbial ecology and planetary science, this research contributes to astrobiology, not merely as the search for life beyond Earth, but as a tool to expand our understanding of life–matter interactions in the universe. The ability of microbes to colonize, transform, and extract elements from extraterrestrial materials enriches the current dialogue on planetary habitability, life detection strategies, and biosignature preservation. It also raises fundamental philosophical and ethical questions about the role of terrestrial life as a geoactive force beyond its home planet. In conclusion, our work highlights the profound interconnection between space exploration and planetary stewardship. Biomining technologies, though developed to sustain life off-Earth, may prove equally vital for regenerating the damaged ecosystems of our own planet. In this sense, astrobiology and space biotechnology offer not only new frontiers, but also a deeper awareness of our responsibility toward Earth’s biosphere.

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Connettere forma, comportamento e funzione: un database open-access di tratti funzionali per i copepodi delle acque sotterranee

Abstract. Functional traits, defined as features that can be measured at the individual level, are key to exploring organism–ecosystem relationships. While trait-based approaches are well-established in surface ecosystems, their application to groundwater fauna is relatively scarce. We present the first open-access database of functional traits for living groundwater-associated copepods. Data from 314 individuals of 14 species (Italy, Slovenia, Romania) include 10 morphometric and locomotor continuous traits, plus sex and ecological category. Analyses reveal strong interspecific differences and intraspecific variability, highlighting adaptive strategies beyond taxonomy and offering a framework to study functional diversity and ecosystem responses to global change.

I tratti funzionali, definiti come caratteristiche morfologiche, fisiologiche e comportamentali misurabili a livello individuale, sono oggi considerati strumenti essenziali per comprendere le relazioni tra organismi ed ecosistemi, poiché riflettono la fitness e la capacità di interazione con l'ambiente (Violle *et al.*, 2007). L'approccio *trait-based* sta progressivamente ridefinendo la ricerca ecologica, spostando il focus dalla tradizionale classificazione tassonomica verso la comprensione delle funzioni svolte dagli organismi e dei processi che regolano il funzionamento degli ecosistemi (Guillerme *et al.*, 2025). Nonostante i significativi avanzamenti in ecosistemi terrestri e acquatici superficiali, l'applicazione di questo approccio agli ambienti sotterranei resta ancora marginale, lasciando ampiamente inesplorata una delle frontiere più promettenti e al contempo più trascurate dell'ecologia moderna.

Le acque sotterranee rappresentano habitat peculiari, spesso difficilmente o per nulla accessibili e ancora relativamente poco studiati, che ospitano una biodiversità straordinaria caratterizzata da adattamenti evolutivi unici. In questo contesto, i copepodi (Crustacea, Copepoda) costituiscono uno dei taxa più rilevanti in termini di diversità, abbondanza e funzioni ecologiche. Questi crostacei hanno sviluppato strategie adattative peculiari per sopravvivere in condizioni di oscurità permanente, cronica scarsità di risorse, ridotta ossigenazione e stabilità termica e delle condizioni chimico-fisiche (Galassi *et al.*, 2009; Fišer *et al.*, 2023). Tuttavia, l'assenza di un database strutturato e standardizzato sui loro tratti funzionali ha finora limitato la comprensione del ruolo ecologico dei copepodi di acqua sotterranea e, più in generale, del funzionamento degli ecosistemi sotterranei.

Per colmare questa lacuna, presentiamo il primo database open-access di tratti funzionali misurati su copepodi vivi associati alle acque sotterranee. Il dataset raccoglie dati individuali su 14 specie campionate in quattro grotte carsiche, una sorgente carsica e un acquifero alluvionale di Italia, Slovenia e Romania. Per ciascuna specie sono stati analizzati fino a 40 adulti (equamente distribuiti tra maschi e femmine), per un totale di 314 individui, consentendo di cogliere sia la variabilità inter- e intraspecifica sia il dimorfismo sessuale. Il database integra cinque tratti morfometrici continui (dimensioni e forma corporea, massa, lunghezza delle antennule, flessibilità) e cinque tratti locomotorio-comportamentali continui (distanza percorsa, velocità media e massima, accelerazione massima, percentuale di movimento). Sono inoltre inclusi il sesso e la categoria ecologica (stigobi, stigofili, stigosseni), fornendo così anche un *life-history trait* e un *habitat-preference trait*.

Le misure morfometriche sono state ottenute da immagini digitali di individui anestetizzati analizzate con il software ImageJ, mentre i tratti locomotori derivano da video di 60 s analizzati mediante tracking digitale con il software Noldus EthoVision (Noldus *et al.*, 2001). Prima delle analisi, gli individui sono stati acclimatati in laboratorio in condizioni prossime a quelle naturali (buio, temperatura stabile pari al valore medio del sito di origine, acqua e sedimenti provenienti dal sito di origine), al fine di minimizzare gli effetti dello stress e preservare la rappresentatività ecologica dei comportamenti osservati.

Le analisi statistiche sono state condotte in R utilizzando test statistici non parametrici: differenze significative sono state valutate con il test di Kruskal–Wallis (Kruskal & Wallis, 1952) e confronti a coppie mediante post-hoc test di Dunn con correzione di Bonferroni (Dunn, 1964), con soglia $\alpha = 0.05$. I range descrittivi mostrano un'ampia variabilità interspecifica: ad es., dimensioni corporee variano da 0.31 a 1.15 mm, la massa da 0.0003 a 0.0250 mg, la velocità media da 0.01 a 2.81 mm s⁻¹, la distanza percorsa da 0 a 168.6 mm. La variabilità intraspecifica dei tratti (ITV), stimata con il coefficiente di variazione di Kvålseth (^KCV; Kvålseth, 2017), ha invece evidenziato che la forma corporea è il tratto meno variabile, quindi più conservato a livello intraspecifico, mentre massa, flessibilità e tratti locomotori risultano altamente variabili.

Il test di Kruskal-Wallis ha rilevato differenze significative per la maggior parte dei tratti, confermate dai confronti post-hoc: dimensione e massa corporea si distinguono soprattutto tra *Nitocrella stammeri* Chappuis, 1938 e gli altri Harpacticoida. Differenze marcate si osservano anche nella lunghezza delle

antennule, in particolare di *N. stammeri*, confermando l'importante ruolo ecologico della morfologia antennulare, soprattutto quando confrontata con la velocità massima, in quanto a maggiore allungamento corrispondono, in gran parte, *performances* locomotorie maggiori (Svetlichny *et al.*, 2025).

L'analisi dell'ITV ha mostrato che i Cyclopoida e alcuni Harpacticoida stigosseni presentano valori di variabilità più elevati rispetto agli Harpacticoida stigobi, soprattutto per massa e distanza percorsa, in linea con l'ipotesi che specie adattate ad habitat stabili, come quelli sotterranei, riducano la variabilità fenotipica e comportamentale (Hose *et al.*, 2022). Inaspettatamente, tuttavia, le quattro specie stigobie di Harpacticoida hanno mostrato valori locomotori superiori a quelli di alcune specie stigossene e dei due stigofili. Questo pattern suggerisce che la specializzazione ipogea non comporti necessariamente una riduzione uniforme delle capacità motorie, ma rifletta piuttosto strategie adattative differenziate. È plausibile che alcune specie stigossene non riescano ad esprimere pienamente il loro potenziale locomotorio in condizioni di oscurità permanente e limitata disponibilità trofica, offrendo nuove prospettive interpretative sulla loro coesistenza negli habitat delle acque sotterranee.

Pur con i limiti legati al numero di specie e tratti analizzati, il database fornisce una base per esplorare la diversità funzionale dei copepodi sotterranei, indagare le dinamiche adattative e stimare il contributo di questi organismi ai servizi ecosistemici sotterranei (Griebler & Avramov, 2015). Inoltre, rappresenta uno strumento applicativo per valutare l'impatto di stress antropici e climatici, come contaminazione chimica e aumento delle temperature (Di Lorenzo & Galassi, 2017; Di Cicco *et al.*, 2024; Tabilio Di Camillo *et al.*, 2024). In un contesto di cambiamenti globali, la messa a disposizione del database costituisce un passo per approfondire la conoscenza della biodiversità funzionale di questi ambienti di importanza ecologica cruciale (Saccò *et al.*, 2023).

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Governance multilivello e conservazione della biodiversità: un'analisi dei Quadri di Azioni Prioritarie (PAF) italiani

Abstract. *Biodiversity conservation involves complex, multilevel governance. Ecosystem restoration requires coordination across jurisdictions and sectors, as ecosystems transcend administrative borders and engage multiple actors at different levels. This study analyses Italy's 21 regional Prioritized Action Frameworks (PAFs) for Natura 2000, exploring multilevel dynamics through the lenses of subsidiarity, flexibility, legitimacy, and participation. Findings reveal a strong reliance on EU funds, limited investment in capacity-building, conflicts arising from policy misalignments, and varied but adaptive regional strategies. Strengthening local capacities and aligning conservation goals with socio-economic contexts emerge as key priorities for more effective and inclusive ecosystem governance.*

La conservazione della biodiversità risulta essere il risultato di processi complessi che si sviluppano su più livelli giurisdizionali (Cumming *et al.*, 2015). In particolare, il ripristino degli ecosistemi richiede un coordinamento efficace tra attori locali, autorità regionali, governi nazionali e istituzioni europee, poiché gli ecosistemi non seguono i confini amministrativi (Bodin *et al.*, 2017) e coinvolgono molteplici politiche settoriali, dalla conservazione della natura all'agricoltura, fino allo sviluppo rurale (Geitzenauer *et al.*, 2017).

Quando le misure di conservazione adottano un approccio esclusivamente top-down, trascurando esigenze e specificità locali, rischiano di generare soluzioni tecnocratiche che alimentano conflitti tra stakeholder, compromettendo legittimità ed efficacia degli interventi (Winkel *et al.*, 2015). È quindi fondamentale concepire la conservazione come frutto di interazioni multilivello tra istituzioni pubbliche, attori privati, società civile e comunità locali (Ekroos *et al.*, 2015).

Questa visione è riconosciuta in documenti strategici come il *Kunming-Montreal Global Biodiversity Framework* e, in ambito europeo, dalla *Strategia per la Biodiversità al 2030* e dalla recente *Nature Restoration Law*. Quest'ultima stabilisce obiettivi giuridicamente vincolanti per il ripristino degli ecosistemi degradati in tutta l'UE, con particolare attenzione agli habitat protetti dalla rete Natura 2000, imponendo agli Stati membri di elaborare Piani Nazionali di Ripristino in collaborazione con autorità locali, stakeholder e comunità interessate.

In questo quadro, la rete Natura 2000, il principale strumento dell'UE per la conservazione della biodiversità, gioca un ruolo centrale nel garantire la coerenza ecologica degli interventi di tutela e ripristino (Campagnaro *et al.*, 2019). A supporto della sua attuazione, i Quadri di Azioni Prioritarie (PAF)

rappresentano strumenti fondamentali per tradurre gli obiettivi europei in strategie operative regionali. I PAF definiscono le priorità di conservazione per Natura 2000, stimano i fabbisogni finanziari e li collegano ai principali fondi europei, fungendo da ponte tra obiettivi comunitari e contesti locali (Geitzenauer *et al.*, 2017). Essi sono quindi essenziali per garantire un'efficace governance multilivello del ripristino ecologico.

Questo contributo analizza la governance multilivello nei 21 PAF regionali italiani, con l'obiettivo di comprendere come principi chiave, quali sussidiarietà, flessibilità, legittimità e partecipazione, siano stati concretizzati (Blicharska *et al.*, 2016). Lo studio adotta un approccio qualitativo focalizzato sulla governance, mirato a identificare tendenze, criticità e innovazioni che possano rafforzare coerenza, inclusività e adattività della gestione di Natura 2000.

L'Italia rappresenta un caso studio emblematico per l'eterogeneità territoriale, ecologica e socio-economica, oltre che per la competenza regionale in materia ambientale. L'analisi ha esaminato 2552 misure di conservazione e ha studiato i flussi finanziari previsti, mediante diagrammi Sankey e mappe di calore. In particolare, si è indagato: (i) il legame tra risorse pianificate dai PAF regionali e tipologie di misure per valutare l'integrazione tra conservazione e multifunzionalità; (ii) la relazione tra risorse pianificate dai PAF regionali e fonti di finanziamento per misurare la coordinazione intersettoriale tra politiche europee.

È stata inoltre condotta una cluster analysis gerarchica mediante il supporto di dendrogrammi per individuare somiglianze e divergenze nelle strategie regionali, facendo emergere due orientamenti prevalenti: uno focalizzato sul ripristino degli ecosistemi, l'altro su incentivi alle comunità locali. Le regioni industrializzate del Nord Italia tendono a seguire il primo approccio, mentre quelle più periferiche e rurali si concentrano sul secondo. Questo risultato dimostra ampia flessibilità nei PAF, che si adattano alle esigenze specifiche del territorio regionale, sia ecologiche che socio-economiche.

Dall'analisi emerge una forte dipendenza dai fondi UE, in particolare dal Fondo Europeo Agricolo per lo Sviluppo Rurale (FEASR), il cui utilizzo pianificato dalla maggior parte delle regioni è stimato a più del 60% del budget PAF. Al contrario, fondi più specifici come LIFE sono scarsamente considerati, spesso sotto il 20%, o del tutto assenti. Questo squilibrio può minare il principio di sussidiarietà, concentrando la responsabilità finanziaria a livello europeo e riducendo la responsabilità condivisa degli enti locali (Geitzenauer *et al.*, 2017).

Il conflitto tra conservazione e altri usi del suolo, in particolare agricoli, emerge come una delle principali sfide. La sovrapposizione tra politiche agricole e ambientali può generare tensioni, soprattutto quando i benefici della conservazione sono percepiti come collettivi, mentre i costi sono sostenuti localmente (es. conflitti con la fauna selvatica) (Strzelecka *et al.*, 2021). I PAF evidenziano due approcci diversi: uno reattivo, basato su compensazioni, e uno proattivo, orientato alla prevenzione e al coinvolgimento attivo. In quest'ottica, l'uso del Fondo Europeo di Sviluppo Regionale (FESR) appare strategico per valorizzare la biodiversità come risorsa, evitando che Natura 2000 sia percepita come vincolo, ma emerga come opportunità (Dawson *et al.*, 2024).

Un dato che penalizza trasversalmente tutti i PAF è la scarsa attenzione allo sviluppo delle competenze, sia in termini di budget destinato a misure di educazione e training, ma anche nell'utilizzo di fondi specifici come il Fondo Sociale Europeo (FES), Horizon e Erasmus. La mancata previsione di fondi diretti competitivi in diversi PAF suggerisce carenze in progettazione e capacità tecnica (Elliot *et al.*, 2018). Questo limita la diversificazione delle fonti di finanziamento e relega la conservazione a un ambito settoriale, spesso collegato esclusivamente all'agricoltura.

Al contrario, regioni come Lombardia e Umbria, che hanno investito in *capacity building* tramite progetti integrati LIFE, mostrano una maggiore diversificazione delle risorse e una migliore integrazione tra conservazione e altre politiche, dimostrando come l'istituzionalizzazione delle competenze possa rafforzare la gestione di Natura 2000 e promuovere una governance della biodiversità più coerente, coordinata e integrata (Elliot *et al.*, 2018).

Questi risultati suggeriscono che per promuovere una conservazione della biodiversità realmente efficace, è necessario andare oltre il rispetto formale di obblighi normativi e obiettivi di spesa, concretizzando una governance multilivello che integri obiettivi ecologici, capacità istituzionali e dinamiche territoriali, attraverso strategie partecipative, inclusive e radicate nei contesti locali.

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***Archiviare la biodiversità per preservarla.
Le collezioni museali, un patrimonio di dati:
il caso del Museo Regionale di Scienze Naturali di Torino***

Abstract. *Natural history museums, originating in the 16th century as wunderkammer, have evolved to assume new roles, functions, and objectives over time. Their activities can be categorized into three main areas: i) collections management; ii) research; and iii) education and outreach. This study focuses on the Museo Regionale di Scienze Naturali (MRSN) in Torino (Piedmont, Italy), examining some of its botanical and zoological collections for endangered species and type specimens. The results of the analysis showed 1038 endangered species, 40 extinct species, 236 data deficient species and 2216 types. However, the complete digitalisation of the collections is fundamental to have the full picture of the heritage preserved in the museum.*

Musei e collezioni naturalistiche svolgono un ruolo fondamentale nella documentazione e nello studio della biodiversità, non solo come depositi di esemplari ma anche come fonti insostituibili di dati storici ed ecologici. Le attività museali possono essere ricondotte a tre aree principali (Novacek & Goldberg, 2013): i) le attività legate alle collezioni, tra cui la loro conservazione, gestione, implementazione, oltre alla digitalizzazione degli esemplari e dei dati ad essi associati; ii) ricerca scientifica, numerosi sono i campi in cui possono essere utili gli esemplari museali quali la tassonomia e la sistematica, la biogeografia, l'ecologia, la genetica, la conservazione della biodiversità, lo studio dei cambiamenti climatici, fino ad applicazioni ambito medico ed economico (Castillo-Figuroa, 2018; He *et al.*, 2021); iii) educazione, formazione e sensibilizzazione.

Le collezioni rappresentano il cuore pulsante dei musei naturalistici e i loro dati sono essenziali per la tutela e la conservazione della biodiversità: le collezioni storiche e la raccolta di esemplari recenti permette infatti di realizzare mappe di distribuzione e identificare eventuali modifiche nel corso del tempo e dello spazio; i dati biometrici e fenologici possono essere associati ai cambiamenti climatici e a impatti delle attività umane sulle specie selvatiche; i tipi conservati nei musei sono alla base della tassonomia e della filogenesi; le tecniche più recenti di estrazione e amplificazione del DNA permettono di effettuare studi genetici sugli esemplari storici, mentre alcuni musei si stanno dotando di collezioni di tessuti più recenti per questo scopo.

Proprio per valorizzare le collezioni conservate nel Museo Regionale di Scienze Naturali (MRSN) di Torino, questo studio ha due principali obiettivi: da un lato indagare il numero di esemplari tipici conservati; dall'altro, individuare l'elenco e il numero di specie a rischio di estinzione secondo le valutazioni della International Union for the Conservation of Nature (IUCN).

Il museo è diviso in 5 sezioni scientifiche di cui 3 biologiche: nelle collezioni botaniche sono presenti circa 90.000 campioni tra piante, alghe, funghi e licheni; in quelle entomologiche circa 11.000 cassette contenenti 3 milioni di esemplari; e infine in quelle zoologiche circa 550.000 tra vertebrati e invertebrati non esapodi.

Per questo studio si è proceduto inizialmente a una indagine dei database disponibili e si è deciso di escludere le collezioni entomologiche. Dai database individuati (36, alcuni dei quali rappresentano solo parzialmente la collezione corrispondente) sono stati estratti gli elenchi dei nomi scientifici per 14 gruppi tassonomici e i dati riguardanti i tipi conservati in museo.

Gli elenchi risultanti sono stati caricati per verificare la presenza di sinonimie su ChecklistBank, un archivio di dati tassonomici realizzato da Catalogue of Life (COL) e Global Biodiversity Information Facility (GBIF), utilizzando come tassonomia di confronto COL25.8 (Bánki *et al.*, 2025). Dai file ottenuti per i diversi taxa (Tab.1) si sono estrapolate le sinonimie e queste sono state aggiunte ai nomi originali per un totale di 46596 nomi scientifici. Gli elenchi così ottenuti sono stati confrontati con quelli scaricati tramite il sito <https://www.iucnredlist.org/search> (IUCN, 2025) in modo da ottenere le specie classificate in pericolo (vulnerable, VU; endangered, EN; critically endangered, CR), le specie estinte (extinct in the wild, EW; extinct, EX) e quelle con mancanza di dati (data deficient, DD).

Per quanto riguarda i taxa esaminati, oltre il 60% delle specie a rischio di estinzione presenti in museo appartengono a anfibi, piante, molluschi e uccelli (Fig. 1); per numero di specie estinte conservate tra le collezioni al primo posto si trovano i molluschi che da soli rappresentano il 60%, seguiti dagli uccelli con il 20% del totale (Fig. 2); infine pesci, piante e molluschi comprendono oltre il 70% delle specie classificate come mancanti di dati (Fig. 3). Dall'analisi dei tipi presenti, sono emersi circa 2200 esemplari di cui la metà appartenenti a molluschi, uccelli, anfibi e rettili (Tab. 1).

Questa prima indagine ha permesso di fare una stima dei problemi tassonomici associati e la necessità di ulteriore perfezionamento del processo di ricerca nomenclaturale che possono aver influenzato al ribasso le stime delle specie a rischio di estinzione. Utilizzando la ChecklistBank, il 23% dei nomi scientifici inseriti non ha trovato corrispondenza seppur con un successivo controllo a campione questi fossero presenti nella banca dati di GBIF. Inoltre, le collezioni del museo presentano errori di battitura o sinonimie per un ulteriore 25%, dimostrando la necessità di aggiornamento dei nomi scientifici presenti in database.

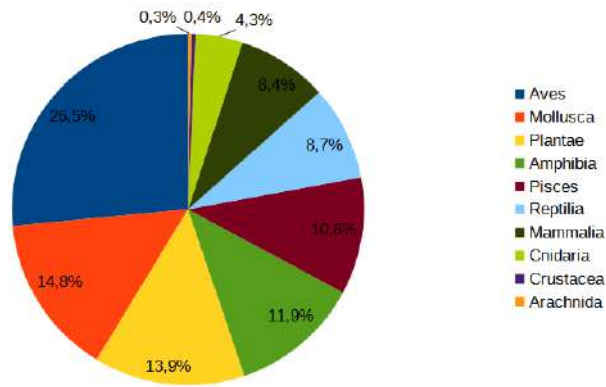


Figura 1 - Proporzioe di specie categorizzate come minacciate (categorie VU, EN, CR secondo IUCN) conservate in museo per i taxa esaminati

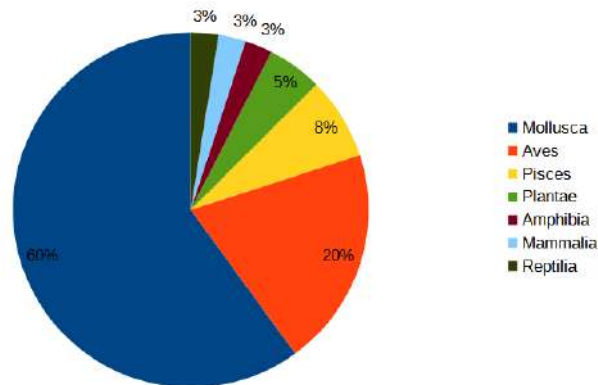


Figura 2 - Proporzioe di specie categorizzate come estinte secondo IUCN conservate in museo per i taxa esaminati

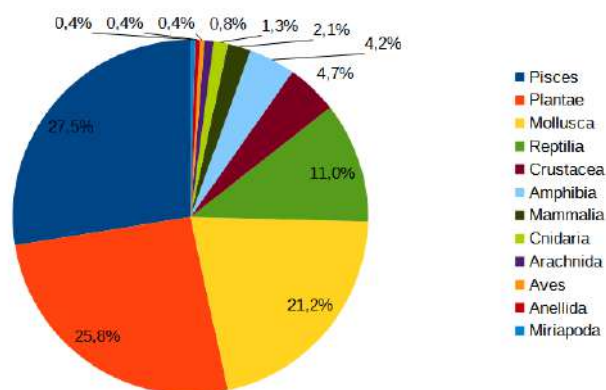


Figura 3 - Proporzioe di specie categorizzate come mancanti di dati secondo IUCN conservate in museo per i taxa esaminati

Anche il confronto con i database scaricati dalla IUCN potrebbe rappresentare una sottostima dei dati emersi: sul sito non viene riportata la tassonomia di riferimento (motivo per il quale si è proceduto a un contatto diretto tramite email, attualmente in attesa di una risposta). Nei dati scaricati, questa non viene esplicitata, mentre aprendo le singole schede delle specie sul sito è possibile trovare per alcune i riferimenti bibliografici; tuttavia, questi non riportano a un'unica tassonomia per il gruppo sistematico relativo.

Tabella 1 - Nella tabella vengono riportati per ogni taxon esaminato i seguenti dati: i) numero database digitali utilizzati; ii) numero di nomi scientifici utilizzati per il confronto con i dati estratti dalla banca dati IUCN; iii) numero di specie a rischio di estinzione; iv) numero di specie estinte; v) numero di specie data deficient; vi) numero di esemplari tipi conservati.

Taxon	N° file utilizzati	N° nomi scientifici	N° specie a rischio estinzione	N° specie estinte	N° specie DD	N° tipi
Amphibia	2	955	124	1	10	~ 300
Anellida	1	342	0	0	1	~ 170
Arachnida	2	1242	3	0	2	~ 100
Aves	2	5475	275	8	1	~ 400
Cnidaria	1	405	45	0	3	~ 70
Crustacea	1	1473	4	0	11	~ 190
Echinodermata	1	284	0	0	0	4
Mammalia	1	1487	87	1	5	~ 10
Miriapoda	1	260	0	0	1	~ 170
Mollusca	2	9638	154	24	50	~ 400
Pisces	2	3334	112	3	65	~ 90
Plantae	17	20178	144	2	61	2
Porifera	1	127	0	0	0	~ 40
Reptilia	2	1398	90	1	26	~ 270

I dati ottenuti sulle collezioni dimostrano il valore delle collezioni del museo: il patrimonio tassonomico soprattutto per la sezione di zoologia è incalcolabile, con i dati attuali infatti emerge che ogni 250 esemplari di zoologia uno sia un tipo e questo elevato valore è dovuto alle collezioni storiche conservate. L'assenza di collezioni storiche è probabilmente il motivo della scarsa presenza di tipi botanici, pari a 2. Anche il valore in ambito conservazionistico non è inferiore, sono infatti oltre 1300 specie a rischio di estinzione, estinte e per le quali non ci sono abbastanza dati.

In conclusione, il lavoro evidenzia come il MRSN rappresenti un patrimonio scientifico e culturale di primaria importanza. Il numero elevato di tipi e la significativa presenza di specie minacciate dimostrano il

ruolo strategico delle collezioni per la ricerca e la conservazione della biodiversità. Tuttavia, restano ampie prospettive di miglioramento, in particolare per quanto riguarda la digitalizzazione completa delle collezioni. Questo processo è fondamentale per rendere pienamente accessibili i dati del patrimonio del museo a supporto della conservazione della biodiversità e della riqualificazione degli ecosistemi, in linea con le sfide globali attuali.

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Cacao e deforestazione in Costa d'Avorio: pratiche agroforestali a supporto di biodiversità e comunità

Abstract. Côte d'Ivoire is the world's leading cocoa producer, but this comes at the cost of severe deforestation and biodiversity loss. We investigated how tree species richness and composition in cocoa plantations affect bird communities, key indicators of ecosystem health. Our field surveys and community-based approach revealed that shade trees enhance bird diversity and provide economic benefits for farmers. These results highlight the potential of agroforestry practices to reconcile biodiversity conservation and human well-being in cocoa landscapes.

La Costa d'Avorio è il principale produttore mondiale di cacao, responsabile di circa il 40% della produzione globale. Questo primato economico ha però un costo ambientale elevato: negli ultimi decenni vaste aree di foresta tropicale sono state convertite in piantagioni, determinando perdita di habitat, frammentazione degli ecosistemi e semplificazione del paesaggio (Rice & Greenberg, 2000; Waltert *et al.*, 2005). Questi processi hanno avuto conseguenze negative sulla biodiversità e sulla stabilità degli agroecosistemi, che risultano più vulnerabili agli estremi climatici e alla pressione di parassiti e patogeni (Maas *et al.*, 2015; Bennett *et al.*, 2021).

Gli uccelli rappresentano un gruppo particolarmente sensibile a tali trasformazioni e costituiscono un indicatore efficace dello stato di salute degli ecosistemi agricoli (Estrada & Coates-Estrada, 2005; Van Bael *et al.*, 2007). Oltre al loro valore conservazionistico, essi svolgono ruoli ecologici cruciali, come la dispersione dei semi e il controllo naturale degli insetti fitofagi, contribuendo così al mantenimento della produttività e della resilienza delle coltivazioni (Nyffeler *et al.*, 2018; Gras *et al.*, 2016).

All'interno di un progetto internazionale e multidisciplinare condotto nel 2023, in collaborazione tra istituzioni svizzere e ivoriane e con il coinvolgimento diretto delle comunità locali, abbiamo indagato come la gestione degli alberi ombreggianti nelle piantagioni di cacao influisca sulle comunità di uccelli (Jarrett *et al.*, 2021; Ferreira *et al.*, 2023). L'attenzione si è concentrata sulla diversità e sulla composizione delle specie

arboree, valutando se e come possano mitigare gli impatti negativi della deforestazione e favorire una gestione più sostenibile (Tscharntke *et al.*, 2011).

Per raccogliere i dati, sono stati effettuati sopralluoghi in piantagioni situate nella regione centro-occidentale della Costa d'Avorio. Abbiamo realizzato censimenti ornitologici tramite osservazioni di campo e punti di ascolto, registrando le specie presenti e la loro abbondanza relativa. Parallelamente, sono stati condotti inventari della vegetazione con attenzione agli alberi utilizzati come ombreggianti e sono state raccolte informazioni dai coltivatori attraverso interviste e discussioni informali, volte a documentare il valore economico e culturale delle diverse specie arboree.

I risultati mostrano che la diversità e la composizione delle comunità avifaunistiche variano in relazione alla gestione degli alberi ombreggianti (Kupsch *et al.*, 2019; Jarrett *et al.*, 2024). Le piantagioni con un maggior numero di specie arboree, soprattutto se comprendenti specie native, ospitano comunità di uccelli più ricche e includono un numero maggiore di specie forestali sensibili. Al contrario, impianti caratterizzati da copertura uniforme, dominata da poche specie esotiche o da alberi selezionati esclusivamente per la produttività, mostrano comunità più povere e dominate da specie generaliste, meno indicative di uno stato ecologico favorevole.

Un aspetto particolarmente interessante riguarda i benefici multipli forniti da alcune specie arboree. Oltre a garantire ombra e stabilizzare il microclima delle piantagioni, esse offrono prodotti utilizzabili dai coltivatori, come frutti, legna da ardere o risorse medicinali, contribuendo alla diversificazione economica delle comunità agricole (Reitsma & Greenberg, 2001; Clough & Putra, 2009).

Questi risultati confermano il ruolo centrale dell'agroforestazione come strumento in grado di coniugare obiettivi ecologici e socio-economici. La presenza di una copertura arborea diversificata migliora le condizioni ambientali per la coltura del cacao, contribuisce alla conservazione della biodiversità e, allo stesso tempo, genera vantaggi diretti per i coltivatori. La chiave per un'adozione diffusa di queste pratiche risiede nel rafforzare il dialogo tra ricerca scientifica e comunità locali, promuovendo soluzioni condivise che garantiscano sia il benessere umano sia la tutela della natura.

In conclusione, lo studio evidenzia come la gestione sostenibile delle piantagioni di cacao in Costa d'Avorio, basata sulla diversificazione degli alberi ombreggianti, possa rappresentare una strategia concreta per affrontare le sfide poste dalla deforestazione e dai cambiamenti climatici, contribuendo alla conservazione della biodiversità avifaunistica e al miglioramento della qualità della vita delle comunità agricole (Tscharntke *et al.*, 2011; Ferreira *et al.*, 2023).

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Eventi climatici estremi nel Nord Adriatico: come risponde la specie invasiva *Callinectes sapidus*?

Abstract. *The blue crab Callinectes sapidus Rathbun, 1896, native to the western Atlantic, has spread along European coasts and established in the Venice Lagoon and Po Delta, where it threatens aquaculture, small scale fisheries, and native species. Its success is linked to high physiological plasticity, favourable habitats, and the new ecological niches open by climate change. To better understand the species' ecology, in the Blue Crab Action Plan project we set up aquarium experiments to examine how extreme temperature–salinity combinations, with values typical of these lagoons, affect adult crab metabolism. Our results highlight the interplay between temperature and salinity in affecting the physiology of this invader, its ecological niche and its impacts on fragile lagoon ecosystems under climate change.*

Il granchio blu *Callinectes sapidus* Rathbun, 1896, è un crostaceo decapode marino nativo delle coste occidentali dell'Oceano Atlantico. Nello specifico, l'organismo riveste un ruolo importante nella zona di Chesapeake Bay, dove costituisce una risorsa per la pesca locale (Hines, 2007). Tuttavia, nella prima metà del 1900 è stata osservata la sua presenza anche nelle zone costiere europee e italiane, come la Laguna di Venezia, nelle quali sarebbe stato trasportato tramite le acque di zavorra delle navi (Mizzan, 1993; Nehring, 2011). L'introduzione in aree favorevoli all'insediamento e proliferazione della specie ha scatenato delle invasioni in diverse zone costiere del continente, causando importanti danni ad ecosistemi e impattando altresì i settori di pesca e acquacoltura (Prado *et al.*, 2020). Il ciclo vitale della specie in ambiente nativo è complesso, con i maschi e gli stadi giovanili che rimangono all'interno degli estuari, mentre le femmine si

spostano periodicamente verso il mare (Epifanio, 2019). Questa specie, come altre specie invasive, è caratterizzata da un'elevata plasticità ecologica: la sua capacità di tollerare un ampio intervallo di salinità (da 24 a 40 psu) e temperatura (da 12 a oltre 35°C) le consente di colonizzare una grande varietà di habitat tramite adattamenti locali, che spaziano dall'ambiente marino alle acque dolci e salmastre (Marchessaux *et al.*, 2023). Tuttavia, i cambiamenti climatici potrebbero aver alterato il ciclo biologico della specie sia nelle sue aree native (DeRivera *et al.*, 2005), che in zone invase. I cambiamenti climatici non includono solamente aumenti di temperatura media o fenomeni di ondate di calore, ma comprendono anche anossie e fenomeni di salinizzazione, che stanno diventando sempre più estremi in zone costiere (Herbert *et al.*, 2015; IPCC, 2023).

Negli anni recenti, anche nel Nord Adriatico si sono registrati cambiamenti climatici anomali come alterazioni di temperatura e salinità drastiche (Bolinesi *et al.*, 2024). In questa zona, sebbene *C. sapidus* fosse stato segnalato per la prima volta già negli anni 40 del 1900 (Mizzan, 1993), la maggiore criticità è emersa con il recente incremento della sua abbondanza, in particolare nella Laguna di Venezia e nel Delta del Po. Per una migliore gestione dell'invasione considerando anche le previsioni future di cambiamenti climatici, è fondamentale comprendere come questi organismi affrontano condizioni ambientali anomale, tipiche di queste aree. I crostacei decapodi sono organismi molto tolleranti, che riescono a sopportare un ampio range di parametri ambientali, incluse condizioni ipossiche e l'esposizione prolungata all'aria (Yamada & Hauck, 2001). È stato quindi avviato un progetto congiunto tra enti locali e istituzioni di ricerca (Regione Veneto, ARPAV, Università di Padova, Università Ca' Foscari di Venezia, Veneto Agricoltura) al fine di raccogliere dati utili a comprendere e contenere l'impatto della specie: il Blue Crab Action Plan, che punta, tra gli altri obiettivi, anche ad analizzare le risposte metaboliche di *C. sapidus* ai fattori ambientali. Questa analisi può fornire informazioni cruciali alle strategie di conservazione ambientale e ripristino di ecosistemi, anche a fronte dei futuri eventi di cambiamenti climatici (Marchessaux *et al.*, 2024). Studiare come il metabolismo degli animali risponde a questi fattori è cruciale per comprendere il loro ruolo ecologico, stimare la resilienza delle popolazioni e costruire modelli predittivi sull'impatto delle future alterazioni ambientali negli ecosistemi, in particolare per le specie aliene invasive. In particolare, tramite questo studio si punta a indagare la plasticità fisiologica del granchio blu nella zona costiera dell'Adriatico del Nord-Ovest. Il metodo utilizzato integra diversi approcci adottati in anni recenti per gli studi di distribuzione delle specie invasive, cioè respirometria (Marchessaux *et al.*, 2024) e analisi della frequenza del battito cardiaco (Kushinsky *et al.*, 2019). Questi approcci permettono di comprendere come il consumo di ossigeno e le pulsazioni, importanti parametri metabolici, possano variare alle diverse condizioni di temperatura e salinità.

Il nostro esperimento si basa sullo studio del consumo metabolico di esemplari adulti di *C. sapidus* di ambo i sessi esposti a diverse combinazioni di temperatura e salinità anche estreme, possibili per periodi prolungati nelle aree lagunari di Venezia e Delta del Po. A tale scopo, i dati di temperatura e salinità, registrati da sonde in continuo nella laguna di Venezia (rete SAMANET), sono stati analizzati per definire nove combinazioni estive di tre temperature (25, 29, 32 °C) e tre salinità (20, 28, 36 PSU). I crostacei sono stati acclimatati per quattro giorni a tali condizioni e successivamente analizzati con test respirometrico e

foto-pletismografo per misurare il consumo di ossigeno e il battito cardiaco. Alla fine del test, sono stati raccolti dati morfometrici dagli organismi analizzati, con prelievo di emolinfa e branchie, per analizzare l'espressione genica causata dai trattamenti.

I risultati preliminari delle analisi respirometriche permettono di avere il quadro delle diverse risposte del granchio blu. Un'analisi PERMANOVA effettuata sul metabolismo aerobico tra i vari livelli di temperatura, salinità e i due sessi mostra che temperatura e salinità influenzano significativamente il metabolismo, mentre il sesso non ha un effetto determinante. In particolare, la respirazione aumenta alle salinità estreme con l'aumento della temperatura, mentre resta all'incirca costante alla salinità intermedia (Fig. 1). A 25 °C e 29 °C gli organismi mostrano un consumo di ossigeno più alto a 28 PSU che alle altre due salinità testate, suggerendo una preferenza di salinità che si discosta da quanto osservato in altre regioni del Mediterraneo (Marchessaux *et al.*, 2024). Tuttavia, a temperature alte, gli effetti della salinità non alterano il metabolismo di *C. sapidus*, probabilmente a causa della già forte influenza della temperatura: nel nostro caso, un declino della respirazione alla temperatura di 32 °C rispetto a 29 °C per 28 PSU potrebbe indicare uno stato subottimale per l'organismo in quelle condizioni (Marchessaux *et al.*, 2022, 2024). Questo studio conferma come il granchio blu sia un organismo caratterizzato da un'elevata plasticità fenotipica da cui deriva la tolleranza ad un ampio range di condizioni ambientali, anche estreme come si possono verificare nelle zone costiere del Veneto. Per verificare in modo completo la sua capacità di adattamento nel Delta del Po, questo studio verrà replicato durante il periodo invernale (novembre/dicembre) dove verranno testate le stesse salinità, ma con temperature estreme tipiche dei mesi più freddi.

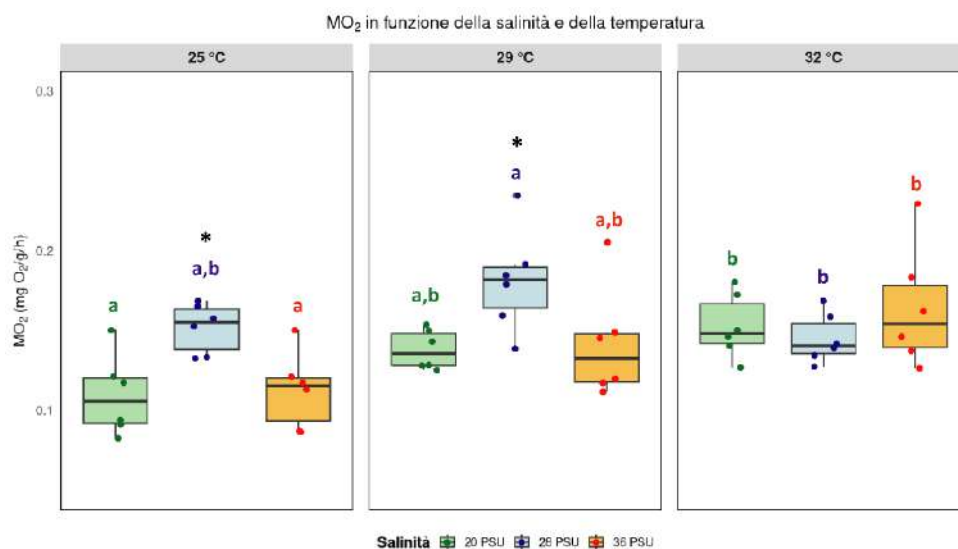


Figura 1 - Consumo di ossigeno di *C. sapidus* (entrambi i sessi) in relazione a salinità (verde: 20 PSU; azzurro: 28 PSU; arancione: 36 PSU) e temperatura (a sinistra: 25°C; in centro: 29°C; a destra: 32°C). L'asse verticale rappresenta il consumo aerobico. I punti rappresentano i singoli organismi testati. Lettere diverse rappresentano differenze significative tra diverse temperature nello stesso trattamento di salinità.

Gli asterischi indicano una differenza di un trattamento di salinità rispetto agli altri nello stesso trattamento di temperatura.

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Deep Learning for dolphin vocalizations, implications for near real-time analysis and archival data

Abstract. *L'uso di tecniche di Machine Learning è aumentato drasticamente nell'analisi bioacustica, dovuto anche alla necessità di dover analizzare un numero sempre più crescente di dati. In questo lavoro, abbiamo sviluppato due modelli di reti neurali convoluzionali (CNN), usate per la classificazione di immagini, per la detezione di click di ecolocalizzazione di tursiopi *Tursiops truncatus*. Le due CNNs hanno ottenuto un true positive rate massimo di 0.89 e 0.90. Questi modelli permettono di analizzare velocemente grandi quantità di dati e fornire indicazioni dell'attività di delfini in un particolare ecosistema. Possono essere inoltre utilizzati in ambiti di analisi in tempo reale nel caso in cui si volessero monitorare attività di interazione reti-delfini o mitigazione da attività umane.*

In recent years, the use of Passive Acoustic Monitoring for marine mammal detection and classification has increased notably and the analysis and processing of this large amount of data results prohibitive in terms of manual analysis from human operators. However, thanks to the impressive advancement of machine learning (ML) algorithms in the last decade, the use of these techniques in bioacoustics has flourished and is expected to support keeping the pace with the speed and amount of data created (Gracic *et al.*, 2024; Kershenbaum *et al.*, 2025) Moreover, Deep Learning models, a sub-field of ML that utilizes neural networks in different architectures, are currently the most successful ones in the analysis of acoustic signals. Going further, Convolutional Neural Networks (CNNs) are models used in image classification where one part of the network extracts information thanks to several layers of filters (convolutional layers - encoder part) and all the information is later passed through the classification head (decoder part) that interprets the information extracted.

In bioacoustics, sounds can be easily converted into images in the form of spectrograms or other representations (e.g. Mel-spectrograms, MFCC); these can then be used by CNNs for detection and classification of signals of interest (e.g. dolphins or boats transit). CNNs need a large amount of data to be trained, often tens of thousands of high quality records are needed, which is challenging to obtain for marine mammals vocalizations, since natural recordings are often affected by disturbance, background noise, etc. In some cases, there is no need to start from scratch: several pre-trained models are available and can be used to

train the new CNNs, reducing significantly the amount of data needed for training. This technique is called fine-tuning.

Dolphins are known to produce a remarkable variety of vocalizations (Jones *et al.*, 2020) that includes whistles, narrow-band modulated signals, used for communication, echolocation clicks used for navigation, orientation and tracking of prey, always produced in trains and burst pulses, impulsive sounds tightly packed together used in communication whose meaning shift according to the behavioral context. These vocalizations are produced in different proportions according to the presence of other individuals and behavioral context (e.g. socializing or hunting for prey) and thus it is important to choose the right signal for detection according to the different target species and specific task.

This work focuses on the creation of a simple model based on CNNs for the detection of echolocation trains (Gracic *et al.*, 2024; Lelong *et al.*, 2025) of bottlenose dolphins (*Tursiops truncatus*) across different soundscapes. Model performance and flexibility to different kinds of environment will be investigated. Tasks go from near real-time analysis to analyzing a large amount of archival data.

The vocalizations of bottlenose dolphins were manually annotated from acoustic recordings coming from archival data of previous projects; most data had been collected in the Ligurian Sea, especially in the Pelagos Sanctuary, a marine protected area created in 1999 within the collaborative efforts of France, Italy and Monaco for the protection of marine mammals living in the area. Recordings were made with uRec hydrophones at 96 kHz of sampling rate, 16 bit depth. The annotated vocalizations were then extracted from the recordings using Raven Pro 1.6 and checked for the type of vocalizations (i.e. whistle, echolocation train and bursts). Most of the annotations belongs to echolocation trains (Fig. 1), and consequently we chose to build a CNN model for the detection of echolocation trains using a binary classification (click/noise).

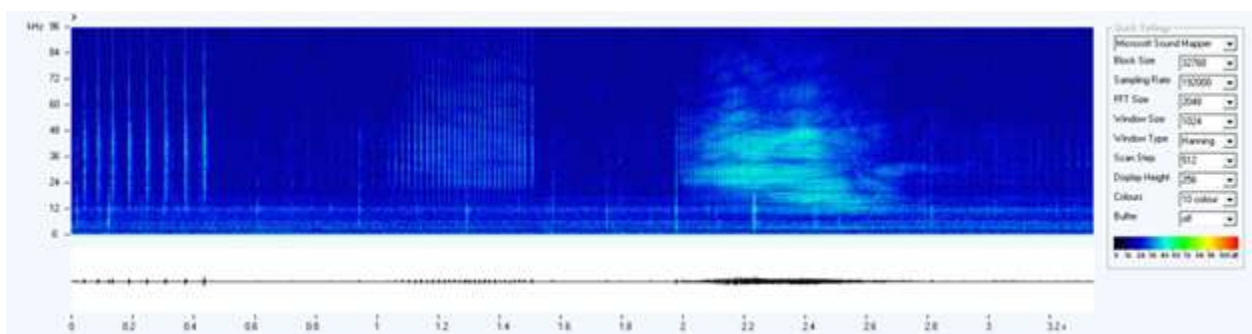


Figure 1 - Spectrogram showing different bottlenose dolphins echolocation trains, corresponding to different phases of prey chasing and tracking

The vocalizations that included echolocation trains were gathered together and split into 2 seconds wav files and saved in a separate folder. Consequently, random segments of 2s containing only noise were extracted from recordings with no vocalizations present. The starting dataset included 1892 segments of echolocation trains and 3600 segments of noise. Then, each single waveform was transformed into spectrograms (FFT 1024 points, 1024 points hop size) and consequently translated in 50 mel-frequency

bands between 20 and 45 kHz. This choice was motivated by the fact that most echolocation train exhibit energy in this frequency band. Then the mel-spectrograms were transformed into a gray images and min-max standardized with values between -1 and 1.

Then, the images were ready for the training of the CNN models whose architecture was a ResNet (He *et al.*, 2015) with different numbers of layers or depths. The model returns a value from 0 to 1 for the signal/noise for binary classification and the user can further set a threshold according to the specific task. In particular, we trained a ResNet-18 (Fig. 2) and ResNet-101 using fine-tuning from pre-trained weights from ImageNet. The dataset was divided into training set (4394 samples) and validation set (1098 samples), with a proportion of 80 and 20 percent, respectively. An independent test dataset of 450 additional samples with homogenous representation of signal of interest and noise was used for the final evaluation of the models performances, which were carried out by assessing precision (metric to measure the amount of false positives), recall (true positive rate), F-1 score and the AUC coming from the precision-recall curve.

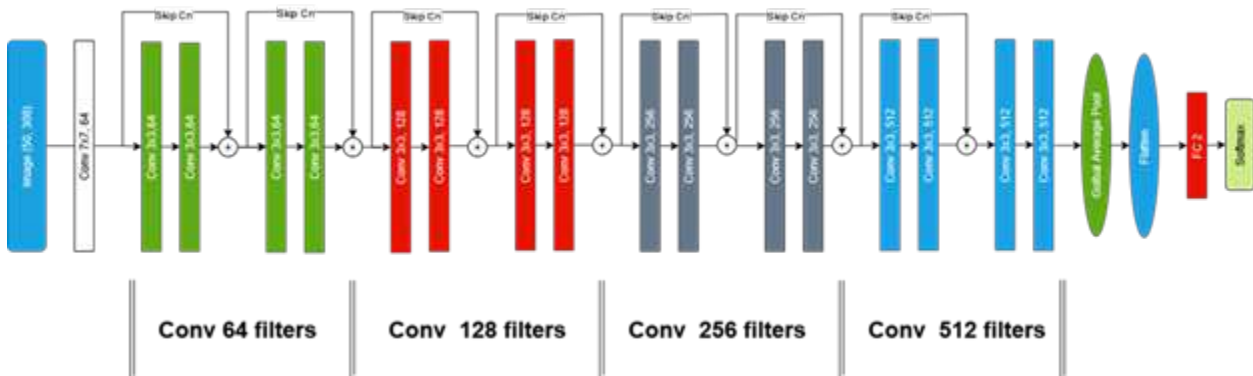


Figure 2 - General architecture of Res-Net 18

The AUC for the ResNet-18 and 101 were 0.96 (Fig 3) and 0.92, respectively, with a maximum recall of 0.89 and 0.90 for the two models. However, these encouraging preliminary results need to be reinforced by applications to other soundscape scenarios, e.g. more noisy environments with close passage of boats and high activity of snapping shrimps close to rocky shores. In fact, these types of noise sources may impact the model performance by increasing the number of false positives and mask the presence of echolocating dolphins.

The current models can aid researchers in the analysis of enormous acoustic dataset searching for dolphins activity and have an initial assessment of their temporal pattern and frequency of occurrence. As false positives can be present it is always important to have care for some human control in the results. Future work will explore ways to make these models robust also to environments dominated by the close passage of boats and snapping shrimps.

The current models can be continuously updated and as more data are used for training, the better the model becomes across different sonic environments. Also, as the model grows in terms of depths (number of

layers), the CNN has the possibility to extract higher-degrees of complexity of the patterns in the image and might consequently become more general and robust to different kinds of environments.

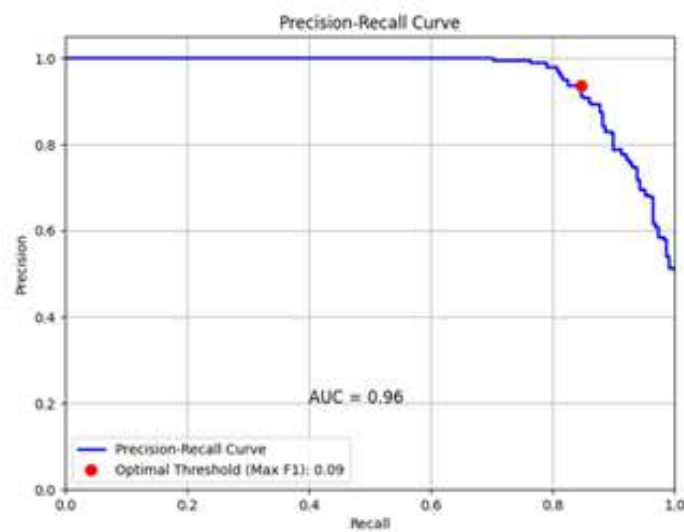


Figure 3 - Precision-recall curve of Res-Net 18. The red dot represents the optimal threshold where the curve has the maximum F-1 score

There is also an active area of research in developing systems where these models can process data near real-time and be used in surveillance and mitigation of human activities. The limitations at the moment are restricted to the hardware, the battery usage or the cost of data transmission that can hamper the duration and efficiency or real-time analysis. Despite few limitations, especially the knowledge barrier that comes from computer science and biology (Kershenbaum *et al.*, 2025), ML is increasingly playing a major role in the analysis of data and monitoring, helping researchers in new findings and accelerating the laborious process of analysis in an era of large datasets.

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Identifying climate refugia to guide adaptive planning: the case study of the Strait of Sicily

Abstract. *Lo studio valuta la capacità di adattamento di tre scenari di pianificazione marittima nello Stretto di Sicilia tramite l'analisi della velocità climatica 3D nel Mar Mediterraneo e l'individuazione di rifugi climatici e hotspot. In tutti gli scenari, le configurazioni spaziali future non proteggono i rifugi climatici (<30%) e molte zone di protezione ricadono in aree hotspot di cambiamento. Inoltre, diverse attività antropiche che dipendono da un buono stato ambientale risultano localizzate in aree instabili, dove in futuro rischiano di perdere efficacia e sostenibilità economica. Gli scenari più conservativi migliorano leggermente la protezione, ma nessuno è pienamente climate-smart. L'approccio supporta strategie adattive verso una pianificazione spaziale marittima climate-smart.*

Climate change is threatening marine ecosystems, which are already experiencing profound shifts in biodiversity and ecosystem functioning. These changes risk undermining the effectiveness of traditional conservation strategies, usually designed based on the present state (Gissi *et al.*, 2019). In a rapidly changing ocean, this approach may fail. To ensure the persistence of biodiversity and ecosystem services, a climate-smart perspective is needed, focused on identifying areas that are most likely to maintain stable conditions over time – so-called climate refugia (Brito-Morales *et al.*, 2018; Buenafe *et al.*, 2023). These stable areas are crucial for conservation and restoration efforts, as they help avoid investing resources in locations that will become unsuitable in the future.

In this study, we aimed to (i) identify climate refugia within the Mediterranean water column, and (ii) assess the climate adaptation and mitigation resilience of three alternative marine spatial planning (MSP) zoning scenarios designed for the Italian MSP process in the Strait of Sicily.

To detect refugia and hotspots, we computed an analogue-based climate velocity, which measures how far and in which direction species would need to move to track similar future climate conditions (Carroll *et al.*, 2015; Kyprioti *et al.*, 2021). We extended the analogue search throughout the full water column, thus producing a 3D climate velocity with both horizontal and vertical components. The analysis was based on nine bioclimatic variables derived from temperature projections under the business-as-usual RCP 8.5 scenario, averaged over two 25-year periods (2006-2030 and 2031-2055). To maintain ecological realism,

analogue searches were constrained within depth ranges corresponding to key biozones (Brito-Morales *et al.*, 2022; Doxa *et al.*, 2022): euphotic, mesophotic, mesopelagic and bathypelagic. In addition, we computed bottom-only velocity, restricting analogue searches to seafloor locations, to assess potential impacts on benthic species unable to move vertically. Refugia were defined as areas with velocity values below the 10th percentile, while hotspots were those above the 90th percentile or with no future analogues.

We then compared the spatial distribution of refugia with the zoning of three MSP scenarios co-designed with stakeholders within the National Biodiversity Future Centre MSP4Biodiversity project. These scenarios represent different planning strategies: *SlowPace* follows a business-as-usual approach, *Nature@Work* focuses on conservation, and *BlueDevelopment* emphasizes the sustainable use of marine resources. Specifically, we evaluated the placement of existing and potential Marine Protected Areas (MPAs) and Other Effective Conservation Measures (OECMs), and developed two indicators to assess climate adaptation resilience: the percentage of conservation areas overlapping respectively with (i) refugia and (ii) hotspots.

In the Strait of Sicily, the euphotic zone is the one with highest exposure to climate change, where the average horizontal velocity is 4.7 km/year. However, even higher velocities were observed below 1000m (~41 km/year) and at the seafloor (~12 km/year), where 10% of cells lack any future analogues. In contrast, intermediate depths appear more stable. Vertical velocities show a clear pattern: downward shifts in the upper layers, upward shifts in deeper layers, and a buffer zone around the mesophotic region where vertical velocities are close to zero.

When evaluating the MSP scenarios, none of them adequately protects climate refugia. Overlap with refugia is consistently low (<30%), with little variation between scenarios. Conversely, a large proportion of MPAs and potential OECMs are located within hotspots, exceeding 50%, in some depth layers and with minimal differences among scenarios. When combining both indices, *Nature@Work* performed slightly better, suggesting that scenarios centred on conservation and featuring more extensive protected areas may help improve the future allocation of conservation efforts. Importantly, a careful allocation of new MPAs in areas with low climate velocity can increase adaptability of zoning plans also under other planning scenarios.

This study provides a practical framework for integrating future climate dynamics into marine spatial planning, highlighting the importance of protecting climatically stable areas to support biodiversity persistence and ecosystem functioning. By identifying where environmental conditions are most likely to change or remain stable, our approach can improve the placement of conservation zones and marine uses while also supporting broader management actions aimed at enhancing ecosystem functioning. In areas projected to experience rapid change, this knowledge can guide the mitigation of local human pressures in stable areas, while stable areas can be prioritised for conservation or restoration efforts. By combining 3D climate velocity with scenario-based spatial assessment, our approach bridges the gap between climate science and policy, offering a tool to design adaptive, forward-looking strategies. Although none of the current planning scenarios fully addresses future climate challenges, these insights can guide more effective

decisions, ultimately contributing to biodiversity protection and the long-term adaptation of marine ecosystems to future changes.

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Nursed into the wild: persistence and behavioural ecology of 1+ and 2+ hatchery-reared marble trout (*Salmo marmoratus*) released into a small spring-fed alpine stream with implications for restocking strategies

Abstract. Il progetto Life GrayMarble mira a migliorare lo stato di conservazione della trota marmorata (*Salmo marmoratus*), endemismo padano. Tra le azioni previste, vi sono reintroduzioni di individui allevati in incubatoio e l'identificazione di aree nursery dove i giovani pesci possano adattarsi all'ambiente naturale prima del rilascio definitivo in fiume. Uno studio telemetrico mediante RFID-tags è in corso su 320 trote di due classi d'età (1+ e 2+), marcate in incubatoio e rilasciate in quattro gruppi, sia di giorno che di notte, in un piccolo corso d'acqua montano alimentato da una risorgiva, a Planaval (Valle d'Aosta). Vengono presentati i risultati preliminari, utili a ottimizzare le future operazioni di rilascio, integrate da interventi di recupero ambientale e monitoraggio costante.

The Life GrayMarble project aims to enhance the conservation status of the endangered marble trout *Salmo marmoratus* (Cuvier, 1829), a freshwater fish species endemic to the Adriatic basin and notably the only native salmonid in the Dora Baltea River basin, spanning Piedmont and Aosta Valley in NE Italy. Formerly regarded as a subspecies of *Salmo trutta*, the marble trout is now fully recognized as a distinct species according to the latest taxonomic revisions (Kottelat & Freyhof, 2007; Abbà *et al.*, 2024). Due to its conservation importance, it is listed in Annex II of the EU Habitats Directive 92/43/EEC and in the revised Appendix I of the Bern Convention. Once widespread throughout the upper salmonid zones of northern Po tributaries, this species is now confined to fragmented habitats with limited genetically pure populations. Major threats include hybridization with introduced brown trout *S. trutta*, habitat alteration, fragmentation, water withdrawals, and angling (Nyqvist *et al.*, 2022; Pengal *et al.*, 2023). National assessment classifies the marble trout as critically endangered (CR) according to IUCN criteria (Rondini *et al.*, 2022). As part of a comprehensive conservation approach, the Life GrayMarble project includes reintroductions of genetically certified marble trout, bred from wild specimens via artificial reproduction, into suitable nursery streams to

support juvenile growth (Chiesa *et al.*, 2016; Polgar *et al.*, 2022). These sites serve as intermediate habitats to facilitate the acclimatization of hatchery-reared fish before their release into larger river systems such as the Dora Baltea River. Although previous studies have investigated reintroductions of hatchery-reared salmonids, information on the success and ecological performance of marble trout using semi-natural nursery habitats remains limited. A Passive Integrated Transponder telemetry study was planned to assess the marble trout reintroduction into a small semi-natural spring-fed mountain stream, located at 1.550 m a.s.l. (Planaval, Aosta Valley), in an approximately 300 meters long reach bounded by a downstream natural waterfall, selected as an ideal closed nursery system for monitoring fish adaptation. The aim of the study is to assess the suitability of the nursery area and release timing by analysing hatchery-reared marble trout response over time (14 months) to the new environment in terms of abandonment, survival, movement, growth (recapture at the end of the study), in relation to age class (1+ and 2+) and time of release (day-dusk). A total of 320 fish, split into two age classes (1+ and 2+), sourced from the Morgex fish breeding facility (Aosta Valley Regional Consortium for the Protection, Promotion, and Practice of Fishing) were tagged with PIT-tags (Oregon, USA; 12×2.1mm; 0.10g), and released in the study area in July 2025. Biometric data for fish from both age classes were recorded. The mean fork length and body weight for 1+ trout were 15.1 ± 2.6 cm and 39.6 ± 23.2 g, respectively, whereas 2+ trout exhibited mean values of 22.3 ± 3.3 cm in fork length and 122.6 ± 60.2 g in weight. Tagged fish were split into four groups (50 specimens 1+ and 30 2+ each) and released into a pool in the upper portion of the study area during four release events: two different times of release (day and dusk) over two days. To continuously monitor fish movements in the system, two stationary receivers (ORMR; Oregon RFID, USA), each equipped with four PIT-antennas, were installed along the study area, four at the lowermost portion of the stream (to track exit from the system) and four in its upper portion (to detect upstream movement and the use of a small perennial tributary). Each antenna covers the entire cross-section of the stream to ensure maximizing the detection of transitioning fish. Concurrently, environmental parameters such as water levels and water temperature were continuously recorded at 20 min intervals using a temperature and water level sensor (HOBO MX2001) installed in the downstream portion of the stream. The stationary continuous monitoring system is complemented by manual tracking sessions carried out with a mobile backpack antenna connected with a portable pole antenna (Mobile HDX Long Range PIT Tag Reader Kit; Oregon RFID) to actively track the tagged fish along the study reach scanning the entire study area by walking or wading upstream (Schiavon *et al.*, 2025a, 2025b). For real-time visualization of individual fish identification codes, the mobile reader is connected to an Android smartphone device via Bluetooth. Datetime and position in a hydromorphological unit-based coordinate system are noted for every detected fish, enabling precise localization of every individual within the study area at each monitoring event, correlating fish position with stream section, water depth, and status (S = seen, A = alive, D = dead, NO = no information, TL = tag lost). To visualize the individual positions and track fish movements over time, the precise fish locations (± 0.75 m) are imported into a GIS environment. Habitat variability was assessed using the MesoHABSIM protocol (Parasiewicz, 2007; Parasiewicz *et al.*, 2011;

Veza *et al.*, 2014). Hydromorphological units (HMUs), such as riffles, pools, and glides, have been delineated as GIS polygons and assigned physical attributes including substrate type, depth, and current velocity. These units will also be mapped under different flow conditions, as discharge variations modify the physical characteristics of HMUs, which in turn influence patterns of fish habitat use and enable habitat-use analyses. Diurnal and nocturnal manual tracking surveys are conducted at regular intervals to thoroughly investigate fish behaviour. To date, manual tracking sessions have been carried out more intensively following release, to assess the immediate fish response to the new environment, and weekly for the remainder of July, while during the remaining months tracking has occurred every two weeks. Other intensive tracking sessions, on a daily and weekly basis, are planned in autumn to monitor fish behaviour during the reproductive period. The study will have a duration of 14 months and will continue until September 2026, allowing the collection of a relevant dataset that would enable a thorough assessment of the suitability of the nursery area and of the overall conservation strategy for reintroducing hatchery-reared marble trout in the main river system.

First results, here presented, include estimates of persistence, behavioural insights, and movement-ecology metrics (i.e., linear range), analysed comparatively across different age classes and release timings. Differences in fish rate of departure (mortality or emigration) between the age groups and release time (day/dusk) were analysed based on the last date of observation. These preliminary results provide valuable insights into the early adaptation responses of hatchery-reared marble trout within their new natural environment and contribute critical data to optimize future release strategies and conservation efforts.

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Intra-annual dynamics of stream biofilm in a mountain catchment with contrasting environmental conditions

Abstract. *Il perifiton costituisce la componente autotrofa principale dei torrenti montani, ma le sue dinamiche temporali sono poco studiate. Questo lavoro indaga le variazioni mensili di biofilm epilittico in cinque siti del bacino del Serio (Alpi Orobie), caratterizzati da condizioni ambientali diverse. Il biofilm è stato campionato per un anno e analizzato per biomassa, pigmenti e composizione dei principali gruppi algali, insieme a parametri ambientali quali disturbo idrologico, temperatura, luce e nutrienti. I risultati mostrano una forte variabilità temporale: le piene riducono biomassa e pigmenti, mentre luce e temperatura guidano la successione stagionale dei gruppi algali. Le differenze spaziali risultano limitate, presenti solo in presenza di invasi, suggerendo che la componente autotrofa varia più nel tempo che nello spazio.*

Periphyton is the dominant primary producer in mountain streams, forming the base of food webs and supporting ecosystem functioning through primary production, nutrient cycling, and organic matter retention (Larned, 2010; McConnell & Singler, 1999). Despite its key ecological role, most studies have focused on spatial comparisons among sites, generally considering only diatoms, while temporal investigations of the whole periphytic community—including biofilm biomass, pigments, and algal groups—remain scarce (Uehlinger, 1991). This study addresses this gap by investigating the intra-annual dynamics of epilithic biofilm in mountain streams of the Serio catchment (Orobic Alps, Northern Italy), within the Alpine Space area. A one-year quantitative campaign was conducted with monthly sampling across five stream sites located between 500 and 1200 m a.s.l. The sites were characterized by contrasting hydrological and thermal regimes driven by differences in water sources and anthropogenic regulation. Sites S and G were located on silicate streams fed by snowmelt and stormwater, with S being unregulated and G regulated by a reservoir. Sites U and D were situated along a calcareous stream fed by both snowmelt/stormwater and groundwater, upstream (U) and downstream (D) of a reservoir. Finally, site N was located on a groundwater-fed stream. These contrasting hydrological settings influenced sediment dynamics and generated a marked gradient of annual temperature variability (from 16 °C in S to 1 °C in N) around a similar annual mean (6–9 °C). At each sampling, biofilm was collected by assembling ~1 dm² of epilithic surface from multiple substrates and analyzed through complementary approaches. Biomass was quantified as ash-free dry mass normalized by sampled area, while pigment content (chlorophyll a, chlorophyll b, carotenoids) was extracted in methanol and measured spectrophotometrically. The relative abundance of periphyton groups (diatoms, green algae,

cyanobacteria, red algae) was assessed with the Phyto-PAM II instrument, which discriminates algal groups based on fluorescence emission. Concurrently, flood disturbance, water temperature, physicochemical conditions, nutrient concentrations, substrate diversity, and light availability were measured to identify potential environmental drivers (Bernhardt & Likens, 2004; Biggs, 1995; DeNicola, 1996; Hansson, 1992). Results showed a pronounced temporal variability of biofilm at all sites. Disturbance was identified as the primary driver of biomass and pigment content, affecting all sites similarly: floods consistently reduced biofilm mass and pigment concentrations, shifting benthic metabolism toward heterotrophy, whereas stable winter flows promoted biomass and pigment peaks under reduced canopy cover. A clear seasonal succession of algal groups was also observed, driven by light and temperature variations: green algae dominated in autumn, cyanobacteria and red algae increased in spring–summer and summer–autumn, respectively, while diatoms remained dominant for most of the year. Spatial differences were also detected but were limited compared to temporal variations. Annual biofilm biomass ranged from 4.4 to 15.0 g/m², with higher values in regulated sites (G, D) compared to unregulated sites (S, U, N), while pigment concentrations did not differ significantly among sites. Contrary to expectations, periphyton group composition was not strongly linked to local site-specific conditions but primarily responded to temporally varying drivers such as disturbance, temperature, light, and nitrate availability. Despite contrasting hydrological and thermal regimes, all sites displayed a similar annual turnover in periphyton composition, indicating consistent community-level responses to seasonal forcing. This study demonstrates that frequent (monthly), quantitative monitoring is crucial for capturing intra-annual variability in biofilm and disentangling the relative importance of environmental drivers. The integration of biomass quantification, pigment analyses, and Phyto-PAM deconvolution proved to be a rapid and effective strategy for detecting shifts in algal groups, although detailed taxonomic identification is still necessary to fully understand changes in community composition. Overall, the findings show that biofilm development in subalpine streams is governed primarily by seasonal forcing rather than by site-specific features. These insights advance our understanding of benthic ecosystem functioning in mountain environments and emphasize the need to incorporate intra-annual variability when investigating stream processes and food-web dynamics.

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Il sapere tassonomico sugli Efemerotteri come bussola per il ripristino degli ecosistemi fluviali

Abstract. *The EU Nature Restoration Law (2024/1991) aims to restore degraded ecosystems and biodiversity. In Italy, the IRSA-CNR is revising the taxonomy of mayflies (Ephemeroptera), key freshwater indicators, due to outdated or incomplete data. A checklist of 106 species, based on morphological data, has been compiled, revealing a high level of endemism (27%) and highlighting cases of uncertainty. Genetic analysis of Cytochrome Oxidase Subunit I and traditional morphological studies are being carried out and combined in the framework of an integrative taxonomy, revealing new putative species. Historical gaps in research and limited recent discoveries highlight the urgent need to boost taxonomic studies to improve the knowledge of freshwater biodiversity and support effective ecological restoration.*

L'articolo 1 del Regolamento (UE) 2024/1991, noto come *Nature Restoration Law* (NRL), stabilisce come obiettivo primario il “recupero a lungo termine e duraturo della biodiversità e della resilienza degli ecosistemi in tutte le zone terrestri e marine degli Stati membri attraverso il ripristino degli ecosistemi degradati”. Oltre agli organi di governo nazionali, la NRL coinvolge attivamente la comunità scientifica a cui è affidato il compito di individuare delle soluzioni in tempi relativamente brevi (un quarto di secolo) a danni ambientali che l'uomo infligge alla natura da circa due secoli. Il ripristino degli ecosistemi allo stato originario rappresenta l'obiettivo ideale anche se forse quello più difficilmente realizzabile. In tal senso, si possono considerare le difficoltà nel raggiungimento degli obiettivi previsti dalla Direttiva 2000/60/EC (*Water Framework Directive*, WFD). Infatti, nonostante la WFD imponesse già agli Stati membri il raggiungimento di obiettivi di qualità almeno pari ad un buono stato ecologico entro il 2027, solo il 37% dei corpi idrici europei ha raggiunto tale stato (<https://www.eea.europa.eu/en/analysis/indicators/ecological-status-of-surface-waters>). Ciò rende ancora più importante l'approvazione di una nuova legge focalizzata sulla biodiversità e la rinaturalizzazione degli ecosistemi. Considerando la comunità macrobentonica delle acque dolci fluviali, una conoscenza lacunosa delle specie potenzialmente presenti in un ecosistema oggetto

di riqualificazione rappresenta un importante limite alla definizione di obiettivi ecologici concreti per il recupero della biodiversità. In termini operativi, la mancanza di una lista delle specie di riferimento, validata e aggiornata da esperti tassonomi, impedisce la completa individuazione di soluzioni mirate al ripristino della biodiversità, rendendo incerta la direzione degli interventi di risanamento ambientale. Tra gli organismi acquatici più abbondanti negli ambienti fluviali, vi sono gli Efemerotteri, un ordine di insetti che rappresenta una parte significativa sia della biomassa (Sartori & Brittain, 2015) sia della diversità e ricchezza in specie (Jacobus *et al.*, 2019). In Europa, l'ordine conta circa 370 specie distribuite in 19 famiglie (Bauernfeind & Soldán, 2012) apparendo relativamente poco numeroso. Nonostante ciò, non è ancora del tutto chiaro quali e quante specie siano presenti sul territorio italiano (probabilmente più di quelle già descritte). Infatti, dal momento della loro descrizione, alcune specie non sono state più rinvenute e la descrizione morfologica di alcune (in particolare le specie descritte prima della metà del secolo scorso) risulta talvolta parziale o approssimativa. È utile inoltre evidenziare che l'ultima descrizione ad opera di ricercatori italiani risale al 1997 (Belfiore *et al.*, 1997). Per tali motivi e per fornire un aggiornamento del quadro conoscitivo generale sugli Efemerotteri in Italia, l'Istituto di Ricerca Sulle Acque di Brugherio - Consiglio Nazionale delle Ricerche (CNR-IRSA) ha avviato, in ambito NBFC, un importante lavoro di revisione tassonomica sull'intero ordine a partire da alcuni generi.

L'area di studio si riferisce principalmente al territorio italiano, con particolare attenzione alle raccolte nelle località tipiche delle specie già descritte. Associati ai campioni si dispone in molti casi di informazioni ecologiche di campo (e.g. microhabitat, tipo fluviale, substrato). Il disegno sperimentale per le ricerche tassonomiche ha previsto uno studio dello stato dell'arte attraverso i) la definizione di una lista delle specie di Efemerotteri che si ritiene siano presenti attualmente in Italia, ii) un'analisi storica delle descrizioni delle specie italiane da Linneo ad oggi, iii) un'indagine prospettica sulle nuove specie putative di Efemerotteri in Italia, in relazione al contesto europeo delineato dai Barcode Index Numbers (BINs) disponibili nel portale Barcode of Life Data Systems (BOLD). Le indagini tassonomiche in corso vengono condotte integrando analisi genetiche e analisi morfologiche. Le analisi genetiche prevedono il sequenziamento della Subunità I della Citocromo Ossidasi (COI), per fornire sia una panoramica preliminare come DNA barcoding, sia una guida per le nuove specie da descrivere. Successivamente, un approccio di filogenesi multilocus potrà aiutare a chiarire e comprendere meglio le relazioni tassonomiche e la storia evolutiva delle specie in esame. Nella fase di estrazione del DNA, è stato sviluppato un protocollo che consente di mantenere l'integrità dell'esoscheletro per le successive fasi di analisi morfologica. Per le specie d'interesse, essa viene eseguita sulle larve selezionate anche in base ai risultati del sequenziamento e prevede i) l'allestimento e l'osservazione di vetrini semi-permanenti, ii) la scelta dei caratteri diagnostici e iii) il rilievo e la quantificazione dei caratteri diagnostici che, nell'ottica di una tassonomia integrata, saranno ove possibile espressi in forma quantitativa, in modo da consentire successive analisi statistiche.

I risultati dell'analisi storica delle descrizioni delle specie italiane, da Linneo fino ai giorni nostri, evidenziano tre periodi di intensa attività scientifica (1758–1791, 1834–1888 e 1951–1997), intervallati da

fasi di stasi o di totale assenza di progressi. L'attuale fase, iniziata nel 1997, ha visto la descrizione di sole 3 nuove specie (Buffagni *et al.*, in press), a dimostrazione della scarsità delle conoscenze sull'ordine e della marginalità ad esso riservata nell'ambito di ricerca nazionale negli ultimi tre decenni. Le indagini hanno inoltre portato a definire una checklist aggiornata che conta, su base morfologica, 106 specie di Efemerotteri che si ritiene siano presenti attualmente in Italia (Buffagni & Belfiore, 2025). La checklist descrive anche i casi controversi e ancora irrisolti (i.e. *species inquirenda*) ed enfatizza l'alto tasso di endemismi, circa il 27%. Questo complesso scenario è confermato dall'analisi dei BINs che sono stati esaminati per ciascun genere al fine di valutare il grado di condivisione o esclusività dei BINs stessi tra i diversi Paesi europei. Nonostante la distribuzione disomogenea dei dati forniti dalle nazioni, i risultati mostrano che l'Europa centrale presenta un numero totale e condiviso di BINs molto più elevato rispetto ad altre aree. Il Mediterraneo centrale (i.e. l'Italia geografica) e l'Europa orientale, invece, mostrano valori elevati di BINs esclusivi, pur avendo un numero complessivo di BINs inferiore (Buffagni *et al.*, in press). Inoltre, l'analisi molecolare in corso sul COI supporta la presenza di nuove specie che, non solo non trovano corrispondenza con le sequenze già depositate nelle banche dati (i.e. GenBank, BOLD), ma anche la cui descrizione morfologica non combacia con quelle disponibili in letteratura. Parallelamente, le analisi morfologiche hanno portato alla realizzazione di circa 120 vetrini, che si sommano ai circa 200 già presenti nelle collezioni storiche dell'IRSA di Brugherio. All'interno del progetto ITINERIS, delle 106 specie di Efemerotteri incluse nella nuova checklist, sono stati digitalizzati e resi disponibili su GBIF 58 vetrini, corrispondenti a 29 specie con identificazione confermata (Buffagni *et al.*, 2025), come strumento di riferimento per la comunità scientifica.

In conclusione, considerando il numero di specie ancora da descrivere, l'elevato tasso di endemismi, la carenza di studi sistematici sull'ordine negli ultimi tre decenni e le crescenti richieste di intervento per il recupero della biodiversità da parte della NRL, emerge con urgenza la necessità di rilanciare la ricerca tassonomica e di base. Essa, infatti, risulta uno strumento imprescindibile per evitare che l'estinzione delle specie avvenga prima della loro formale descrizione, nonché per garantire che le attività di ripristino ecologico siano condotte con la dovuta consapevolezza scientifica e conoscenza tassonomica.

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Effects of hydrological connectivity on benthic metabolism and nitrogen cycling in a restored perfluvial wetland

Abstract. *Le aree umide perfluviali trattengono e trasformano l'azoto in eccesso, ma i processi bentici che li regolano restano poco compresi. Nel 2023, un'area lungo il Po è stata riqualificata aumentando la connessione idraulica con l'alveo principale. L'effetto sul metabolismo bentico è stato valutato con simulazioni in laboratorio e misure in situ prima e dopo l'intervento: le simulazioni mostrano un potenziale di denitrificazione oltre sei volte superiore ai tassi naturali ($<1000 \mu\text{mol N m}^{-2} \text{d}^{-1}$), probabilmente per variabilità temporale e competizione per il nitrato tra componente microbica e fitoplancton. Lo studio evidenzia come la riconnessione idraulica possa aumentare la denitrificazione, ma i risultati sperimentali possono non riflettere la complessità naturale e restano da valutare gli effetti a lungo termine.*

Perfluvial wetlands provide multiple ecosystem services, including water quality improvement, flood protection, landscape diversification, and regulation of biogeochemical cycles (Knox *et al.*, 2022). Acting as natural buffers, they can help mitigate nitrogen pollution - one of the major threats to freshwater ecosystems in highly anthropized watersheds - by filtering, transforming, and retaining excess nitrogen (Wohl *et al.*, 2024). Despite their importance, perfluvial wetlands are often compromised by human impact, partly due to the poor evaluation and understanding of their functions (Fluet-Chouinard *et al.*, 2023). Over the past two centuries, extensive engineering interventions - including channelization, damming, and other flood-control measures - have reduced hydrological connectivity between river channels and perfluvial wetlands, fundamentally altering river biodiversity, ecosystem functioning, and the floodplain's capacity to incorporate nutrients into its biogeochemical processes (Coder *et al.*, 2025; Knox *et al.*, 2022).

To counteract this widespread simplification and alteration of river ecosystems, European policies promote the restoration of natural hydrological and morphological processes as a strategy for water retention, reduction of flow velocity, and adaptation to climate change, in line with the Water Framework Directive (2000/60/CE) and the Flood Directive (2007/60/CE). In this context, floodplain restoration efforts in recent years have focused on reconnecting wetlands and side channels to the main river by lowering or removing embankments. However, the effects of these interventions remain uncertain as their effectiveness depends on multiple factors and varies with site specific characteristics.

In these shallow aquatic environments, the water sediment interface is an important compartment for nitrogen processing. However, the role of specific benthic biogeochemical processes is still not well understood, especially under different hydrological conditions (Houser, 2016). In particular, processes such as denitrification, DNRA, nitrification, and ammonification, together with nitrogen assimilation by benthic primary producers, require further investigation to clarify their role in regulating retention, recycling, and permanent removal of nitrogen. Stagnation tends to favour organic matter accumulation because water renewal limits the supply of electron acceptors. Under these conditions, benthic nitrogen recycling is expected to prevail over nitrogen dissipation (Lau *et al.*, 2018). Nevertheless, ecosystem structure and functioning may respond in contrasting and complementary ways to environmental factors: on one hand, enhanced hydrological exchange can increase nitrogen supply, stimulating benthic metabolism and improving nitrogen removal; on the other, altered flow regimes may increase primary productivity and modify sediment properties and microbial communities, potentially reducing removal efficiency over time (Guillon *et al.*, 2019; Welti *et al.*, 2012). Testing these contrasting hypotheses is crucial for understanding the ecological outcomes of restoration interventions.

The Po River Basin is a heavily impacted area in northern Italy, with high nutrient loads due to agricultural and industrial sources. Much of the Po River is channelized, resulting in extensive floodplain disconnection, particularly in the lowlands. This condition has caused water scarcity and stagnation in perfluvial wetlands, many of which are completely disconnected. In 2023, one such wetland was restored by reconnecting it to the main river. The restoration involved lowering the upstream embankment, allowing reconnection during more frequent, ordinary flood events, rather than only during exceptional floods. This study aims to evaluate whether hydrological reconnection between the perfluvial wetland and the main river channel influences benthic nitrogen metabolism, accounting for the spatial and temporal variability of nitrogen inputs. It also investigates potential changes in denitrification rates associated with restoration intervention and assesses how increased nitrate availability during reconnection events, together with potential sediment erosion, may influence the wetland's capacity for nitrogen removal.

From 2022 to 2024, benthic metabolism, inorganic nitrogen fluxes and denitrification rates were measured seasonally along a gradient from the littoral zone to the wetland center. Laboratory simulations of hydraulic reconnection were performed to evaluate whether nutrient-rich river water stimulates benthic nitrogen metabolism and enhances short-term sediment denitrification rates. Benthic fluxes were determined by incubating intact sediment cores, and denitrification rates were quantified following the isotope pairing technique with $^{15}\text{NO}_3^-$ additions on the same set of cores after flux measurements (Nielsen, 1992). Concurrently, water and sediment samples were also collected and analysed for nutrient concentration, organic matter and chlorophyll content.

Results show that nutrient concentrations were consistently lower in the perfluvial wetland than in the main channel, but after restoration their variability increased. This pattern reflects nutrient inputs from the Po River, as concentrations were higher at elevated river stages. The wetlands exhibited a strong capacity to

metabolize these inputs: NO_3^- concentrations declined rapidly after disconnection, indicating nutrient uptake or retention, while reconnection acted as a fertilization pulse, stimulating phytoplankton growth as evidenced by increased chlorophyll-a. Sediment core incubations with river water, revealed that the benthic system has a high denitrification potential, with rates between 2500 and 5000 $\mu\text{mol N m}^{-2} \text{d}^{-1}$ - up to 6 times higher than under disconnected conditions. Sediments also exhibited negative fluxes of dissolved inorganic nitrogen, indicating that they acted as a sink rather than a source of nitrogen. By contrast, in situ denitrification rates, measured before and after restoration, were consistently low (below 1000 $\mu\text{mol N m}^{-2} \text{d}^{-1}$) and sediments acted as a net nitrogen source under summer conditions.

The discrepancy between in situ measurements and laboratory simulations may reflect the strong temporal variability of these systems and competition between benthic microbial processes and planktonic primary producers. Indeed, after a reconnection event, decreases in nitrogen concentrations were coupled with an increase in chlorophyll-a, suggesting nitrogen assimilation in phytoplankton biomass, especially during summer months.

This study highlights how hydrological connectivity with the main river channel enhances nutrient inputs into the wetland, promotes denitrification, and enhances potential for nitrogen removal. However, experimental simulations may not capture the complexity of natural conditions after high flow conditions, and further research is needed to evaluate how long-term and spatiotemporal variations in hydraulic connectivity influence benthic nitrogen metabolism.

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Eradication dynamics of alien fish from 16 alpine lakes

Abstract. *Fish introductions in originally fishless alpine lakes pose a severe threat to native biodiversity. To restore natural conditions, eradication efforts are required in addition to stocking and fishing bans. Sixteen eradication actions have been carried out within two LIFE projects (BIOAQUAE and RESQUE ALPYR) in Gran Paradiso National Park and Mont Avic Natural Park (Western Italian Alps). While the BIOAQUAE lakes are now fish-free, most RESQUE ALPYR lakes are still undergoing treatment. Eradication was achieved using a combination of mechanical removal methods—such as fyke nets, gillnets, rod angling, and electrofishing—with the intensity of effort varying according to habitat complexity and target species. Here, we describe the main dynamics of these eradication efforts, with the aim that sharing practical cases can inspire future restoration efforts.*

I laghi alpini sono ecosistemi isolati originariamente privi di fauna ittica, ma l'introduzione di pesci per la pesca sportiva (es. salmonidi) e di altre specie utilizzate come esche vive (es. ciprinidi) è una pratica molto diffusa e popolare in tutto il mondo, con conseguenze ecologiche drammatiche (Ventura *et al.*, 2017). A causa della portata dell'impatto ecologico e della diffusione globale delle introduzioni di pesci nei laghi montani, i pesci introdotti rappresentano forse la minaccia più importante per la biodiversità di questi ecosistemi (Knapp *et al.*, 2001).

I divieti di ripopolamento e di pesca possono fermare questa invasione ecologica ma, per invertirla e ripristinare le condizioni naturali dei laghi, sono necessarie azioni di eradicazione. In Italia sono stati realizzati due progetti di eradicazione di pesci: il progetto LIFE11 BIO/IT/000020 BIOAQUAE (2013–2017) e il progetto LIFE20 NAT/ES/000369 RESQUE ALPYR (2022–2026), che hanno interessato 16 laghi d'alta quota (Tab. 1) situati nel Parco Nazionale del Gran Paradiso e nel Parco Naturale del Mont Avic (Alpi occidentali). I laghi coinvolti nel progetto LIFE BIOAQUAE sono già stati riportati a condizioni prive di pesci, mentre 11 dei 12 laghi del progetto LIFE RESQUE ALPYR sono ancora in fase di trattamento.

In questo studio descriviamo le dinamiche di eradicazione di queste popolazioni ittiche. Il declino e l'eradicazione dei pesci sono stati ottenuti combinando diversi metodi:

- Reti branchiali: reti verticali con maglie di diversa ampiezza, posizionate in punti strategici del lago. Permettono una cattura massiva e selettiva di pesci di varie dimensioni.

- Nasse: trappole passive a imbuto, efficaci soprattutto per i pesci di piccola taglia. Collocate lungo le sponde, sono selettive e hanno un basso impatto ambientale.
- Elettropesca: applica un campo elettrico che immobilizza temporaneamente i pesci, successivamente raccolti con retini. È particolarmente efficace nelle aree poco profonde o con vegetazione acquatica.
- Tecniche di pesca sportiva: in quattro laghi sono state organizzate giornate di pesca intensiva per coinvolgere le comunità locali e ridurre le popolazioni ittiche prima del posizionamento dei dispositivi di cattura.

Tabella 1 - Caratteristiche dei laghi d'alta quota oggetto di intervento di eradicazione. Le sigle dei parchi indicano: PNMA = Parco Nazionale del Mont Avic; PNGP = Parco Nazionale del Gran Paradiso. *Sal* e *Cyp* indicano la presenza (1) o assenza (0) di salmonidi e ciprinidi. *Eradicazione* indica l'anno in cui l'eradicazione dei pesci è stata completata.

codice	Lago	Parco	lat	long	Altitudine (m)	Area (ha)	Profondità (m)	Sal	Cyp	Eradicazione
BA2	Balena 2	PNMA	45.6379	7.5476	2564	1.74	4	0	1	-
BA3	Balena 3	PNMA	45.6396	7.5521	2570	0.39	3.8	0	1	-
BAL	Balena	PNMA	45.6396	7.5484	2564	1.73	5.8	0	1	-
DJO	Djouan	PNGP	45.5577	7.1787	2516	1.41	3	1	0	2013
DRE	Dres	PNGP	45.4128	7.224	2087	2.42	7.4	1	0	2015
LEI	Leità	PNGP	45.4937	7.1322	2703	6.48	11	1	0	-
LES	Leser	PNMA	45.6577	7.6016	2020	1.28	4.8	1	0	-
LEY	Leynir	PNGP	45.5077	7.1518	2746	4.5	21.1	1	0	2016
LTA	Leita	PNMA	45.6434	7.5492	2537	1.39	7.5	1	1	-
MI2	Miserino 2	PNGP	45.5847	7.4701	2666	0.23	2	1	0	-
MIS	Miserino	PNGP	45.5832	7.4704	2667	4.22	9.9	1	0	-
MUA	Muanda	PNGP	45.5198	7.4358	2390	1.2	10.5	1	0	-
MUF	Muffet	PNMA	45.6379	7.6051	2076	0.82	4.5	1	0	2025
NDJ	Nero Djouan	PNGP	45.5519	7.1687	2666	1.6	6	1	0	2014
NMS	Nero Miserin	PNMA	45.6049	7.5143	2551	1.66	5.8	1	0	-
VER	Devernouille	PNMA	45.6338	7.5925	2145	0.53	3.6	0	1	-

La strategia e gli sforzi di eradicazione sono stati adattati alla complessità dell'habitat e alle specie target, modulando lo sforzo in base alle caratteristiche del lago e alle specie presenti. I salmonidi, tipicamente meno abbondanti, possono essere eradicati in modo efficace utilizzando reti da posta a maglie multiple e sessioni di elettropesca. I ciprinidi, invece, formano popolazioni dense e richiedono un maggiore sforzo: la strategia più efficace si è dimostrata la combinazione di reti a maglie fini, nasse e intensa elettropesca lungo le zone litorali.

Complessivamente, i metodi utilizzati, le caratteristiche ambientali e le specie target influenzano lo sforzo richiesto per un'eradicazione efficace. In questo contesto, il successo dell'eradicazione viene considerato raggiunto quando, dopo un periodo di un anno di monitoraggio, non si registrano ulteriori catture.

Nel corso del primo progetto (LIFE BIOAQUAE) è stata completata l'eradicazione in tutti e quattro i laghi coinvolti, caratterizzati esclusivamente dalla presenza di salmonidi (Tiberti *et al.*, 2019). La rapidità con cui si è raggiunto l'obiettivo è risultata proporzionale alle dimensioni, alla profondità e alla complessità di habitat del lago, con tempi di eradicazione più brevi nei laghi di minori dimensioni e meno complessi.

Nei laghi interessati dal secondo progetto (LIFE RESQUE ALPYR) non erano presenti esclusivamente salmonidi, ma in alcuni casi anche ciprinidi e, come nel caso del lago LTA, entrambe le famiglie. In particolare, per i ciprinidi si è osservato che nei primi due anni di intervento le quantità di biomassa rimossa erano molto elevate, mentre a partire dal terzo anno si è registrata una netta riduzione, fino ad arrivare al quarto anno, quando le catture si sono assestate su livelli molto bassi o prossimi allo zero. Per i laghi con presenza di salmonidi, si è riscontrato un andamento simile a quello del progetto precedente, con la conferma della prima eradicazione completa nel 2025 (L. MUF; Tab. 1). In altri laghi (BA3, LEI, MIS, MI2, NMS, VER), le catture sono arrivate a zero già da diverse settimane o mesi nel corso dell'estate 2025; gli sforzi attualmente in corso serviranno verosimilmente a verificare il completamento dell'eradicazione nel 2026.

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Artificial nest sites in conservation: reproductive use of bricks and plastics by a critically endangered spring goby

Abstract. *Il panzarolo Orsinigobius punctatissimus è una specie ittica endemica della pianura padana a rischio critico d'estinzione. In questo studio, abbiamo verificato la preferenza per alcune macroplastiche (cartucce da caccia) come rifugio riproduttivo. In contemporanea, è stato svolto un miglioramento dei substrati riproduttivi tramite posizionamento di substrati artificiali (mattoni forati), trovando una relazione negativa tra la presenza del gambero killer della Louisiana (Procambarus clarkii) e la presenza di uova di panzarolo nei mattoni. È stata inoltre verificata l'efficacia sperimentale osservando un aumento nelle densità della specie nei siti sperimentali.*

The Italian spring goby *Orsinigobius punctatissimus* (Canestrini, 1864) is a critically endangered freshwater fish endemic to the Padanian plain in northern Italy. This small species (<60 mm) inhabits spring-fed environments such as resurgences and oxbow lakes and reproduces mainly in spring and summer. Spawning occurs under suitable substrates like stones, branches, and leaves, where females attach 100–300 eggs (2 – 3 mm diameter) to the nest ceiling while positioned upside down, followed by fertilization and prolonged parental care by the male until hatching. Embryonic development lasts 10–12 days at 18–20 °C and up to 20–25 days at 13–14 °C (Gandolfi *et al.*, 1985; Lugli *et al.*, 1997; Vanni *et al.*, 2019; Zanetti *et al.*, 2019). Over recent decades, the species has experienced a >70% reduction in its range within Lombardy (LIFE Gestire 2020), driven by habitat loss, pollution, spring droughts, and climate change. These pressures have fragmented habitats and reduced the availability of reproductive substrates, thereby impairing reproduction and accelerating population decline. Moreover, springs and resurgences are increasingly exposed to plastic contamination, especially near agricultural and urbanized areas. While most studies on macroplastic (>1 cm) impacts in freshwater ecosystems emphasize ingestion, especially in fishes (Azevedo-Santos *et al.*, 2021), recent evidence indicates that plastic debris can also be used as refuge or nesting substrate (Jagiello *et al.*, 2024). During a monitoring campaign (2022–2025), we documented plastic debris being used as nest sites by *O. punctatissimus*, suggesting an opportunistic exploitation of any available cavities and emphasizing the critical importance of nest availability and microhabitat diversity for this species. Based on these observations, we hypothesized that improving the availability of suitable artificial substrates could enhance reproductive success and support population recovery. The first aim of this study

was to test whether *O. punctatissimus* shows a preference for specific types of macroplastic as nesting sites. To do so, we systematically collected all macroplastic items from ten reproductive sites across the Adda, Oglio, and Po river basins. Sampling was conducted during the peak breeding season (April–May 2025) in known spawning areas, mainly springheads. Each item was photographed, categorized by type and color, and examined for the presence of eggs. We classified samples into two groups: hunting shotshells (with a small cavity) and fragments/objects (without cavities). A binomial generalized linear model (GLM) with logit link was used to model the probability of egg presence, and a Fisher's Exact Test was performed to validate results given the limited sample size. Odds ratios with 95% confidence intervals quantified effect size. The second aim was to evaluate the effectiveness of artificial reproductive substrates. We employed 134 hollow bricks (8–20 per site) at eight springs hosting populations. Bricks had different hole sizes (small, medium, large) and were arranged within 4 × 5 m cells: empty cells, low-density cells (1 brick), and high-density cells (3 bricks), with an average density of 1 brick/20 m². Sites were monitored monthly to record reproductive use of bricks, collect environmental data, and document usage by other species, notably the invasive red swamp crayfish *Procambarus clarkii* (Girard, 1852) and the Padanian goby *Padogobius bonelli* (Bonaparte, 1846). A binomial generalized additive model (GAM) with logit link tested brick preference, and an Analysis of variance (ANOVA) assessed changes in fish density before versus after brick placement. Egg presence was negatively correlated with the number of *P. clarkii*, showed a nonlinear relationship with *P. bonelli* density and varied significantly by season and basin. Multiple oviposition occurred in the same brick, with a marked preference for small holes. A significant interaction emerged between hole size and *P. clarkii* abundance: small holes were preferentially used when crayfish were present, likely providing better protection. Mean fish density increased by 0.68 ± 0.47 ind/m² after substrate placement, whereas controls showed no change. These findings demonstrate that *P. clarkii* exerts negative effects on nest-site selection via spatial competition, while *P. bonelli* may influence reproduction in a density-dependent manner, potentially shifting from competitor to commensal at higher densities. Hole size preferences suggest a trade-off between clutch size and protection from predators and competitors. The plastic survey yielded 188 items from eight sites, including shotshells (n=65, 34.6%), non-rigid fragments (n=60, 31.2%), rigid fragments (n=33, 17.6%), threads (n=9, 4.8%), and other objects (n=21, 11.2%); 5.9% of items contained eggs, with shotshells used most often (72.7%). Statistical analysis confirmed a strong association between shotshells and egg presence (GLM: OR = 9.75, 95% CI = 2.64–46.69, p = 0.001; Fisher's test: OR = 9.55, 95% CI = 2.12–59.43, p < 0.001). This preference is likely driven by their small, enclosed cavity that provides protection from crayfish and gobies. Overall, our results highlight that nest-site availability is a critical limiting factor for *O. punctatissimus*, and that habitat enhancement via provision of suitable artificial substrates can significantly increase local density and support conservation of this endangered species.

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Diversità tassonomica e funzionale dei macroinvertebrati bentonici negli agroecosistemi risicoli del Piemonte

Abstract. *Despite their anthropogenic origin, rice fields can play a role in biodiversity conservation. In this study, the taxonomic and functional composition of macroinvertebrate communities associated with rice fields was analyzed over two seasons in three areas of the Piedmont Region, each including an organic rice field, a conventional rice field, and a natural wetland. The results show more generalist communities in rice fields, especially in conventional ones, and more specialized communities in natural wetlands. Moreover, organic rice fields displayed intermediate levels of diversity and taxonomic composition between conventional rice fields and natural wetlands. These findings suggest that, if managed sustainably, rice fields can provide ecological functions akin to natural wetlands.*

La perdita, il deterioramento e la frammentazione degli ecosistemi umidi rappresentano una delle sfide centrali del cambiamento globale. Infatti, a causa della crescente pressione antropica e degli effetti del cambiamento climatico la letteratura scientifica ha ampiamente dimostrato che stiamo assistendo a un forte declino della biodiversità. A tal riguardo, la biodiversità acquatica sembra essere persino più vulnerabile di quella terrestre (Dudgeon, 2019; Tickner *et al.*, 2020). In questo scenario, la riqualificazione ecologica degli ecosistemi naturali e l'individuazione di habitat alternativi diventano priorità non solo per la ricerca scientifica, ma anche per le politiche orientate alla conservazione di specie e habitat. Le risaie della Pianura Padana, pur nate come ambienti agricoli artificiali, offrono un'opportunità e alcune potenzialità in questa direzione: la loro estensione, la stagionalità idrologica e la connessione con corpi idrici naturali le rendono potenziali habitat surrogati (Guareschi *et al.*, 2020). Tuttavia, gli studi ecologici che hanno approfondito la conoscenza della biodiversità animale associata all'agroecosistema risicolo si sono focalizzati su pochi gruppi faunistici, adottando prevalentemente un approccio di tipo tassonomico (Bo *et al.*, 2025; Lupi *et al.*, 2013).

Il presente studio si inserisce in questo contesto, indagando la composizione e i tratti funzionali delle comunità macrobentoniche, organismi chiave per il funzionamento delle zone umide e indicatori sensibili della qualità ecologica degli ecosistemi acquatici. La ricerca è stata condotta tra il 2024 ed il 2025 in tre aree distinte della Pianura Padana piemontese, ciascuna comprendente una risaia a gestione biologica, una convenzionale e una zona umida naturale limitrofa che ha svolto la funzione di habitat di controllo. Per ogni area sono stati effettuati due campionamenti, in momenti cruciali del ciclo culturale: all'inizio della

primavera, subito dopo la semina, e a fine estate, poco prima della raccolta. In questo contributo vengono presentati i risultati completi della prima campagna di campionamento (2024), confrontati con quelli preliminari già disponibili della seconda campagna (2025).

I dati derivano da 108 campioni, per un totale di 90 taxa identificati. Il numero medio di individui per campione conteggiati durante il primo campionamento è di 366,87 (range: 37-2218) ed il numero medio di taxa è di $14,54 \pm 4,39$. I gruppi tassonomici più abbondanti del campionamento estivo risultano essere i Coleotteri ditiscidi ed i gasteropodi del genere *Gyrulus* e *Physa*. La seconda campagna invece risulta essere mediamente più povera con un numero di individui per campione di 130,37 (range: 6-954) e di taxa di $7,81 \pm 3,25$. I gruppi più abbondanti identificati sono i Ditteri chironimidi seguiti da *Gyrulus* e *Physa*.

Le analisi univariate mostrano differenze limitate in termini di ricchezza e abbondanza complessive, mentre l'indice LCBD (Local Contribution to Beta Diversity) risulta significativamente più elevato nelle zone naturali, indicando una maggiore unicità delle comunità rispetto alle risaie, con valori inattesi ma intermedi in quelle convenzionali.

L'analisi multivariata (NMDS e PERMANOVA, $p < 0.001$) ha confermato differenze significative nella composizione faunistica in relazione a habitat, area geografica e loro interazione. Le comunità delle zone naturali si distinguono nettamente, mentre quelle delle risaie mostrano maggiore compenetrazione. Tuttavia, le risaie biologiche risultano più vicine alle aree naturali rispetto alle convenzionali, suggerendo una maggiore affinità ecologica legata al regime gestionale.

La scomposizione della beta-diversità ha evidenziato pattern differenziati: nelle zone naturali prevale il *turnover* (sostituzione di taxa tra aree), mentre nelle risaie domina la *nestedness* (perdita o acquisizione di taxa). Questo riflette la maggiore eterogeneità delle comunità naturali e la maggiore omogeneità di quelle risicole.

L'analisi delle specie indicatrici (ISA) ha permesso di associare specifici taxa agli habitat (Fig.1). Le risaie biologiche ospitano taxa come i coleotteri Dryopidae, legati alla sostanza organica vegetale, e la libellula *Sympetrum foscolombii*. Le risaie convenzionali sono invece caratterizzate da taxa più generalisti come Notonectidae, mentre le zone umide naturali risultano significativamente associate a coleotteri acquatici specializzati come *Rhantus* e *Peltodytes*. Alcuni taxa (es. *Laccophilus*, *Dolomedes*) mostrano preferenze condivise tra naturali e biologiche, rafforzando l'idea che una gestione sostenibile avvicini le risaie ad habitat di maggiore qualità.

L'approccio funzionale, basato sul calcolo dei Community Weighted Means (CWM) dei tratti, conferma differenze ecologicamente rilevanti. Nelle risaie convenzionali si osserva una maggiore diffusione di forme di resistenza (diapausa/dormienza), mentre nelle biologiche e nelle zone naturali prevalgono specie prive di forme di resistenza, più sensibili alla stabilità ambientale. Gli *shredders* risultano penalizzati nelle risaie convenzionali, mentre predatori e raschiatori sono più abbondanti nelle biologiche, con valori talvolta comparabili a quelli delle aree naturali. Anche per il voltinismo emergono pattern netti: specie monovoltine dominano nelle risaie, mentre nelle zone naturali è maggiore la presenza di taxa plurivoltini. Questi esempi

mostrano come le risaie biologiche possano ospitare comunità con tratti funzionali più simili a quelle naturali rispetto alle convenzionali.

In sintesi, i risultati confermano che le risaie, pur ospitando comunità meno specializzate e funzionalmente semplificate rispetto alle zone naturali, possono svolgere un ruolo complementare nella conservazione della biodiversità acquatica, in particolare quando gestite secondo pratiche sostenibili.

Questa ricerca, parte del progetto *PNRR – Spoke 6 Innovarisi*, contribuisce a ridefinire la percezione delle risaie non solo come ambienti produttivi, ma come ecosistemi multifunzionali in grado di fornire habitat e servizi ecosistemici in un paesaggio agricolo trasformato. L'integrazione di dati tassonomici e funzionali rappresenta un valore aggiunto in un contesto ancora poco esplorato. Il completamento della seconda campagna di monitoraggio permetterà di testare la stabilità interannuale dei pattern osservati e il ruolo delle pratiche gestionali sulla struttura delle comunità.

Questi risultati si inseriscono, inoltre, nel progetto *INNOVARISI – Modelli innovativi di gestione e patrimonializzazione degli ecosistemi del riso in Italia*, in particolare nel *Work Package 3 – Biodiversità come misura della sostenibilità*, che adotta un approccio multi-taxon per valutare il ruolo degli agroecosistemi risicoli nella conservazione e nei servizi ecosistemici. I dati raccolti potranno orientare politiche agricole e ambientali verso modelli più sostenibili, capaci di integrare produttività e conservazione, in linea con gli obiettivi di riqualificazione ecologica richiesti dal cambiamento globale.

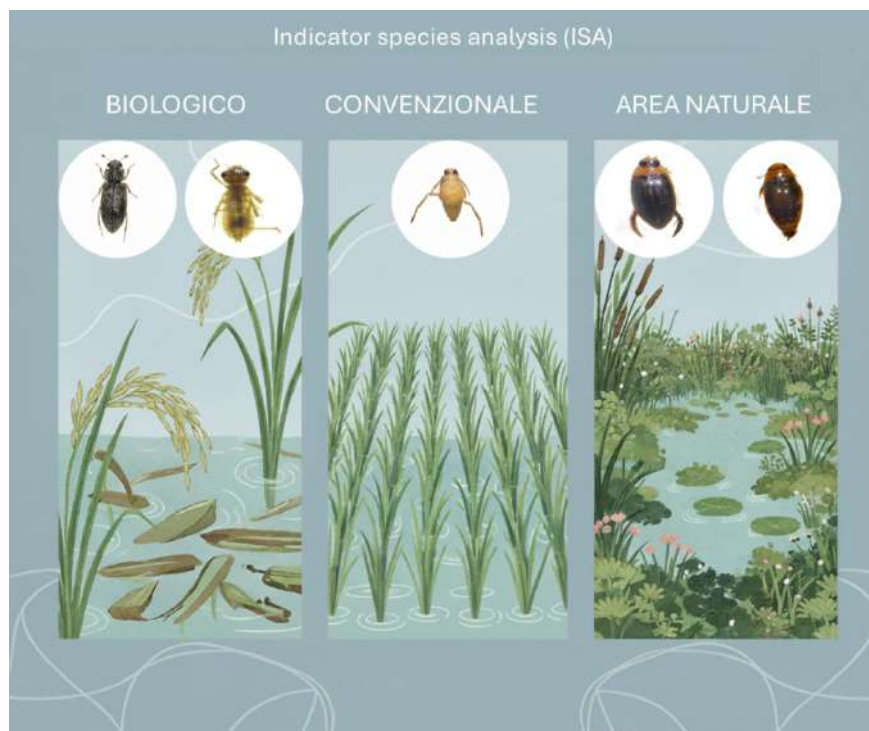


Figura 1 - Associazioni ecologiche tra taxa indicatori e tipologie di habitat acquatici

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POSTER

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From the river to the sea: habitat restoration along fluvial systems

Abstract. *Gli habitat d'acqua dolce e la biodiversità che ospitano sono tra i più minacciati al mondo principalmente a causa delle numerose alterazioni antropiche dell'habitat fluviale (sbarramenti, canalizzazioni, escavazioni, inquinamento, introduzione di specie non native). Il progetto LIFE Minnow (LIFE21-NAT-IT-LIFE-Minnow/101074559) mira a contrastare il declino di sei specie ittiche nell'alto bacino del Po attraverso interventi di riqualificazione fluviale: realizzazione e miglioramento di passaggi per pesci, riqualificazione di risorgive e fontanili, rinaturalizzazione di sponde e corsi d'acqua. Le azioni puntano a ripristinare la connettività e la funzionalità ecologica, contribuendo alla conservazione della biodiversità e agli obiettivi della EU Nature Restoration Law.*

Freshwater habitats, along with the rich biodiversity they support, are among the most threatened worldwide. The drivers of their degradation largely result from human activities that modify riverine environments in various ways and at different scales (Albert *et al.*, 2021; Dudgeon, 2019). The construction of dams and barriers disrupts the longitudinal connectivity of rivers, altering the natural flow regimes to which organisms are adapted and hindering the movement of organisms, particularly migratory species. This leads to demographic and genetic declines in populations and increasing the risk of extinction (Chen *et al.*, 2023). Additional human interventions – including channelisation, bank reinforcement, dredging, the removal of riparian vegetation and water abstraction – further degrade riverine habitats, compromising their capacity to provide essential resources and ecological functions. Alteration of terrestrial habitats also affects freshwater systems. For example, land-use change, urbanisation, and deforestation modify the input of organic matter, nutrients and pollutants, with cascading impacts on aquatic biodiversity (Albert *et al.*, 2021; Dudgeon, 2019). Other pervasive threats include pollution, overfishing, the spread of non-native species –

particularly numerous, abundant, and impactful in freshwater ecosystems – and climate change. These drivers rarely act in isolation, but often interact, amplifying their effects (Dudgeon, 2019).

In this context, the urgent need for habitat restoration in freshwater ecosystems becomes clear (Piczak *et al.*, 2024; Tickner *et al.*, 2020). But what does *restoration* mean in practice in a fluvial context? Here, we present examples of habitat improvement measures planned within the LIFE Minnow Project (LIFE21-NAT-IT-LIFE-Minnow /101074559), which aims to reverse the decline of six small-sized fish species in the upper Po River basin (Piedmont, NW Italy). Planned interventions include the restoration of longitudinal connectivity through fish passes, the rehabilitation of springs, and other forms of habitat enhancement.

Fish passes, also known as fish ladders, are constructed to restore longitudinal connectivity at barriers such as dams and weirs. Their purpose is to enable fish to move both upstream and downstream, providing a biological corridor that allows access to spawning grounds, facilitates gene flow among populations, and supports migrations. Structurally, a typical fish ladder consists of a series of interconnected pools arranged at increasing elevations, which function like steps that fish can gradually ascend. Various designs exist: “nature-like” fish passes mimic the physical and hydraulic characteristics of a natural stream, while “technical” passes are usually engineered with concrete structures and flow control devices. The choice of design depends on river morphology, the height of the barrier, and the biological requirements of the target species.

Ensuring that fish passes are effective and regularly monitored is crucial, as many installations have proven inefficient upon evaluation (Błońska *et al.*, 2024). In some cases, existing structures require modifications - for example, by creating a low-flow channel to guide fish during periods of reduced flow. Alternatively, where barriers are obsolete, complete removal may represent the most effective solution to restore connectivity. As part of the LIFE Minnow project, several fish passes are being built or upgraded across different streams, including the Banna, Stellone, Meletta and Bialera del Principe.

Springs, whether natural (“*risorgive*”) or man-made (“*fontanili*”), are characteristic freshwater habitats typically found in lowland floodplains and valley bottoms. These environments are distinguished by relatively stable water temperatures - around 9-10 °C in winter and 12-15 °C in summer - and host a unique biodiversity that is today highly threatened. In artificial springs, water emerges from an excavation known as the *head* (“*testa*”), from which it flows into a channel called the *stem* (“*asta*”), often used for agricultural irrigation. Pipes (“*tubi calandra*”) are often installed to facilitate groundwater emergence at the head. When springs are left unmanaged for extended periods, maintenance interventions may be required to restore their hydrological and ecological functions. These include clearing, cleaning, or replacing pipes; removing accumulated or unstable material from channel beds and banks; removing invasive shrub species; and reinforcing banks with wooden structures (“*palificate*”) together with the planting of native shrub species. Such measures contribute to bank stabilization while promoting the recovery of typical spring habitats. Within the LIFE Minnow project, several springs are being restored, including the artificial springs of Capolea, Carpice, Melano, and Mogliacche, and the natural springs of Agostinassi and Merlino.

Further restoration actions aim to rehabilitate riverine environments heavily degraded by artificial modifications such as channel reshaping, straightening, widening, damming, embankments, and dredging. A range of interventions can be applied depending on the specific context, but the overarching goal is to recreate structured habitats capable of self-sustaining over time. Common measures include restoring banks using wooden structures (“*palificate*”) and riparian vegetation to stabilize them and re-establish natural transition zones between the wetted channel, the floodplain, and surrounding land; enhancing morphological diversity by restoring the original river course, creating gravel or sand bars, and reactivating floodplain depressions and expansion zones; and creating fish refuges and spawning grounds. Within the LIFE Minnow Project, restoration actions are planned in several sites, including Lake Staffarda, stretches of the Roggia Marina and Roggia Molinara, and sections of the Roggia Stura.

Freshwater habitat restoration must be considered a priority, as also emphasized by the recent EU Nature Restoration Law, which represents a major opportunity for safeguarding freshwater biodiversity. However, emerging threats are increasingly affecting river systems, most notably climate change, which is expected not only to intensify existing pressures but also to further undermine the wide range of ecosystem services that freshwater provides to humans (Dudgeon & Strayer, 2025; Reid *et al.*, 2019). It will therefore be essential to implement measures that ensure water, energy, and food security for society while avoiding further deterioration of aquatic ecosystems. Achieving this goal requires a concerted effort involving political, legislative, social, and scientific stakeholders. Moreover, conservation actions must be integrated across multiple spatial scales - local, catchment, and international - to enhance coordination and effectiveness (Dudgeon & Strayer, 2025; Piczak *et al.*, 2024; Stoffers *et al.*, 2024). The LIFE Minnow project contributes to these broader objectives not only by providing concrete restoration actions in the upper Po River basin, but also by fostering cross-sectoral synergies, stakeholder engagement, and the transfer of results to support freshwater biodiversity conservation at broader European scales.

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Progetto Blue Crab Action Plan

Abstract. *Callinectes sapidus* is a crustacean from the American Atlantic coasts, now invasive in the Mediterranean. Its wide tolerance to salinity and temperature, combined with high fecundity allows rapid colonization of marine habitats and lagoons, making it one of the most impactful invasive species in the region, threatening biodiversity, fisheries, and shellfish farming. Climate change may worsen the issue by boosting its survival rate and reproduction. The Blue Crab Action Plan uses traps and environmental monitoring in lagoons, involving local fishers. The preliminary data show a population with a majority of male individuals and few juveniles, with further sampling aimed at understanding recruitment dynamics.

Callinectes sapidus Rathbun, 1896 (Famiglia Portunidae), comunemente noto come granchio blu, è un crostaceo originario delle coste atlantiche americane, la cui presenza è ormai accertata anche nelle acque del Mar Mediterraneo (Chiesa *et al.*, 2025). La sua introduzione in quest’area è avvenuta, con ogni probabilità, in maniera accidentale, principalmente attraverso le acque di zavorra delle navi (Mancinelli *et al.*, 2021), sebbene non si escludano introduzioni intenzionali. Questa specie è caratterizzata da un’elevata plasticità ecologica: la sua capacità di tollerare un ampio intervallo di salinità (da 24 a 40 PSU) e temperatura (da 12 a oltre 35 °C) le consente di colonizzare una grande varietà di habitat, che spaziano dall’ambiente marino alle lagune costiere, fino ad arrivare ad acque dolci e salmastre (Marchessaux *et al.*, 2023). Tale adattabilità, unita all’elevata fecondità della specie, ha favorito la rapida espansione del granchio blu, che oggi è annoverato tra le peggiori specie aliene invasive del Mar Mediterraneo (Chiesa *et al.*, 2025). I suoi impatti sono rilevanti sia dal punto di vista ecologico sia da quello socioeconomico, poiché interferisce con la pesca artigianale e con l’acquacoltura dei molluschi bivalvi. Questo problema assume una particolare gravità nelle lagune costiere dell’Alto Adriatico, che rappresentano una delle principali aree di produzione di molluschi in Italia (Chiesa *et al.*, 2025). Le invasioni biologiche, infatti, costituiscono una seria minaccia per la struttura e il funzionamento degli ecosistemi acquatici su scala globale. Esse determinano perdite significative di

biodiversità e alterazioni delle funzionalità ecologiche degli habitat (Marchessaux *et al.*, 2024). Il cambiamento climatico potrebbe giocare un ruolo significativo nella dinamica delle popolazioni di *C. sapidus*: attraverso il riscaldamento delle acque costiere, potrebbe aumentare la sopravvivenza, la riproduzione e la fitness di questa specie favorendone l'espansione nel Mediterraneo e influenzando gli equilibri ecologici locali (Mancinelli *et al.*, 2017).

La gestione di queste invasioni si presenta particolarmente complessa, poiché la velocità di insediamento e diffusione delle specie invasive supera spesso le risorse economiche e operative disponibili per il loro contenimento (Marchessaux *et al.*, 2024). Per far fronte a questa emergenza ecologica, diversi enti di ricerca – tra cui l'Università di Padova e l'Università Ca' Foscari di Venezia e istituzioni, come ARPAV e l'Agenzia Veneta per l'innovazione nel settore primario – hanno avviato progetti finanziati dalla Regione Veneto, finalizzati a raccogliere dati utili per contenere l'impatto della specie. Tra questi spicca il progetto Blue Crab Action Plan, che, tra i vari work package, comprende anche l'implementazione di un programma di monitoraggio distribuito nelle principali lagune venete. Il monitoraggio viene effettuato con nasse e cogolli, trappole a doppia camera di maglia 25 mm dotate di aperture a imbuto che permettono l'ingresso dei granchi ma ne impediscono la fuga. Sia le nasse, di forma parallelepipedica, che i cogolli, di forma tubolare, una volta posizionati vengono lasciati in pesca per circa 24 ore. Successivamente avviene il recupero. Tutti gli esemplari di *C. sapidus* vengono contati e per ognuno sono rilevati i dati biometrici: sesso, stadio di maturità, peso e dimensioni del carapace. Il peso è misurato con un dinamometro applicato a un secchio come bilancino, mentre le dimensioni del carapace (larghezza e lunghezza) vengono rilevate con un metro da sarto (precisione ± 1 mm). La larghezza è riportata secondo due parametri: CW (larghezza massima con le spine laterali) e CS (larghezza senza le spine). Vengono inoltre raccolti dati ambientali mediante l'utilizzo di sonde multiparametriche: i parametri di maggiore interesse per questo progetto includono temperatura, salinità, ossigeno disciolto e conducibilità. Un aspetto fondamentale del progetto è la collaborazione con i pescatori locali, che rappresentano un'importante risorsa grazie alla loro conoscenza del territorio lagunare e partecipazione attiva alle operazioni di campionamento, affiancando il personale scientifico. Tale sinergia consente di unire il sapere tradizionale a quello accademico, aumentando l'efficacia del monitoraggio e favorendo strategie di gestione più sostenibili e condivise.

Nei primi tre mesi dall'avvio del progetto, i campionamenti sono stati effettuati con cadenza quindicinale. Le principali aree di interesse individuate sono quattro: le lagune del Delta Sud (Barbamarco, Canarin, Scardovari), le lagune del Nord Polesine (Caleri, Marinetta, Vallona), la Laguna di Venezia (Nord, Centro e Sud) e la Laguna di Caorle. In ciascuna uscita in laguna, i ricercatori hanno affiancato i pescatori locali, partecipando attivamente alle operazioni di cattura per raccogliere un numero rappresentativo di esemplari di granchio blu.

Da una prima analisi dei dati raccolti nei campionamenti effettuati nelle lagune, i maschi di *C. sapidus* risultano più abbondanti (82.5%) rispetto alle femmine (17.5%). Questa differenza nella numerosità è plausibilmente legata alla diversa distribuzione dei due sessi, in relazione al comportamento riproduttivo

della specie. Infatti, il ciclo riproduttivo di *C. sapidus* prevede che i maschi tendano a stanziare in acque a ridotta salinità, come quelle delle zone lagunari ed estuarine, che rappresentano anche le aree in cui avviene l'accoppiamento della specie. Le femmine, dopo la fecondazione, migrano verso il mare aperto, un ambiente caratterizzato da salinità più elevate che garantisce condizioni ottimali per lo sviluppo delle uova. Ogni femmina produce per singola ovatura un numero molto elevato di uova, mediamente compreso tra 2 e 6 milioni, contribuendo così alla rapida espansione della popolazione se le condizioni ambientali risultano favorevoli (Marchessaux *et al.*, 2023). Dopo la schiusa, le larve completano il loro sviluppo nelle acque costiere ed entrano in habitat salmastri nella fase post-larvale fino a raggiungere lo stadio giovanile (Castriota *et al.*, 2024). I dati raccolti sulla distribuzione degli individui giovanili vanno ad evidenziare come siano la minoranza degli individui campionati. I campionamenti proseguiranno nei prossimi mesi per consentire uno studio più approfondito della dinamica di popolazione, in particolare della classe giovanile, ancora poco conosciuta e cruciale per comprendere la crescita e il reclutamento della specie.

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Antimicrobial resistance in pristine arctic lakes: metagenomic and phenotypic insights

Abstract. *La resistenza agli antimicrobici (AMR) ha origini antiche, precedenti all'introduzione degli antibiotici nell'era moderna. Dopo aver valutato la diversità delle popolazioni microbiche in sei diversi laghi dell'Alaska, ne abbiamo caratterizzato mediante sequenziamento il resistoma antimicrobico. I dati metagenomici sono stati poi combinati con un approccio coltura-dipendente, che ha previsto l'isolamento di ceppi batterici e le analisi dei relativi fenotipi di resistenza. Il confronto ha permesso di verificare la presenza di una correlazione tra i geni di resistenza rilevati nella popolazione microbica ed i fenotipi di resistenza negli isolati.*

Antimicrobial resistance (AMR) is the ability of microorganisms to develop resistance to antimicrobial treatments. As a result of the rapid spread of AMR we are witnessing, the World Health Organization has recognized it as one of the top 10 global health threats (World Health Organization, 2022). Although the massive use of antibiotics is recognized as a relevant cause of AMR, it is considered to be an ancient and natural phenomenon (D'Costa *et al.*, 2011), predating the introduction of antibiotics in human medicine in the last century. Antibiotic resistance genes (ARGs) and antibiotic resistance bacteria (ARB) are found ubiquitously in the environment and have been detected even in remote regions, including Arctic and Antarctic freshwater environments (Jara *et al.*, 2020; Sjölund-Karlsson *et al.*, 2008).

Indeed, in natural ecosystems, many bacteria produce antimicrobial molecules to inhibit the growth of other microbes competing for the same ecological niche and resources. At low environmental concentrations, antibiotics might exert selective pressure, forcing bacteria to develop resistance traits. Two are the main mechanisms evolved by bacteria to defend themselves against antibiotics: mutation of pre-resistance genes (Martinez & Baquero, 2000) and acquisition of ARGs through horizontal gene transfer (HGT) (Bengtsson-Palme *et al.*, 2018; Davies, 1994). Studying AMR in remote and pristine environment is crucial to characterizing the ancient resistome, i.e., the total content of ARGs naturally already present in the microbial community in the pre-antibiotic era (Agudo & Reche, 2024; D'Costa *et al.*, 2011). Furthermore, remote areas are known to be particularly vulnerable not only to direct and indirect anthropogenic pressures, including

commercial shipping, transport infrastructure, and tourism, but also to global warming (Adams *et al.*, 2010; Onana *et al.*, 2025), making them sentinels of environmental change also in other regions of the world. Despite these emerging insights, little is known about the extent, diversity, and functional potential of AMR in microbial communities inhabiting Arctic freshwater lakes, particularly in remote areas with a negligible direct human impact.

In this study, we investigated the prevalence and features of AMR in bacterial communities from remote lakes. To achieve this, we applied a combined approach: (i) metagenomic shotgun sequencing and 16S rRNA amplicon sequencing to assess the overall structure and diversity of microbial populations and their intrinsic resistome, and (ii) culture-based methods involving microbial isolation and AMR profiling, which provided direct evidence of AMR phenotypes in selected bacterial strains. Six Arctic lakes located on the North Slope of the Brooks Range in Alaska, near the Toolik Field Station, were selected for this study. Sampling campaigns were conducted in August of both 2023 and 2024. Water samples were collected and filtered using cellulose ester filters for microbial isolation and polycarbonate filters for DNA extraction. The antimicrobial resistance profiles of bacterial isolates were assessed with the Kirby Bauer Assay with a panel of 19 antibiotics.

Among the antibiotics tested, the highest frequency of resistant isolates (>50% of isolates showing a resistant phenotype) were observed for ampicillin and penicillin G, whereas fewer than 20% of isolates showed resistance to meropenem, rifampicin, gentamicin, erythromycin, tetracycline, and chloramphenicol. In parallel, 16S rDNA gene sequencing and metagenomic shotgun sequencing were performed by Illumina sequencing. No significant differences in α -diversity were observed among the microbial communities across lakes. In terms of β -diversity, PCoA based on Bray-Curtis dissimilarity, showed that the first two axes explained 23.8% and 15.2% of microbial variation among lake samples. PERMANOVA analysis revealed significant differences in community composition among lakes ($p = 0.013$, $R^2 = 0.375$), and between sampling years ($p = 0.005$, $R^2 = 0.122$). ARGs were detected in all water samples and the annotation of the reads revealed 827 different genes that cover resistance to 50 classes of antimicrobials. Finally, by comparing results from the culture-dependent and independent approaches, we proved that all resistance traits identified through metagenomic analysis were also observed at the phenotypic level. For some antibiotics, such as aminoglycosides, carbapenems, fluoroquinolones, sulphonamides, and tetracycline, the antimicrobial resistant phenotypes could be reliably predicted starting from the metagenomic data analysis. In contrast, for penam antibiotics, the ARG reads were much less abundant compared to the observed phenotypes.

Overall, this study presents the first analytical comparison between phenotypic and metagenomic AMR traits in pristine Arctic Alaskan lakes and contributes to building a comprehensive picture of the resistome features of such pristine and yet vulnerable region.

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Ecologia della conservazione dei ragni disderidi endemici italiani (Araneae: Dysderidae)

Abstract. Spiders of the family Dysderidae (Arachnida: Araneae) occur mainly in Eurasia and North Africa, with their diversity center in the Mediterranean Basin, showing high endemism in Italy, Greece, and Spain. In Italy, 10 genera and 83 species are present, 52 of which are endemic. This study assesses the conservation status of the 52 Italian endemics using georeferenced occurrence data, ecological and habitat information, protected-area coverage, and potential threats, with IUCN Redlist criteria and distribution models to estimate climate effects. Most are threatened, listed as Endangered, Critically Endangered, or Vulnerable due to habitat loss and human activity. This work provides the first conservation assessment of Italian endemic Dysderidae and supports research on Italian endemic spiders.

I Dysderidae (Arachnida: Araneae) costituiscono una famiglia di ragni terricoli facilmente riconoscibili grazie alla colorazione rossastra del prosoma, ai sei occhi disposti a semicerchio e ai cheliceri prominenti (Fig. 1). Gli habitat tipici includono la lettiera fogliare di foreste di latifoglie, la macchia mediterranea, i detriti rocciosi e gli ambienti sotterranei. Sono diffusi soprattutto in Eurasia e Nord Africa, con il fulcro di maggior diversità nel bacino del Mediterraneo dove l'Italia rappresenta il paese con il più alto grado di endemismi. In Italia, infatti, la famiglia Dysderidae è rappresentata da 10 generi e 83 specie, con un totale di 52 endemismi, presenti principalmente nelle regioni meridionali (Pantini & Isaia, 2019). Il genere *Dysdera* presenta il numero di endemiti italiani più ricco (25 specie), seguito da *Harpactea* (14), *Parachtes* (6) e *Kaemis* (3), mentre *Dasumia*, *Harpactocrates*, *Rhode* e *Sardostalita* sono rappresentati da un'unica specie endemica italiana ciascuno. Nonostante la loro importanza ecologica e biogeografica, i Dysderidae italiani sono rimasti finora inesplorati sotto il profilo conservazionistico.



Figura 1 - Quattro specie endemiche italiane di Dysderidae (esemplari maschi): a. *Dysdera jana* Gasparo & Arnedo, 2009 (vista laterale del prosoma, modificato da Arnedo *et al.*, 2009); b. *Harpactea sicula* Alicata, 1966 (foto: Ciro Amata); c. *Parachtes andreinii* Alicata 1966 (foto: Luca Borio); d. *Rhode testudinea* Pesarini, 1984 (foto: Marco Tolve).

La metodologia ha quindi previsto i seguenti passaggi: (i) raccolta e georeferenziazione dei record di presenza noti in letteratura (dal 1878-2025) (Fig. 2), (ii) integrazione con dati ecologici ed aree protette, (iii) calcolo di *Extent of Occurrence* (EOO) e *Area of Occupancy* (AOO), (iv) identificazione delle minacce e (v) valutazione del rischio secondo criteri quantitativi IUCN. Per le specie con 15 o più punti di presenza, EOO e AOO sono stati stimati con modelli di distribuzioni delle specie (MDS) basati su variabili climatiche e topografiche mentre per le specie con meno di 15 record l'EOO è stato calcolato come minimo poligono convesso (cioè il poligono più piccolo che contiene tutti i punti di presenza della specie in esame) e l'AOO come prodotto del numero delle celle quadre di dimensioni di 2×2 km² occupate dal taxon.

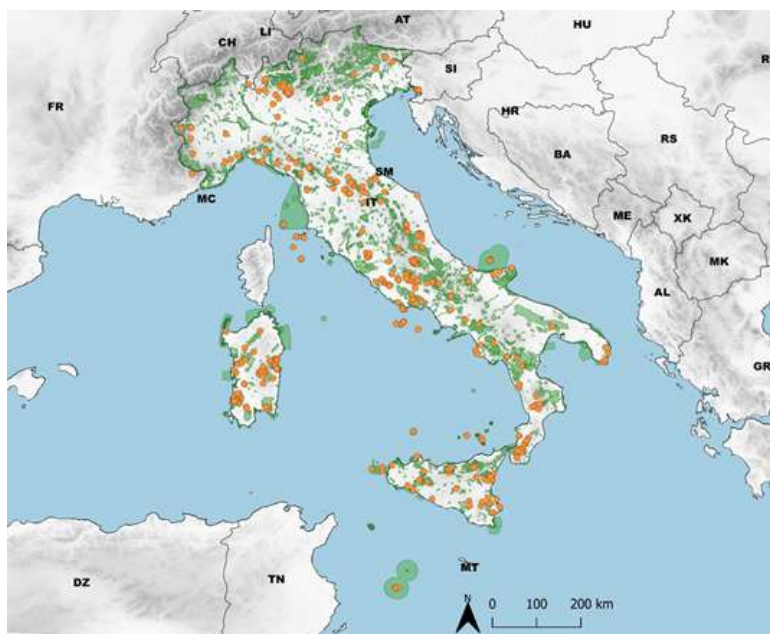


Figura 2 - Mappa di distribuzione dei ragni disderidi endemici italiani con punti di presenza (367) (punti arancioni), aree protette (zone verdi), confini regioni italiani (linee nere)

La maggior parte delle specie è presente, almeno in parte, in aree protette, soprattutto in faggete (*Fagus sylvatica* Linneo) e leccete (*Quercus ilex* Linneo), altre sono presenti in macchie mediterranee e garighe oppure ristrette ad habitat ipogei. Nonostante il 79% dei punti di presenza delle specie ricada in aree protette, la maggior parte delle specie è soggetta a minacce (Tab.1) che degradano gli habitat di appartenenza. Tali minacce sono principalmente conseguenti al cambiamento climatico come: l'aumento degli incendi boschivi naturali (Lozano *et al.*, 2017), soprattutto sulle isole maggiori; il degrado degli habitat forestali, in particolare la forte diminuzione stimata del tasso di crescita delle foreste di faggio nelle aree mediterranee (Martinez del Castillo *et al.*, 2022); il continuo aumento delle temperature negli ambienti sotterranei a cui le specie ipogee non sono sufficientemente adattate (Mammola *et al.*, 2018). Infine, per le specie di disderidi abitanti le piccole isole italiane, si registrano minacce di diretta origine antropica come l'introduzione di specie invasive animali e vegetali (Crudele *et al.*, 2005) e le improvvise frammentazioni dell'habitat naturale dovute a urbanizzazione e turismo (Drius *et al.*, 2019).

Tabella 1 - Principali minacce per le specie endemiche italiane di Dysderidae

Minacce principali	N. specie
Incendi boschivi naturali, intensificati da siccità e ondate di calore	25
Degrado degli habitat forestali, in particolare nelle faggete (<i>Fagus sylvatica</i>) e leccete (<i>Quercus ilex</i>)	12
Specie invasive (ad es. capre sull'isola di Montecristo che degradano le leccete)	2
Impatti dei cambiamenti climatici sugli habitat sotterranei, con l'aumento delle temperature che riduce l'idoneità degli habitat.	7
Pressioni antropiche, comprese urbanizzazione e turismo	6

I risultati mostrano che 47 delle 52 specie endemiche risultano minacciate, di seguito etichettate: 11 *Critically Endangered* (CR), 35 *Endangered* (EN) e un *Vulnerable* (VU). Solo cinque specie sono state classificate come *Least Concern* (LC, 4) o *Near Threatened* (NT, 1) (Fig. 3). Il criterio B della Lista Rossa è stato determinante: 14 specie hanno un EOO minore di 20000 km², 15 minore di 5000 km² e 17 minore 100 km². I valori di AOO sono risultati ancora più ridotti, con 37 specie minore di 500 km² e 10 minore di 10 km², giustificando l'inserimento in CR.

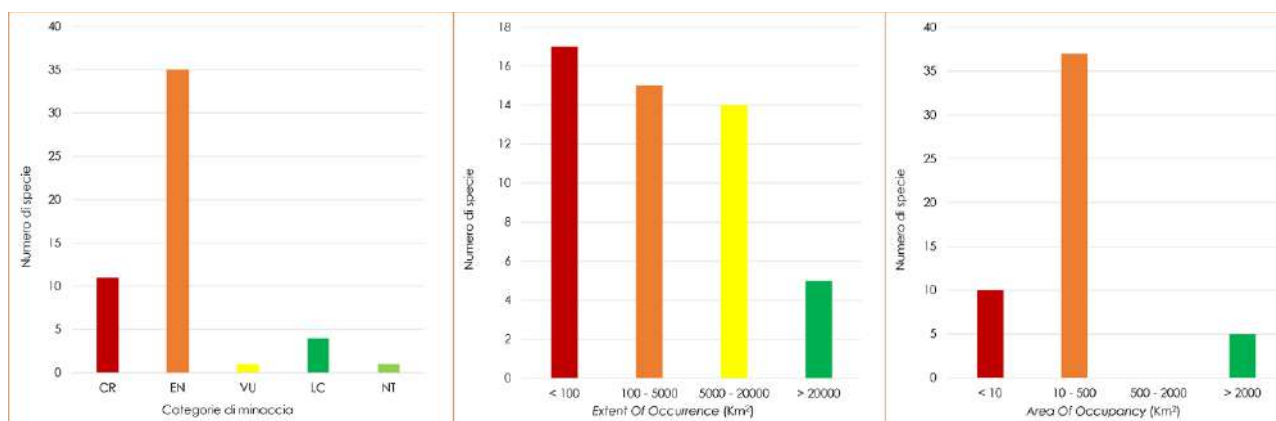


Figura 3 - Da sinistra verso destra gli istogrammi quantificano: numero delle specie endemiche italiane di Dysderidae per ciascuna categoria di minaccia IUCN; areali delle specie endemiche italiane di Dysderidae valutate in questo studio: *Extent Of Occurrence* (EOO) e *Area Of Occupancy* (AOO)

Questo lavoro integra e amplia gli attuali e i precedenti studi conservazionistici sui ragni italiani condotti su *Vesubia jugorum* (Simon, 1881), sul genere *Troglohyphantes* e su *Dolomedes plantarius* (Clerck, 1758) (Milano *et al.*, 2018; 2022; 2023), estendendo l'analisi a una famiglia con un alto numero di endemismi. I dati e gli approcci metodologici qui proposti contribuiscono a identificare minacce che interessano non solo i Dysderidae, ma anche altri ragni associati ad habitat vulnerabili come suoli forestali mediterranei, grotte o arbusteti termofili. In conclusione, i risultati evidenziano la vulnerabilità estrema dei Dysderidae endemici italiani, la maggior parte dei quali presenta distribuzioni molto ristrette e soddisfa pienamente i criteri di minaccia IUCN. Il coinvolgimento di questi taxa, sebbene poco studiati ma ecologicamente significativi, rappresenta un passo necessario per una più completa valutazione della biodiversità e per l'elaborazione di strategie di conservazione efficaci. Azioni mirate, come la protezione delle grotte più sensibili e la gestione attiva degli habitat forestali, unite alla riduzione delle pressioni antropiche, possono contribuire ad aumentare la resilienza di specie ed ecosistemi di fronte ai cambiamenti globali.

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***Hydrological control of phosphorus export and bioavailability
in two Northern Apennine streams:
implications for eutrophication risk evaluation***

Abstract. *L'esportazione di fosforo (P) dai bacini idrografici è regolata da dinamiche idrologiche che influenzano quantità e forme chimiche trasportate. Nei laghi Mignano e Trebecco, i carichi di P provenienti dagli immissari impediscono di raggiungere lo stato ecologico buono previsto dalla Water Framework Directive. Le forme più biodisponibili di P rappresentano però circa un terzo del carico, sottolineando l'importanza della speciazione del P per stimare il reale rischio di eutrofizzazione. Le analisi dei suoli mostrano concentrazioni di P maggiori in aree agricole, confermando il ruolo delle pressioni diffuse. Si evidenzia inoltre come eventi idrologici estremi amplificano il rischio di eutrofizzazione. Lo studio offre quindi spunti per la gestione sostenibile e il ripristino dei due laghi.*

Phosphorus (P) is a significant driver of eutrophication in lakes, resulting in higher primary production with cascading undesirable effects, such as hypoxic or anoxic conditions, reduced water clarity, and the onset of harmful algal blooms (Elser & Bennett, 2011; Goyette *et al.*, 2018). Significant efforts have been made to reduce and control P inputs from anthropogenic sources, which have led to a considerable reduction of loads from point sources (such as municipal and industrial wastewater, Dolan & Chapra, 2012). However, despite point source control, the eutrophication problem has not been completely resolved, and extensive phytoplankton blooms are still a common occurrence in many aquatic systems around the world, mainly driven by diffuse sources (Le Moal *et al.*, 2019). Therefore, there is a need to understand factors regulating diffuse P sources, including the origins, the primary transport mechanisms, their temporal variability, and the reactivity of different P compounds (Dupas *et al.*, 2015; Némery *et al.*, 2005).

The origin and transport of diffuse P loads can be influenced by multiple factors, including varying soil types and retention capacities, land use, and rainfall intensity. Several studies have demonstrated a positive correlation between extreme events and P loads, showing that a few events can account for the majority of the annual P load transported by rivers (Carpenter *et al.*, 2014; 2018; Van Esbroeck *et al.*, 2017). However, much of the P load is bound to particulate matter and is therefore not directly available to organisms (Ruttenberg, 2003). Thus, simply considering total phosphorus (TP) is insufficient for assessing the actual risk of eutrophication, since much of the phosphorus may be transported in particulate, non-bioavailable

forms. This is particularly important in the context of climate change. Given the increasing trend of extreme precipitation events and discharge in mid- and high-latitude regions, climate change could exacerbate the issue of diffuse P load transport even further (Lucas *et al.*, 2023).

Although watershed P export driven by surface discharge during storm events has been studied previously, the dynamics of P chemical speciation during low- and high-flow regimes have received less attention, and many phosphorus management and monitoring programs routinely estimate only TP (Bhat *et al.*, 2007; Carpenter *et al.*, 2018; Chen *et al.*, 2015; Markovic *et al.*, 2020). Effective management measures must be based primarily on the identification of the main P sources, the dominant transport mechanisms, their temporal variability, and the reactivity of the different compounds (Dupas *et al.*, 2015). These aspects are also considered highly relevant for improving the methodology used to classify the ecological and trophic status of reservoirs.

Monitoring carried out by the Emilia-Romagna Regional Agency for Environmental Protection and Energy (ARPAE) in the Mignano and Trebecco reservoirs (PC) from 2014 to 2019 revealed critical issues that hinder the attainment of 'good ecological status' as defined by the Water Framework Directive. These issues mainly involve high levels of TP and, to a lesser extent, soluble reactive phosphorus in the lake waters, resulting in high trophic status. Previous studies, carried out during the exceptionally dry biennium of 2021-2022, showed a rapid response of the catchment area to meteorological events: during intense rainfall, over 90% of the TP load reaching the lakes was transported. However, it remains unclear how P loading is regulated during wetter years, and the actual risk of eutrophication related to this load must be evaluated based on the true bioavailability of P. Therefore, this study aims to improve the understanding of phosphorus sources, transport dynamics, and bioavailability within the catchments of the Trebecco and Mignano reservoirs. Specifically, it aims to: (1) evaluate the impact of hydrological variability on P loads; (2) assess the eutrophication potential of the P load considering its bioavailability; and (3) estimate P accumulation and speciation in surficial soils in relation to land use.

Water samplings were conducted monthly from October 2023 to September 2025 at the closing stations of the Arda and Tidone rivers, the two main tributaries of the reservoirs. Samplings were carried out during both base flow and high flow events to take into account the impact of flow variability on water chemistry. A minimum of one sampling per month was conducted during base flow conditions, and at least 3 high flow events were sampled at each site. Following collection, water samples were analysed for soluble and particulate phosphorus. Particulate material was characterized via sequential P extraction to assess forms with differing bioavailability (Hupfer *et al.*, 1995). Soil samples were collected upstream of the two reservoirs in September 2024 and May 2025. At each site, triplicate samples from the top 5 cm were taken from 10 natural and 10 cultivated areas. Samples were analysed for organic matter content, total phosphorus, and phosphorus speciation.

In both tributaries, TP concentrations showed high variability (ranging from 3.4 to 1497 $\mu\text{g P L}^{-1}$). The highest TP concentrations were recorded during flood events and were largely dominated by the particulate

fraction (>50%). The proportion of soluble reactive phosphorus accounted for about 28% of the total load, reaching approximately 32% under base flow conditions and decreasing to about 20% during floods.

Sequential extraction analyses indicated that the predominant form of particulate P was bound to calcium, the most stable form, while more labile fractions (exchangeable and Al-bound) decreased during floods. This suggests that particulate P fluxes, although quantitatively dominant, may exhibit limited bioavailability. Overall, the exchangeable particulate fraction accounted for approximately 8.5% of the total inorganic particulate phosphorus load, reaching around 13% under base flow conditions and decreasing to about 4% during flood events. Soil analysis confirmed higher TP concentrations in cultivated areas than in natural ones, especially in the Arda basin, underlining the role of agricultural and livestock pressures in the generation of the diffuse load.

These results confirm that phosphorus concentrations in streams are tightly regulated by hydrological dynamics, with extreme precipitation events representing critical 'hot moments' for eutrophication risk. Although the proportion of labile particulate P fractions (exchangeable and Al-bound) decreased during floods, the overall P flux during these events remains substantial. With the projected increase in extreme rainfall events, eutrophication risk is expected to intensify unless bioavailable particulate P inputs from non-point sources are effectively mitigated.

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The MEIOGYPSOS project

Preliminary results and prospects of a study on biodiversity in the caves of the Vena del Gesso Romagnola Regional Park

Abstract. *L'Emilia-Romagna presenta meno dell'1% di rocce carsificabili, costituite quasi esclusivamente da gessi risalenti alla Crisi di Salinità del Messiniano. Ne è esempio la Vena del Gesso Romagnola, affioramento oggi tutelato dall'omonimo Parco, con le sue circa 300 grotte censite. Nel biennio 2024-2025 queste sono state interessate dal progetto MEIOGYPSOS, volto a studiare le comunità meiofaunali e microbiologiche delle acque sotterranee del Parco. Gli studi sono stati portati avanti attraverso campionamenti stagionali e utilizzando il metabarcoding. I primi risultati stanno evidenziando variazioni significative nella beta diversità tra le grotte in relazione a diversi fattori ecologici quali l'apporto organico e la distanza del punto di campionamento dall'ingresso.*

Emilia-Romagna is the Italian region with the lowest incidence of karst areas, with less than 1% of its territory occupied by karstifiable rocks. These consist almost exclusively of evaporitic rocks belonging to the Gessoso-Solfifera Formation, characterized by Miocene sediments deposited during the Messinian Salinity Crisis (De Waele *et al.*, 2024). Despite their limited extent, these gypsum outcrops – rare at the international scale – hold considerable naturalistic value, as evidenced by the fact that nearly all of them are under protection within Regional Reserves or Parks. A notable example is the Vena del Gesso Romagnola Regional Park, named after the peculiar miniature mountain range, that stretches for approximately 25 km across the provinces of Ravenna and Bologna, representing one of the most significant geomorphological features of the northern Apennines (Demaria, 2003; Ercolani & Lucci, 2014). The outcrop is composed of 16 gypsum strata, corresponding to cycles of intense evaporation and precipitation, alternated with thin clay layers indicative of more humid periods (Lugli *et al.*, 2015). Within this geological context, some of the region most important karst phenomena have developed and over the years, thanks to the research efforts of local speleological groups, about 300 caves have been mapped within the Park alone (Costa *et al.*, 2017).

These caves, and particularly the aquatic animals that live within them, are the focus of the MEIOGYPSOS project - Meiofauna of karst waters of the Vena del Gesso Romagnola. The project, active in 2024-2025, is funded by the National Biodiversity Future Center (NBFC), through resources provided by the Italian National Recovery and Resilience Plan (PNRR) and the European NextGenerationEU fund. We developed the project through a tight collaboration between the Parks and Biodiversity Authority - Romagna and subterranean biologists at Water Research Institute of the National Research Council (IRSA-CNR) in Verbania. The main goal was to expand knowledge on the biodiversity of karst aquifers, with particular attention to meiofaunal and microbiological communities. Furthermore, we compared pre-existing hydrogeological data with new meiofaunal data to investigate connectivity among karst systems, as well as subterranean-surface connections. The project also included actions aimed at engaging local communities, particularly speleological groups, both in operational research phases and in awareness-raising initiatives on the importance and conservation of subterranean biodiversity.

Studying the biodiversity of karst aquifers is challenging due to the fragmentation of subterranean habitats, which makes it difficult to trace subterranean connections among caves and the generally limited accessibility of cave environments. To overcome these impediments, we used metabarcoding, the gold-standard tool for monitoring difficult-to-access environments. An initial phase consisted of a literature review aimed at identifying the most suitable caves for sampling. Selection was based on the presence of lentic or lotic waters, fed either by external inputs or by percolation, with the aim of ensuring heterogeneous coverage of the Park area. Both natural and artificial caves, such as mines, were considered. Following site inspections, we selected 10 caves for sampling which we carried out in both winter and summer seasons. Sampling involved the collection of sediments, both in their entirety and through kick sampling, as well as filtering the water column using 53 μm mesh nets. To assess connectivity between karst systems and the external environment, additional samples were collected from surface streams and soils in proximity to or in direct connection with the caves. Afterward, we extracted and quantified DNA using the DNeasy PowerSoil Pro Kit protocol. Samples were then sent to a specialized laboratory for sequencing, targeting the 18S and COI genes. We implemented an enhanced annotation pipeline to correctly classify Amplicon Sequence Variants (ASVs) representing meiofauna into different taxa and functional groups. Afterwards, the study focused on building models to analyze potential changes in community *richness* and *beta diversity* among the sampled caves, in relation to variation in selected ecological factors. These included: water type (lentic/lotic), number of organic matter inputs, distance from the nearest organic matter input, distance from the nearest light source and position relative to the main entrance. Although analyses are still ongoing, models have not shown significant variance in ASV richness due to the latter explanatory variables. Nevertheless, the number of organic inputs, the position and the cave, showed a significant influence in the composition of the community, mainly explained by turnover of ASVs.

Future analyses will extend the same models to summer samples and will focus on the functional traits of nematodes, in order to assess whether the observed ecological changes are accompanied by shifts in the functional structure of communities, particularly in relation to adaptations to subterranean environments.

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Perfect algorithms and flawed designs: goals and outcomes in conservation planning

Abstract. *Il Systematic Conservation Planning (SCP) è uno strumento chiave per la protezione della biodiversità, ma la definizione degli obiettivi e la comprensione del loro legame con i risultati restano critiche. Questo studio esplora, tramite simulazioni, le implicazioni di diversi approcci: endemismo vs. ricchezza tassonomica, ruolo dei modelli di distribuzione delle specie (“Species Distribution Models”), metriche di biodiversità vs. costi/aree e strategie di gestione delle minacce. I risultati mostrano come scelte iniziali, pur fondate, influenzino profondamente gli esiti. Mappando curve di trade-off, il framework proposto aumenta trasparenza ed efficacia, offrendo un metodo trasferibile per affinare gli obiettivi anche in contesti con dati limitati e rafforzare la protezione a lungo termine della biodiversità.*

Systematic Conservation Planning (SCP) is widely recognized as a foundational framework for guiding biodiversity protection efforts (Giakoumi *et al.*, 2025; Margules & Pressey, 2000). Its strength lies in its algorithmic precision, enabling the identification of optimal trade-offs when balancing complex objectives such as species representation, economic costs, and the spatial extent of protected areas (Kukkala & Moilanen, 2013). However, the ultimate effectiveness of SCP is critically dependent on the initial phase of goal setting. The fundamental challenge often resides not within the sophisticated algorithms that identify optimal solutions, but rather in the inherent complexity and often-underestimated subjectivity of defining what to optimize (Baker, 2025; Popov, 2022). This choice is rarely neutral; it inherently risks embedding human misconceptions and biases, particularly when applied to ecosystems that are isolated, fragmented, or poorly understood (Watson *et al.* 2011). Such embedded biases can lead to suboptimal conservation solutions, driven by flawed decision-making at the strategic planning stage, ultimately undermining long-term biodiversity protection and resource allocation efficiency. This research addresses this fundamental issue by rigorously exploring the implications of diverse goal definitions within SCP.

To clarify how conservation goals should be rigorously defined within SCP frameworks, we investigated four central questions for robust conservation planning. These questions were: (1) how should conservation resources be allocated between protecting endemism versus overall taxonomic richness, and how can meaningful and ecologically relevant thresholds for these targets be quantitatively established? (2) what is

the precise role and added value of integrating Species Distribution Models (SDMs) within SCP, considering their inherent uncertainties and potential for overprediction (Velazco *et al.*, 2020)? (3) how do prioritization outcomes shift when driven by direct biodiversity metrics (e.g., species counts, phylogenetic diversity) compared to area-based or cost-efficiency considerations (Fastré *et al.*, 2020)? And (4) when dealing with dynamic threats (e.g., climate change, habitat destruction), what is the optimal balance between strategies aimed at avoiding these threats (e.g., proactive land acquisition) and those focused on directly addressing them through active conservation interventions (e.g., habitat restoration)?

To rigorously examine these complex scenarios, we developed and utilized a comprehensive simulation-based framework, leveraging prioritizR as a specialized conservation planning software (Tulloch *et al.* 2019). This framework emulated key characteristics of study areas, including Planning Units (PUs) with environmental and biodiversity attributes, hypothetical species distributions (endemic, rare, common), spatially varying conservation costs, and dynamic threat distributions (Wilson *et al.*, 2019).

For Question 1 (Endemism vs. Richness), we simulated three scenarios: (A) prioritizing 100% representation of endemic species with minimal targets for non-endemics; (B) maximizing total species representation (e.g., 30% distribution for each species); and (C) a weighted approach balancing endemism and richness. Outcomes were compared based on protected endemic species, total species protected, total cost/area, and connectivity/compactness.

For Question 2 (SDM Integration), we compared prioritization based solely on raw species occurrence data (Scenario D) against prioritization incorporating SDM-derived habitat suitability maps (Scenario E). SDMs were built using species occurrences and environmental variables, generating probability maps for each species (Velazco *et al.*, 2020). Evaluation focused on robustness to habitat loss, representativeness (especially for data-limited species), and cost/area efficiency.

For Question 3 (Optimization Objectives), we explored three optimization goals: (F) minimizing total cost for species representation; (G) minimizing total area for species representation; and (H) maximizing protected species given fixed budget/area. Comparisons focused on efficiency (species protected/cost or area), representativeness of rare/endemic species, and spatial configuration (size, connectivity, compactness).

For Question 4 (Threat Management), we simulated dynamic threat scenarios and compared strategies focusing on threat avoidance versus direct intervention, as well as balanced approaches. Outcomes were assessed in terms of long-term species persistence and loss rates under evolving threat landscapes.

Evaluation Metrics included: Effectiveness (Species Representativeness as % of range covered, Number of Species Protected, Network Robustness under simulated perturbations); Efficiency and Spatial Configuration (total cost, total area, connectivity and compactness using perimeter/area ratios). Statistical analyses (ANOVA, GLM) and visualizations (thematic maps, trade-off curves) were employed to interpret results and test hypotheses.

Preliminary simulations indicate that goal definition exerts a strong influence on conservation outcomes. Even small variations in how objectives are framed can lead to markedly different, and sometimes

counterintuitive, spatial solutions. Strategies emphasizing endemism tended to favor more restricted and fragmented networks, while approaches centered on overall taxonomic richness consistently expanded protected area coverage, often reshaping connectivity patterns.

The inclusion of Species Distribution Models (SDMs) altered prioritization outcomes by improving representation in undersampled regions but also introduced uncertainties that shifted resource allocation in unexpected ways. Trade-off analyses between biodiversity, cost, and area objectives highlighted that efficiency-driven plans could achieve comparable representation at lower cost, though often at the expense of flexibility and resilience under changing conditions.

Dynamic simulations of threat evolution underscored the importance of adaptive strategies (Reside *et al.*, 2018). Approaches that combined threat avoidance with targeted interventions consistently outperformed those focused on a single dimension, supporting higher long-term species persistence across scenarios.

Taken together, these results emphasize that conservation outcomes are shaped less by the precision of optimization algorithms than by the goals chosen at the outset. Our framework clarifies the consequences of alternative strategies, reduces arbitrariness in decision-making, and strengthens the transparency of conservation planning. This simulation-based approach provides a transferable methodology for refining goal setting, particularly in data-limited and hard-to-access systems, helping to identify which elements of complex conservation problems matter most for ensuring long-term biodiversity protection.

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Le Soglitelle Wetland (Campania, Italy): renaturalization, fruition and climate mitigation

Abstract. La zona umida delle Soglitelle, tra le province di Napoli e Caserta, è il sito più importante per gli uccelli migratori acquatici in Campania. Si tratta di un complesso di stagni artificiali, prevalentemente salmastri, lungo i quali si sviluppano canneti di *Phragmites australis* ((Cav.) Trin. ex Steud., 1841) e praterie di *Salicornia* (Linnaeus, 1753), che era utilizzato dalla criminalità organizzata per trarre profitto da attività illecite, in particolare il bracconaggio. A seguito di una campagna di repressione promossa dalla Lipu e dai Carabinieri, l'area è stata sequestrata nel 2005 e sottoposta a diversi interventi di tutela, alcuni dei quali ancora in corso. Il progetto di rinaturalizzazione prevede la differenziazione dell'area in base alle diverse esigenze ecologiche dei vari gruppi di specie ornitologiche. Infine, ampio spazio è stato dato anche alla fruibilità naturalistica e alla divulgazione ambientale.

“Le Soglitelle” wetland is a complex of artificial ponds created for hunting purposes in the 1970s and has become the main site for poaching in Campania. In 2005, following actions to combat poaching promoted by Lipu, the ponds were seized by the Carabinieri and the judicial authorities, included in the “Foce Volturno - Costa di Licola” Regional Nature Reserve, and subjected to renaturalization and utilization measures (Usai *et al.*, 2023). The area covers over 400 hectares in the Volturno Plain, between the provinces of Naples and Caserta (Fig. 1).



Figura 1 - Le Soglitelle wetland

The vegetation is typical of brackish wetlands and therefore features extensive salt marshes, mainly because the ponds were created by illegally pumping hyperaline water from an aquifer about 80 meters deep. Although this mechanism is no longer in operation following the seizure, salt water still flows from the wells and, mixing with rainwater, creates a suitable environment for numerous aquatic species. The habitats currently present can be classified as Natura 2000 type “1310: *Salicornia* and other annuals colonizing mud and sand” and the type “1420: Mediterranean salt meadows (*Juncetalia maritimi*)” (European Commission, 2013).

Depending on the amount of water present in the various seasons, the ponds make it possible for species with different ecological needs to be present, mainly during the migratory and winter periods, but also for many birds to nest, such as *Himantopus himantopus* (Linnaeus, 1758), *Recurvirostra avosetta* (Linnaeus, 1758), *Glareola pratincola* (Linnaeus, 1766) and *Tadorna tadorna* (Linnaeus, 1758), for some of which Le Soglitelle is the only nesting site in Campania (Usai *et al.*, 2021). Today, it is the most important site in Campania for migratory waterfowl.

However, climate change is making rainfall patterns more extreme and irregular. In Le Soglitelle, due to reduced rainfall compared to the past, the ponds tend to dry up and experience longer periods of drought. These conditions, in addition to making the habitat less suitable, encourage predation by foxes and stray dogs, prompting breeding pairs to give up nesting or abandon their broods. Consequently, the renaturalization of the wetland cannot be achieved spontaneously by allowing aquatic habitats to develop freely, as these were guaranteed by human activities. The renaturalization project had to provide for the continuous management of water flow through a system of sluice gates to be opened and closed depending on rainfall patterns (Fig. 2).



Figura 2 - The renaturalization and fruition project

Water management allows that the degree of salinity in the ponds, the period and the quantity of water present, on which the suitability of specific species depends, must be guaranteed by the irrigation channels that cross the wetland, by operating sluice gates mounted on the embankments (Fig. 3). This is as the result of studies carried out by the Vanvitelli University of Campania on the water balance between well water, rainwater and evapotranspiration (Alessandrino *et al.*, 2025).



Figura 3 - A pond in flood condition

The supply of fresher water is then used to promote the growth of riparian tree species *Populus alba* (Linnaeus, 1753), *Populus nigra nigra* (Linnaeus, 1753) and *Salix alba* (Linnaeus, 1753), which will form a roosting site useful for heron species that currently nest in riparian strips along the Canale dei Regi Lagni in unprotected conditions.

All these measures, in addition to improving the environmental suitability for migratory and nesting birdlife, will also mitigate climate change in favor of the surrounding agricultural and urbanized areas. The project also focused extensively on scientific research and environmental education thanks to the inclusion of the wetland in the network of bird refuges managed by Lipu. Thanks to an initial investment of €2 million from the Ministry of the Environment between 2017 and 2018, most of the infrastructure for public access has been completed and some hydraulic management work has been carried out, while the rest of the work is currently underway.

Currently, riparian vegetation is being planted to create a heronry, thanks to the collaboration of SMA, a company owned by the Campania Region that deals with environmental restoration. To this end, phytosociological surveys were carried out in riparian areas of the Volturno River to be used as a model for the coverage of different tree and shrub species. Additional resources have been committed by the Region to complete the hydraulic regulation and renaturalization works, using PR Campania FESR 2021-2027 funds. Calls for interest are being published for these works.

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Shaping effective strategies: standardized methods for monitoring and managing Coypu (*Myocastor coypus*) invasion in Lombardy, Italy

Abstract. *La nutria è una delle specie aliene invasive più dannose in Lombardia. Originaria del Sud America, è stata introdotta e si è diffusa grazie all'alta capacità riproduttiva raggiungendo una popolazione di milioni di individui. Provoca gravi danni di natura agricola e ambientale: ogni esemplare adulto consuma grandi quantità di vegetale e le sue gallerie indeboliscono argini e infrastrutture, aumentando il rischio idraulico. Le perdite economiche sono considerevoli. Per questo motivo, la normativa europea, nazionale e regionale impone il loro contenimento. Questo progetto vuole creare un sistema di monitoraggio standardizzato, valutare l'efficacia dei controlli e fornire strumenti decisionali, utilizzando app e modelli statistici, per stimare la distribuzione e pianificare interventi mirati.*

In Lombardy (Italy), the coypu (*Myocastor coypus*) has become one of the most damaging invasive alien species (IAS), having both economic and ecological impacts. Native to South America, it was first introduced to Europe in the 1930s for fur farming, but escapes and intentional releases soon allowed it to spread widely, due to its high ecological plasticity and reproductive capacity. Females can breed before reaching one year of age and usually produce litters of 4-6 young, though litters of up to 12 have been reported (Gosling, 1981). Natural predation plays only a marginal role, affecting mainly juveniles or weakened individuals, occasionally taken by wolves, dogs, or foxes. Latest population estimates suggested 1-3 million individuals were present in Lombardy in 2012-2013 (Balestrieri *et al.*, 2016; Prigioni *et al.*, 2013).

The species' impact is particularly severe in agricultural and wetland areas. Adults consume between 1.2 and 2.5 kg of fresh plant material per day, with a preference for nutrient-rich crops such as cereals, sugar beet, soybeans, vegetables, and the bark of young trees (Gosling, 1981). Beyond crop losses, coypu activity threatens water and road safety. Their burrowing weakens irrigation and drainage canals, riverbanks, dykes, artificial basins, and even railway embankments, leading to erosion, subsidence and increased flood risk. Across Italy, agricultural and irrigation losses caused by coypu were estimated to exceed €11 million between 1995 and 2000 (Panzacchi *et al.*, 2007). In light of these impacts, the species has been listed under EU Regulation No. 1143/2014 and Implementing Regulation 2016/1141, both of which require its eradication or containment. In Italy, these obligations are enforced through national Law 157/1992 and Legislative Decree 230/2017, as well as regional frameworks such as Lombardy Regional Law 20/2002 and

the 2024-2026 Three-Year Plan. Nevertheless, management remains challenging, largely due to outdated abundance estimates and the absence of standardized monitoring protocols.

In this context, the project sets out three main goals: (i) to establish a large-scale monitoring program across Lombardy to estimate local abundance and investigate coypu population dynamics; (ii) to assess the effectiveness of control measures; and (iii) to create a tool that will support decision-makers in controlling coypu. A distinctive feature of the project is the use of a customized CyberTracker app, which enables standardized, georeferenced field data collection with photos and metadata, reducing errors. The study area focuses on lowland landscapes below 20 m a.s.l., particularly the Po Valley and adjacent plains, where coypu populations are most diffused. Lombardy's dense hydrographic network – 1925 km of primary rivers, 9425 km of secondary watercourses, and more than 40,000 km of artificial canals – offers ideal conditions for coypu dispersal. Land use is dominated by intensive agriculture with narrow, fragmented riparian strips and seasonal temperature cycles influence both activity patterns and reproduction.

For local abundance estimates, the project employs capture-mark-recapture (CMR) methods. At each site, two trapping sessions of seven days are carried out, separated by ten days. Individuals are PIT-tagged and their age, sex, and body weight recorded. Previous studies in Lombardy indicated an average capture rate of about 0.087 coypus per trap-day (Prigioni *et al.*, 2005). CMR provides the calibration baseline for indirect monitoring. From 2025 to 2027, indirect monitoring will use the active path count method along transects of approximately 3 km within 5×5 km grid cells. Double Observer (DO) (Suryawanshi *et al.*, 2012) surveys will be conducted at 10-40% (Panaccio *et al.*, 2024) of sites to estimate detection probabilities and account for imperfect detection. During fieldwork, observers will record vegetation height, slides, footprints, faeces, and direct sightings, with all data georeferenced and photographed through CyberTracker. These records will be analyzed with a Bayesian double-observer model. In preliminary trials, one transect yielded an estimate of 46 active paths (95% CI: 36-65), adjusted for observer detection probabilities (Observer A: 0.57, Observer B: 0.42) and data augmentation. Calibration factors from CMR will be used to translate path counts into abundance estimates. In parallel, removal data from ongoing control operations will feed into an Integrated Population Model (IPM), making it possible to evaluate population responses, optimize resource allocation, and set realistic removal targets. By combining indirect indices with CMR calibrations, the project will generate spatially explicit density maps, highlighting gradients in distribution and abundance. Preliminary analyses point to substantial spatial and temporal variation in removals, as well as uneven cost-effectiveness, underscoring the importance of standardized training, monitoring, and data protocols to improve control outcomes. This integrated approach will enable the project to deliver scientific and operational tools that mitigate the impact of coypu in Lombardy. These tools will help to safeguard agricultural and aquatic ecosystems, while contributing to the long-term resilience of biodiversity.

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Management effects in rice field margins: a QBS-ar approach

Abstract. *I margini delle risaie, se gestiti correttamente, possono agire come rifugi e corridoi ecologici, mitigando gli impatti della gestione. Lo studio ha analizzato l'indice QBS-ar in margini di risaia convenzionale e biologica nel Piemonte orientale, confrontandoli con aree naturali. I risultati hanno mostrato che le aree naturali presentano valori QBS-ar significativamente più alti, indicando una maggiore qualità del suolo. Non sono state rilevate differenze statisticamente significative tra le gestioni convenzionali e biologiche, suggerendo che le loro comunità ipogee sono più simili di quanto ipotizzato, probabilmente a causa della gestione non uniforme dei margini. Ulteriori ricerche con campionamenti più frequenti sono necessarie per cogliere la dinamica stagionale dell'ecosistema.*

Rice cultivation techniques, particularly the use of pesticides and chemical fertilizers, have been shown to have severe negative impacts on soil biodiversity, especially on invertebrates, which has been widely demonstrated at a European level (Dermiyati & Niswati, 2014; Tsiafouli *et al.*, 2015). Moreover, the diverse management practices applied in the paddies and their margins, such as water control, seedbed preparation and the grass removal profoundly alter the vertebrate and invertebrate communities (Toffoli & Ruggetti, 2017; Giuliano *et al.*, 2018). Rice fields are now primarily composed of three habitat structures: flooded paddies, irrigation canals, and paddy banks. In this context, agricultural margins -the transition areas between the cultivated field and the surrounding environment-play a fundamental role. If correctly managed, they act as refugia for invertebrate populations and other species, providing stable habitats not subjected to the disturbances of agricultural practices (Cardarelli & Bogliani, 2014). They also function as ecological corridors that facilitate the dispersal and movement of species, which is essential for maintaining the connectivity and health of the entire agricultural ecosystem (Vickery *et al.*, 2009). The strategic management of these margins can therefore significantly mitigate the negative impacts of intensive practices, increasing the resilience and functional biodiversity of rice paddies.

Soil invertebrate communities include a wide range of species: from Arachnida and Myriapoda to Collembola and insects. They play a crucial role in the functioning of the ecosystem and in providing essential ecosystem services, including the decomposition of organic matter, nutrient cycling, and soil formation. The Arthropod-based Biological Soil Quality Index (QBS-ar) is a tool used to assess the biological quality of soil by analyzing the community of microarthropod community present in the top

centimetres of soil. The index is based on the morphological specialisation of these organisms for hypogean life, known as the Morpho-Ecological Index (EMI). This method is particularly useful because it does not require specialized taxonomic identification, making it a simple and widely applicable tool that provides rapid and synthetic information on soil quality (Menta *et al.*, 2018). Moreover, based on the overall QBS-ar value, soil can be classified into different classes, each characterized by increasing environmental quality (Parisi *et al.*, 2005).

The aims of this work are: 1) to verify if QBS-ar index is a sensitive tool to analyse the different management regimes on rice paddies; 2) to understand if hypogean communities are sensitive to the different rice agricultural managements; 3) to understand if the rice paddy banks are subject to the same cultivation management impacts as the rice paddies.

The project focused on three areas in eastern Piedmont (Italy): Crescentino, Rovasenda, and Casalbeltrame in Vercelli province. In each area, we selected two farms with different crop management: conventional and organic, and a natural freshwater area. In each farm, we sampled the soil on two banks from three rice paddy chambers. A total of 56 points were sampled in two different periods: September 2024 and May 2025. Once the soil cores were collected, arthropods were isolated from each sample with the Berlese-Tüllgren extractor for 15 days. Then, Generalized Linear Mixed Models were used to detect statistical differences between farm management techniques considering QBS-ar, taxonomic richness and Shannon index. Finally, NMDS was applied to analyse beta diversity distances between different microarthropod communities.

A total of 16155 soil arthropods were extracted, belonging to 52 distinct taxonomic units. The most abundant class was Arachnida (N = 6135; Fig. 1) followed by Insecta (N = 5936) and Collembola (N = 3252).

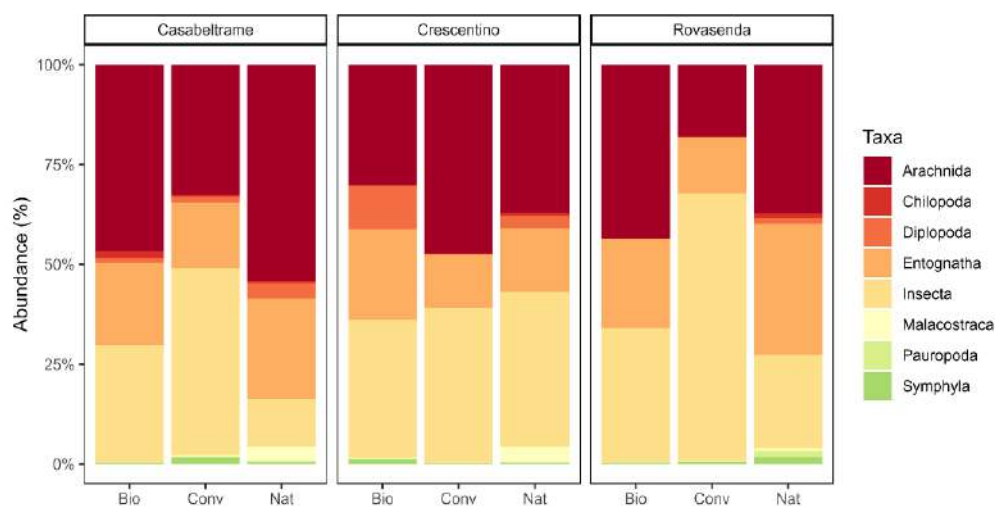


Figure 1 - Abundances of soil arthropod classes for each area and treatment (Conv: conventional crop management; Org: organic crop management; Nat: natural freshwater area)

The mean QBS-ar value was generally higher in natural controls compared to the conventional treatment (EMMs, p-value = 0.01, Fig. 2). This trend was particularly marked in the Crescentino areas, where the mean value for the conventional treatment was lower than both the organic and the natural areas (EMMs not significant). Furthermore, the Rovasenda natural area showed significantly higher values compared to its corresponding organic (EMMs, p-value = 0.0003) and conventional (EMMs, p-value = 0.01) rice paddies. Finally, based on mean QBS-ar values, organic and conventional farming management systems fall into a similar class of 5, while natural areas have a higher quality class of 6-7.

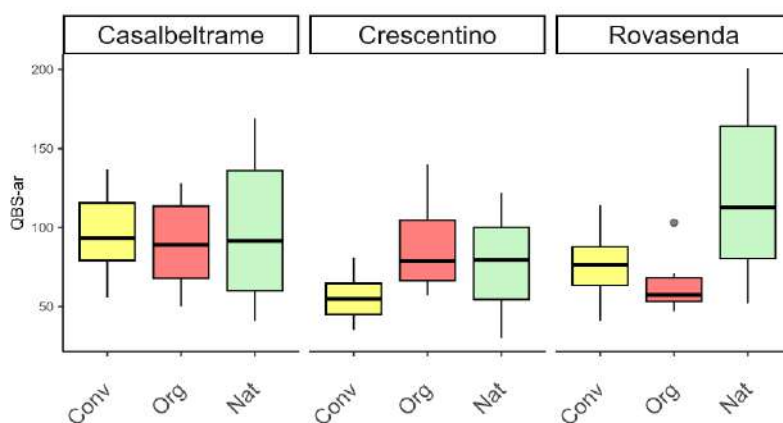


Figure 2 - Boxplots of QBS-ar index for each treatment and area (Conv: conventional crop management; Org: organic crop management; Nat: natural freshwater area)

Taxonomic richness calculated for the different treatments was similar across the various management regimes and natural areas (GLMMs, p-value = 0.1545). An interesting result emerged again from the Crescentino area, where the taxonomic richness of organic treatment was significantly higher than the conventional treatment (EMMs, p-value = 0.03). Shannon index showed no statistically significant differences between the two management and the natural areas. On the contrary, higher mean Shannon values were observed for the Casalbeltrame conventional farm compared to the organic and natural control sites.

In general, the communities in the natural controls from all three areas, with a few exceptions, were more distinct from the organic and conventional crop management (Fig. 3). The latter two generally clustered in the lower part of the NMDS plot, with significant overlap and more similarity, while the natural areas tended to occupy the upper part. The communities from the different treatments were significantly different both overall (PERMANOVA, p-value = 0.046) and within the different areas (PERMANOVA, p-value = 0.012). More specifically, the communities sampled from the organic and conventional management regimes seem to be similar (PERMANOVA, p-value = 0.443), while the community in natural area was more distinct from the others (PERMANOVA, p-value = 0.031 and 0.030) and within the sampled areas (PERMANOVA, p-value = 0.012 and 0.009).

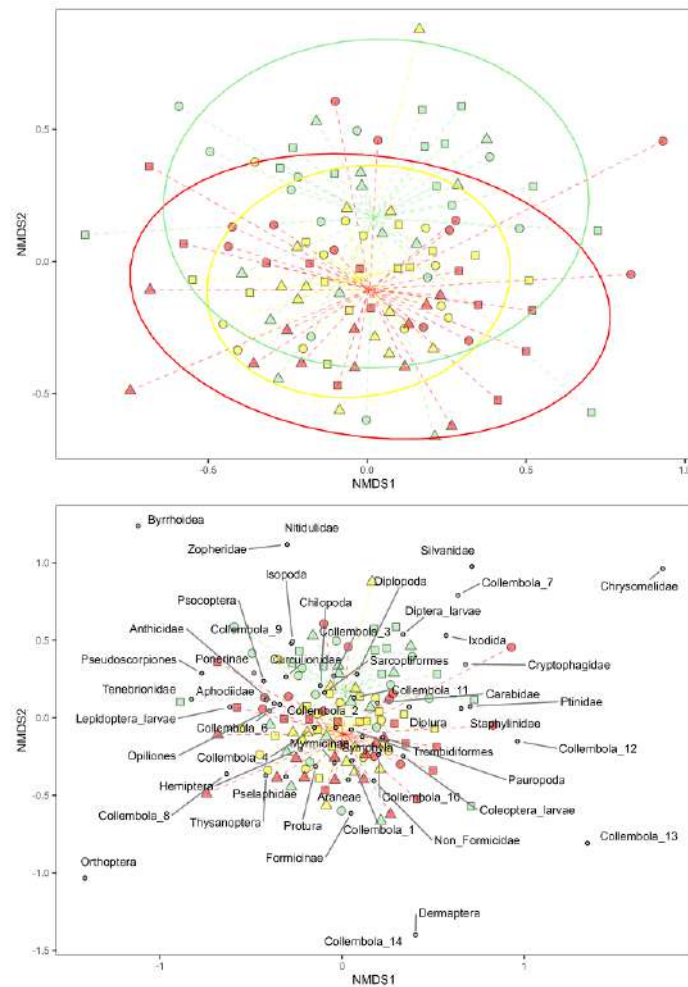


Figure 3 - Non-metric Multidimensional Scaling (NMDS) with Bray-Curtis distances between soil communities; conventional sampling points are in red, organic sampling points in yellow and natural control points in green; triangles represent Rovasenda sampling points, circles represent Casalbeltrame sampling points and squares Crescentino sampling points. In the plot below, taxonomic groups are shown

Soil arthropods are sensitive to agricultural management, being extremely important for the right functionality of soil ecosystems and thus fundamental bioindicators (Menta & Remelli, 2020). Nevertheless, QBS-ar showed no statistically significant differences in the values within conventional and organic, in contrast to other studies in the same region (D'Antoni *et al.*, 2020). However, similarly to this study, QBS values are little greater in organic management (Min = 47, Max = 140) compared to the conventional one (Min = 35, Max = 137). In addition, our study included natural areas that showed significant higher values compared to both management regimes (Min = 30, Max = 201). Thus, in this case, hypogean communities are more similar between different rice paddies management than expected, both in terms of community composition and morphological adaptation. At the same time, it must be noticed that greater distances between communities of rice paddies and natural areas were recorded.

Intensive management in rice field margins produces a severe impact on invertebrates (Cardarelli & Bogliani, 2014). However, in our case, margins management practices across rice fields are not always

consistent. This can lead to profound changes, even in the same area and treatment, in invertebrate communities that do not match our hypotheses. Furthermore, our sampling was conducted exclusively during two specific windows of the rice cultivation cycle: spring and late summer. This approach may not have fully captured the dynamic seasonal variations that characterize the rice paddy ecosystem. Given that the rice paddy environment undergoes distinct phenological phases which drastically alter the composition of plant and arthropod communities, future research should integrate a more continuous sampling approach to achieve a more comprehensive understanding of the relationship within management practices (e.g D'Antoni *et al.*, 2020).

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***Evaluation of the effects of a controlled sediment flushing operation
on the functional trophic groups of the benthic macroinvertebrate
community of an Alpine stream***

Abstract. *In questo studio sono stati indagati gli effetti ecologici di un'operazione di fluitazione di sedimento controllata, effettuata nel 2023 dal Serbatoio di Isolato, sulla rete trofica del Torrente Liro. L'indagine si è focalizzata sulla comunità di macroinvertebrati bentonici e sulle loro risorse alimentari. Dopo la fluitazione, è stato rilevato un grave impatto a breve termine sulla biomassa sia del perifiton che dei macroinvertebrati, con una riduzione superiore al 90% nel tratto a valle del serbatoio. I successivi eventi di piena hanno ulteriormente compromesso la comunità bentonica, ma hanno anche rimosso i depositi di sedimento fine dall'alveo, facilitando il recupero della comunità, che è tornata alle condizioni precedenti alla fluitazione dopo più di un anno.*

Dams cause the deposition of sediments transported by the streamflow in the reservoirs. This phenomenon alters the natural hydro-sedimentary regime of rivers and is often managed through controlled sediment flushing operations (CSFOs) in the European Alps (Quadroni *et al.*, 2025). A CSFO consists in the controlled release of the deposited sediments in the river reach downstream of the dam to recover the volume of the reservoir and, partly, rebalance the sediment flux (Espa *et al.*, 2015). However, these operations can cause severe ecological impacts on the downstream aquatic ecosystems (Espa *et al.*, 2019).

In this study, the ecological effects of a CSFO carried out in winter 2023 from an Alpine reservoir (Isolato Reservoir) on the Liro Stream were investigated. Biomonitoring was performed once before and on twelve occasions after the CSFO over 2 years, from December 2022 to January 2025. Benthic macroinvertebrates (i.e., organisms larger than 0.5 mm that live in contact with the river substrate) are widely used river bioindicators, particularly sensitive to sediment pressure, thus their biomass was monitored focusing on four main trophic guilds (i.e., shredders, grazers/scrapers, collectors and predators) (Fenoglio *et al.*, 2020; Schmidt-Kloiber & Hering, 2015). Moreover, the sampling and analysis of periphyton and coarse particulate organic matter (CPOM) allow to investigate the impact on the main components of a stream food web, essential for maintaining ecosystem functionality.

Three monitoring sites were sampled (Fig. 1): one upstream of the Isolato Reservoir and two downstream of the dam, separated by the confluence of a tributary (Scalcoggia Stream) used to dilute the sediment load during the CSFO. After quantitative multihabitat sampling, benthic macroinvertebrates and CPOM were

sorted in the lab, macroinvertebrates were identified to family level, and all samples were dried and then weighed. Close to macroinvertebrate sampling points, periphyton was collected from cobbles and then, after sample filtration, the chlorophyll-a content was analysed in the lab through spectrophotometric detection (APAT & IRSA-CNR, 2003). To relate the components of the stream food web, the values of periphyton, CPOM and the four trophic guilds of benthic macroinvertebrates were expressed using the same unit of measure, i.e., the organic carbon content (g C/m^2), using conversion factors provided by the literature (Gosselain *et al.*, 2000; Salonen *et al.*, 1976).

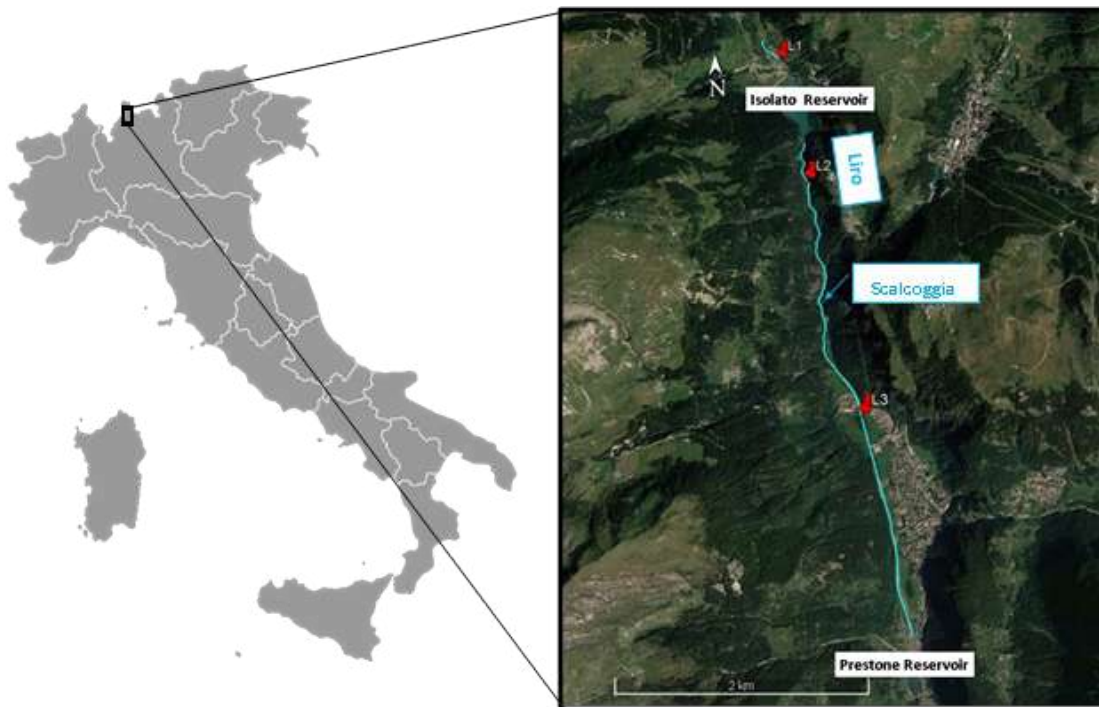


Figure 1 - Study area in the Central Italian Alps with the three monitoring sites (L1, L2 and L3)

After the CSFO, a severe short-term impact on the biomass of both periphyton and benthic macroinvertebrates was detected, with reduction higher than 90% at both the downstream sites (Tab. 1). In the five months since the CSFO, the recovery was slow, even if slightly faster at L2 than at L3, probably due to a higher sediment deposition at the stream site characterized by a lower slope. Then, flood events further impaired the benthic community but also removed the fines from the streambed, facilitating the subsequent recovery of the community, which returned to the pre-CSFO condition at the end of the study period.

The comparison with the biomonitoring results of another CSFO carried out in a close study area (Quadroni *et al.*, 2024) allows to highlight that longer CSFO (ca. 80 vs. 15 days duration) has greater ecological impact on the stream food web (Tab. 1).

Table 1 - Comparison of the percentage reduction of periphyton and benthic invertebrate biomasses immediately after the CSFO between our case-study on the Liro Stream and a previous one on the Roasco Stream (Quadroni *et al.*, 2024); the detail of the four trophic guilds is also reported

	Periphyton	Invertebrates	Grazers	Shredders	Collectors	Predators
L1	- 76%	- 41%	- 31%	- 20%	- 45%	- 56%
L2	- 95%	- 97%	- 99%	- 98%	- 99%	- 90%
L3	- 90%	- 94%	- 95%	- 93%	- 94%	- 94%
Roasco	- 36%	- 71%	- 87%	- 47%	- 76%	- 54%

In conclusion, this study highlighted that:

- CSFO has negative effects on periphyton and benthic macroinvertebrate communities both in the short and in the middle term, with a complete recovery after more than one year;
- CSFO has a greater impact on certain trophic groups depending on the availability of periphyton and CPOM, and on the resilience of different taxa from sediment pressure;
- clear water releases during flood events further impair the benthic community but favour the recolonization process by removing fines from the streambed;
- the longer the CSFO duration, the longer the recovery time of benthic organisms.

Studies like this are fundamental to provide ecological criteria for the improvement of sediment management strategies in order to maintain reservoirs for anthropic uses while preserving river ecosystems.

Aknowledgements

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Ecological analysis in the field: standardized approaches to study species' space use

Abstract. *La ricerca ecologica applicata analizza la variazione di variabili note in relazione a quelle ignote, al fine di comprenderne l'entità e la natura delle interazioni. Il progetto sviluppa un approccio metodologico per analizzare la coesistenza tra specie in ambienti eterogenei, valutando come le differenze di taglia corporea influenzino la ripartizione dello spazio e delle risorse. Attraverso una revisione sul concetto di patch e l'integrazione di radiotelemetria miniaturizzata e video trappole su piccoli mammiferi terrestri, si indagano home range e dinamiche di uso delle risorse. I risultati forniscono strumenti operativi per comprendere le interazioni tra specie ed orientare azioni di riqualificazione ecosistemica.*

Understanding how animals use space and resources is fundamental to the study of animal ecology and the development of effective conservation and restoration strategies. This project aimed to develop a standardized methodological framework to investigate how ecological and individual factors influence resource partitioning and space use, with a particular focus on the role of body size in shaping inter- and intraspecific coexistence.

A key part of this work is a systematic literature review (title: *The patch concept in Ecology: from theoretical models to operational applications*, in preparation), which highlights how the operational definition and application of the *patch* concept is strongly dependent on three key aspects: the taxa under investigation, the habitat type, and the specific research objectives. The bibliographic analysis revealed that, due to the favorable trade-off between body size, detectability, and environmental conditions, most operational studies have been conducted on herbivorous ungulates and small terrestrial rodents.

Small terrestrial mammals represent an ideal group for the empirical study of space use and resource partitioning, especially in the context of coexistence (Jędrzejewski & Jędrzejewska, 1993; Morris, 1987). These species often live in sympatry and are distributed across a wide range of habitat types, from mountainous to coastal environments (Braithwaite *et al.*, 1978; Symes *et al.*, 2013). Their ecological plasticity and high population turnover make them particularly suitable for testing spatial and behavioral hypotheses under different environmental pressures (Morris, 1996). Moreover, their limited home ranges allow for fine-scale monitoring and reduce the logistical complexity of continuous tracking in the field (Abramson *et al.*, 2006).

Body size plays a central role not only as a structural trait but also as a proxy for metabolic activity and individual fitness (Kleiber, 1947). It provides an energetic baseline for evaluating the costs and benefits of space use and foraging strategies (Brown *et al.*, 2004). By integrating body size into spatial models, it becomes possible to explore how energy expenditure, competitive asymmetries, and access to resources vary across individuals and species, offering a more mechanistic understanding of coexistence in heterogeneous landscapes (Peters, 1983; Basset, 1995).

The core objective of this research is to quantify the home range size for coexisting vole individuals across varying body sizes and to evaluate how natural resource availability and distribution influence foraging strategies and space use. Furthermore, the study aims to test predictions of metabolic theory and optimal foraging theory regarding the relationship between body size and resource partitioning. Standard methodologies will be employed to quantify resource use by individuals, such as the giving-up density (GUD) framework (Bedoya-Perez *et al.*, 2013; Brown *et al.*, 1989; Brown & Kotler, 2004), which provides a powerful experimental approach to investigate how differences in size scaling metabolic costs and perceived predation risks affect resource harvesting.

The project is guided by three main hypotheses: H1 (Metabolic Theory) predicts that larger voles will exhibit larger home ranges due to higher energetic demands; H2 (Optimal Foraging Theory) proposes that voles will select areas with higher density and quality of natural resources to maximize foraging efficiency; and H3 (Coexistence) suggests that resource partitioning will be influenced by body size, leading to reduced spatial overlap among individuals of different sizes.

The experimental design will be conducted across two contrasting Italian study areas: a rocky scree environment in the Adamello Brenta Geopark and a Mediterranean maquis woodland in the Castelporziano Presidential Estate. These sites provide diverse habitats and ecological gradients to ensure methodology robustness and to explore how structural complexity impacts patterns of individual space use and overlap, focusing on sympatric arvicoline rodent communities (voles).

The methodology involves first Animal Capture and Tagging: voles are live-trapped with Sherman traps, and biometric data (head-body length, tail length, body mass), sex, and age recorded. Miniaturized 1g VHF radiotelemetry tags will be applied using surgical adhesive for continuous monitoring, and individuals will be identified with unique codes before being released at the capture site.

The second step is Home Range Estimation: an automated, miniaturized VHF radiotelemetry system with fixed receiving stations will establish a standard coverage area for spatial analyses. Location data (e.g., trilateration coordinates) will be collected for 7-14 consecutive days to capture space use variability. This data will be analyzed using specialized software, such as Kernel Density Estimation (KDE), to estimate daily home ranges, which will then be correlated with individual body mass and other biometric data.

The third step, Environmental Resource Sampling, will quantify natural resource distribution within the standard telemetry coverage area using the quadrat method (e.g., 0.5×0.5 m quadrats, randomly or systematically deployed). Within each quadrat, resource availability (e.g., edible plant biomass, seeds,

invertebrates, ground cover, refugia) and habitat structural characteristics (e.g., vegetation height, canopy cover) will be quantified, resulting in a spatial distribution map of resources. Data analysis will involve Home Range analysis using Linear regressions or Generalized Linear Mixed Models (GLMMs) to examine relationships between home range size and body size, controlling for factors like sex, age, season, and habitat type, while home range overlap will assess space partitioning.

Furthermore, Resource-Space Use Integration will be performed by overlaying home range maps with resource availability maps to evaluate preferential use of resource-rich areas using Spatial analyses such as Resource Selection Functions (RSFs) to determine how resource distribution influences habitat selection. The expected outcomes are the confirmation of body size influence on home range and resource use, consistent with metabolic theory, the identification of foraging preferences and resource partitioning strategies, and the provision of operational tools for understanding inter-species interactions and guiding ecosystem restoration. All animal procedures will adhere to ethical regulations and require appropriate permits, prioritizing minimal animal stress.

The resulting standardized protocol enables the investigation of behavioral and spatial dimensions of coexistence and provides an operational tool for testing theoretical and semi-theoretical ecological models in the field. Moreover, the portability and scalability of the approach allow for the extension of future research to additional sampling sites. This includes potential collaborations with national parks, regional protected areas, and ecological restoration projects aimed at understanding and promoting biodiversity through spatial and behavioral analysis of key species.

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Effetti del sedimento fine sulla composizione delle comunità di macroinvertebrati bentonici fluviali

Abstract. *This field experiment aims to analyze the short-term effects of siltation, an excessive accumulation of fine sediment on the riverbed that negatively impacts on benthic macroinvertebrate communities. We used six artificial flumes to simulate the river ecosystem, filling three of them with sand and comparing their community composition with the other three flumes used as control. We noted a more marked difference in macroinvertebrate communities between the two treatment types in samples positioned lower in the substrate, but we also obtained variable data: the use of artificial mesocosms may limit the representativeness of natural conditions but is a very useful tool for controlling variables by manipulating factors of interest in river ecology and the threats to lotic ecosystems.*

La *siltation* è un fenomeno che riguarda un eccessivo accumulo di sedimento fine sul substrato fluviale che può derivare da fenomeni naturali ma soprattutto antropici, ed è una delle cause mondiali di alterazione di corsi d'acqua e fiumi (Owens *et al.*, 2005). Il disturbo dovuto a questo fenomeno influenza negativamente le comunità dei macroinvertebrati bentonici: può far perdere eterogeneità al substrato su cui vivono (Wood & Armitage, 1997), ostacolare gli scambi di ossigeno tra il fondale e la colonna d'acqua, ostruirne gli organi per la respirazione o produrre degli stress abrasivi (Bilotta & Brazier, 2008).

L'esperimento, svolto presso il centro Alpstrem di Ostana (CN), vuole essere una analisi sugli effetti a breve termine di questo fenomeno sulla composizione delle comunità di macroinvertebrati bentonici fluviali: sono state utilizzate sei canalette, dette *flumes*, ovvero dei mesocosmi artificiali che simulano specifici elementi dell'ecosistema fluviale, permettendo di fare esperimenti controllati manipolando uno o più fattori di interesse.

Le sei canalette (Fig.1) ricevono e riversano acqua dal Po e sono state disposte in tre gruppi da due, permettendo l'associazione con la canaletta che verrà sedimentata e quella di controllo: dopo un iniziale allestimento con l'inserimento di ciottoli e ghiaia per simulare il substrato fluviale, sono stati inseriti 18 cilindri in PVC forati (diametro 11 cm, altezza 15 cm) per ogni canaletta contenenti ognuno due sacchetti, uno sopra l'altro, composti da una rete ripiena di sedimenti di diversa granulometria (10% minore di 2 mm, 25% 2-8 mm, 15% 5-15 mm, 20% 30-40 mm, 30% 60-80 mm) che prenderanno poi il nome di campione up, quello sopra, e campione down, quello sotto (Fig. 2).



Figura 1 - I sei flumes del centro Alpstream di Ostana (CN); da destra verso sinistra: prima coppia, flumes 1-2; seconda coppia, flumes 3-4; terza coppia, flumes 5-6



Figura 2 - I sacchetti di rete ripieni di sedimenti, posizionati all'interno dei cilindri nel substrato dei flumes

Nella fase T0 dell'esperimento, avvenuta il 18 aprile 2023, sono state aperte le valvole e riempite le canalette con l'acqua, per permettere l'arrivo e l'insediamento dei macroinvertebrati nei cilindri: per evitare una bassa colonizzazione sono stati prelevati direttamente dal substrato del fiume Po quindici campioni ricchi di macroinvertebrati, tramite il retino Surber, e aggiunti successivamente alle canalette. Questa fase di colonizzazione è durata 3 settimane.

Nella fase T1, dall'8 al 9 maggio 2023, è avvenuto lo sversamento di 2.25 kg di sabbia per ogni metro delle canalette numero 1, 3 e 5; 24 ore dopo si è prelevato il contenuto dei cilindri per ogni canaletta riversando il contenuto dei sacchetti in appositi contenitori di plastica etichettati e riempiti con etanolo 94%.

I campioni sono stati poi portati in laboratorio di Ecologia presso il polo San Giuseppe dell'Università del Piemonte Orientale e analizzati per la determinazione sistematica: i taxa sono stati classificati fino alla famiglia, mentre per i soli ordini di Ephemeroptera e Plecoptera si è proseguito fino al genere. Il conteggio finale degli individui di ciascun taxon è stato registrato in un database utilizzato per le analisi statistiche tramite R. La comunità totale delle sei canalette è dominata dalla presenza dei Diptera, seguiti poi dai Plecoptera, dagli Anellida, dagli Ephemeroptera e dai Coleoptera (Fig. 3).

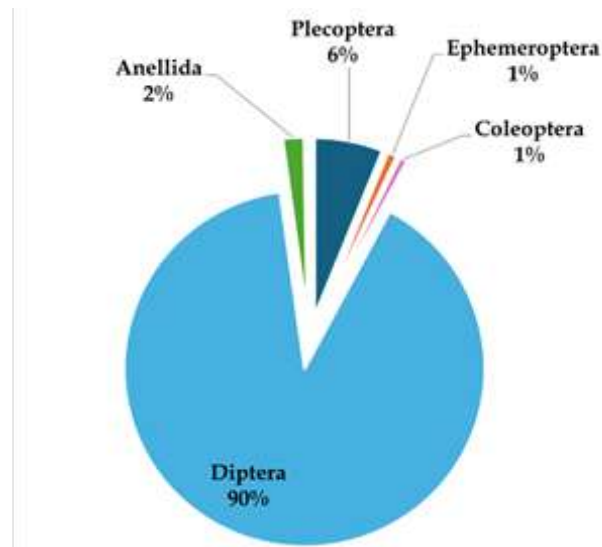


Figura 3 - Comunità totale dei macroinvertebrati nei flumes

L'analisi multivariata mostra delle similitudini nelle comunità dei campioni up, sia nelle canalette sedimentate che in quelle di controllo, tutte orientate al centro: la sabbia non sembra aver influenzato particolarmente le comunità (Fig. 4). Si possono notare invece delle differenze più marcate tra le comunità dei campioni down delle canalette sedimentate, verso il basso, e quelle dei campioni up, verso l'alto.

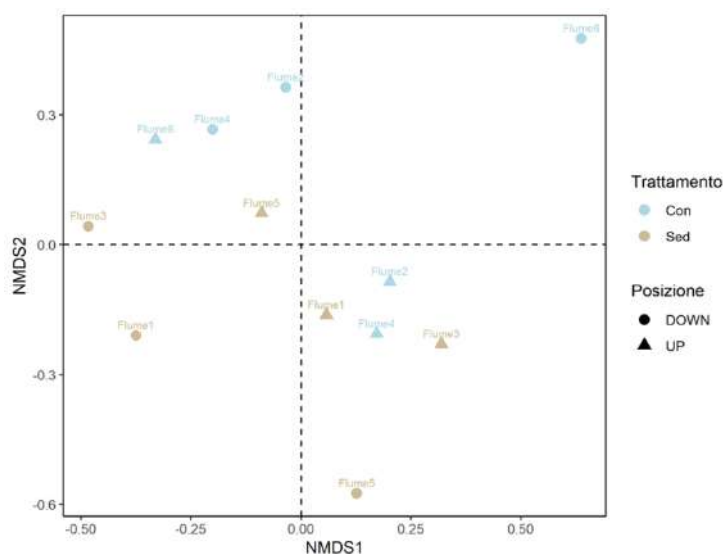


Figura 4 - Grafico NMDS sulle differenze tra comunità di macroinvertebrati

In seguito si è applicata una analisi statistica per individuare i taxa generalisti o specialisti in due habitat distinti, ovvero tra habitat sedimentato e di controllo, e tra campioni up e campioni down. La famiglia dei ditteri Chironomidae è risultata specialista delle canalette di controllo: questo gruppo di insetti può essere stato influenzato negativamente dalla presenza della sabbia, che ne ha diminuito il numero nelle canalette sedimentate. I plecoteri *Amphinemura* sono stati classificati come specialisti del sedimento e, anche se sono considerati generalmente sensibili agli stress e all'inquinamento, si è visto in uno studio precedente come la CPOM, ovvero la componente organica fogliare di cui si nutrono, sia cruciale per la loro sopravvivenza e può tamponare gli effetti negativi della *siltation* (Doretto *et al.*, 2017): difatti le canalette erano ricche di materiale organico accumulato trasportato dall'acqua. Questi due taxa hanno mostrato inoltre una interazione positiva: la crescita di uno ha portato alla crescita dell'altro. Possono quindi aver mostrato una aggregazione interspecifica, presentandosi insieme più spesso di quanto previsto casualmente: è lecito presupporre che l'elevata presenza di detrito organico nelle canalette ne ha influenzato positivamente l'abbondanza e che siano riusciti a sfruttare assieme le risorse trofiche presenti. Classificati come specialisti dei campioni down troviamo vari macroinvertebrati, tra cui i coleotteri Elmidae, i tricoteri Hydropsychidae e i ditteri Athericidae: molti insetti si possono trovare infatti negli strati più profondi del substrato fluviale, come la zona iporreica, per avere ulteriore spazio per la colonizzazione (Koutný & Rulik, 2007) o proteggersi dall'abrasione data dai sedimenti fini (Statzner *et al.*, 1988).

In conclusione, tramite questo esperimento con i mesocosmi, si è vista una reale differenza delle comunità tra i *flumes* sedimentati e quelli di controllo, ma le conseguenze della *siltation* sono parzialmente in linea con quelli fatti in altri studi (Couceiro *et al.*, 2011; Nuttall, 1972). I mesocosmi possono essere uno strumento molto utile per la ricerca e lo studio degli eventi che minacciano gli ecosistemi: gli articoli su questi esperimenti sono infatti costantemente cresciuti dagli anni Sessanta (Menczelesz *et al.*, 2020). Potendo controllare la maggior parte delle variabili in atto si possono manipolare uno o più fattori di interesse ma, di conseguenza, si limita la rappresentatività delle condizioni ambientali naturali, contribuendo così all'ottenimento di risultati variabili.

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Comparing forest ecosystem services in two Italian parks: insights from Stelvio National Park and Orobie Bergamasche Regional Park

Abstract. *Le foreste alpine offrono molteplici servizi ecosistemici – legno, stoccaggio di carbonio e protezione da frane – fondamentali per benessere umano, biodiversità e resilienza climatica, ma spesso sottovalutati nella pianificazione. Questo studio valuta in modo integrato tali servizi in due aree protette della Lombardia (Parco Nazionale dello Stelvio e Parco delle Orobie Bergamasche), usando dati forestali, modelli digitali, mappe di rischio e prezzi di mercato. I risultati mostrano forti differenze: le Orobie generano maggiori entrate da legname e accumulo di carbonio, mentre lo Stelvio eccelle per valore per ettaro e stabilità dei versanti. L'analisi evidenzia sinergie e trade-off tra specie e funzioni, e la maggiore resilienza dei servizi regolativi rispetto alle oscillazioni di mercato. Integrare la valutazione economica nei piani di gestione può conciliare conservazione, adattamento climatico e opportunità socio-economiche, garantendo benefici equi alle comunità presenti e future.*

Forests in mountain regions provide a diverse array of ecosystem services (ES) that underpin human well-being, biodiversity conservation and climate resilience, yet their economic significance is still underestimated in policy and management. Building on the growing literature on ES valuation and its integration into sustainability targets (Díaz *et al.*, 2018; MEA, 2005), this study delivers a comprehensive assessment of timber production, carbon sequestration and protection against shallow landslides across two protected areas in Lombardy, northern Italy: Stelvio National Park (SNP) and Orobie Bergamasche Regional Park (OBRP). These sites, characterised by contrasting altitudinal gradients, stand composition and disturbance histories, offer a natural laboratory for understanding how ecological and socio-economic factors drive ES provision under changing environmental pressures. We combined forest inventory data, digital elevation models, soil and hazard maps, and market information for 2011-2023 to estimate annual and spatial values. Timber benefits were quantified from stumpage and roadside prices corrected for post-disturbance salvage (Chirici *et al.*, 2019; Grilli *et al.*, 2015). Carbon storage was derived from biomass growth and dead organic matter, applying voluntary carbon market prices and sensitivity tests for carbon social cost (Coomes *et al.*, 2002; Peters-Stanley *et al.*, 2013).

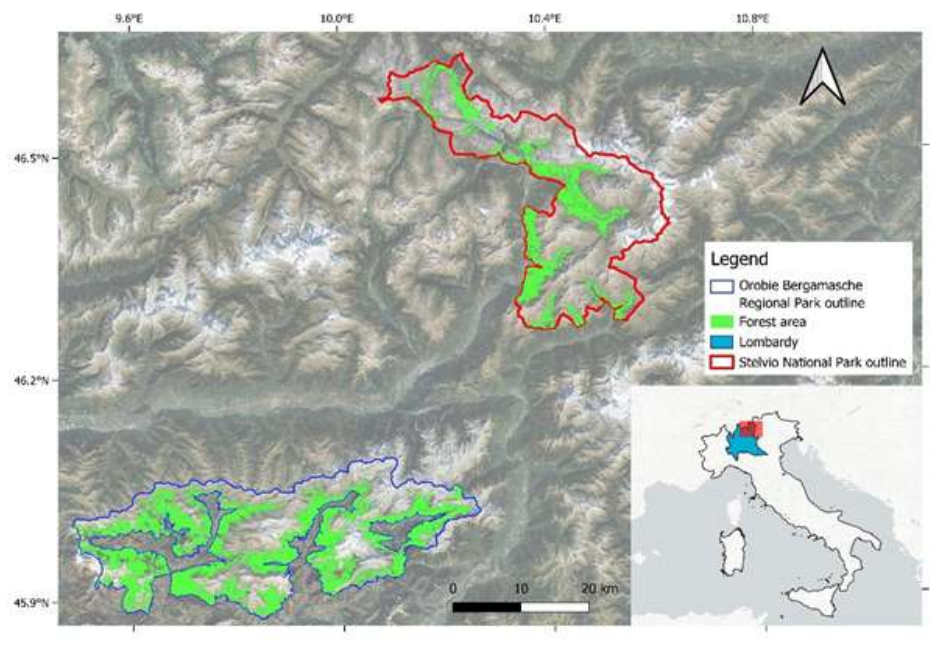


Figure 1 - Study area including the Stelvio National Park (SNP, red outline) and the Orobie Bergamasche Regional Park

Landslide mitigation was measured through a replacement-cost approach based on forest cover in high-susceptibility slopes, incorporating species-specific protective indices (Notaro & Paletto, 2012). Results indicate marked contrasts: OBRP shows the highest timber revenue (1.46 M € yr⁻¹) and carbon accumulation (338,000 € yr⁻¹), reflecting rapid growth and active harvesting, whereas SNP achieves greater per-hectare carbon value (1,174 € ha⁻¹ yr⁻¹) and stronger slope stabilisation (389,000 € yr⁻¹), owing to rugged terrain, older stands and long-standing protection. Service-specific rankings reveal trade-offs: larch optimises timber but offers limited carbon, spruce balances timber yield and stability, while mountain pine maximises carbon retention with negligible market return. Provisioning services appear more vulnerable to price oscillation and extreme events, as evidenced by losses after storm Vaia (Laurin *et al.*, 2021), whereas regulating functions show higher persistence, underlining their role as “natural insurance”. Sensitivity analyses demonstrate that carbon price assumptions, discount rate and hazard-class thresholds substantially affect monetary estimates (Häyhä *et al.*, 2015; Richards & Stokes, 2004).

Beyond quantitative results, our findings highlight the multifunctionality of Alpine forests, where ES synergies and trade-offs stem from stand structure, hazard exposure, governance instruments and socio-cultural preferences. Sustainable management should integrate adaptation to climate extremes, prevention of mass-movement risks, and revenue diversification, encouraging mixed stands, structural complexity and natural regeneration to safeguard co-benefits for residents, downstream water users and wildlife (Munang *et al.*, 2013). Embedding ES accounting into forest planning, protected-area strategies and payment schemes could align conservation with economic opportunities and contribute to EU biodiversity and climate neutrality targets. Future research should enlarge the portfolio to cultural, recreational, biodiversity and

cryosphere-related services, employing high-resolution remote sensing, participatory mapping and dynamic modelling to inform adaptive governance and equitable benefit-sharing in European mountain landscapes.

Ultimately, by explicitly recognising the interconnectedness of biophysical processes, market dynamics and societal values, this study demonstrates that embedding a robust and transparent valuation of multiple forest ecosystem services into long-term conservation and management strategies is essential not only to safeguard carbon storage, timber revenues and natural hazard mitigation, but also to strengthen the social legitimacy of protected areas, enhance adaptive capacity to climate change and extreme events, and ensure that the benefits derived from mountain forests are equitably shared among present and future generations.

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Dal rischio all'opportunità: strategie per evitare l'estinzione locale di Phengaris alcon

Abstract. The butterfly *Phengaris alcon* feeds on *Gentiana pneumonanthe* during its larval stage and has an obligate myrmecophilous parasitic relationship with *Myrmica* ants. A three-year study in Val Grande National Park (NW Italy) assessed the effects of climate change and management on the butterfly and its host plant to identify strategies for conservation and climate change mitigation. Methods included mark-release-recapture and phenological and water potential assessments. Results revealed a small, unstable population (25-105 individuals), ~200 host plants and an average 13-day phenological mismatch. Overall, the study shows that an experimental management plan, currently in progress, can enhance host plant availability and help preserve *P. alcon* at the southern edge of its range.

Riconoscendo gli ecosistemi come reti complesse di interazioni, è essenziale valutare gli impatti del cambiamento climatico e dell'uso del suolo sulla biodiversità all'interno di un quadro ecologico. Tale complessità deve essere considerata nelle strategie di conservazione per habitat minacciati e specie con capacità di dispersione limitata (de Chazal & Rounsevell, 2009; Oliver & Morecroft, 2014; Wallisdevries & Swaay, 2006). Nel nostro studio abbiamo cercato di investigare questo aspetto considerando il sistema *Phengaris alcon* (Denis & Schiffermüller, 1775) - *Gentiana pneumonanthe* (L.) - *Myrmica* spp. (Latreille, 1804). La farfalla *P. alcon* è classificata come “Quasi minacciata” in Europa e “Vulnerabile” in Italia (Bonelli *et al.*, 2018; Van Swaay *et al.*, 2010). La specie rientra nel complesso non separabile da *Phengaris rebeli* (Hirschke, 1904) (Balletto *et al.*, 2014; Als *et al.*, 2004). È un lepidottero monofago e univoltino, con periodo di volo da metà luglio a fine agosto (Corezzola *et al.*, 2012), e con ciclo biologico mirmecofilo obbligato (Fiedler, 1991). Le femmine depongono le uova esclusivamente sui boccioli di *G. pneumonanthe* che si trovano in determinate condizioni fenologiche, ritenute ottimali per garantire la fitness e la sopravvivenza delle larve che si nutrono dell'ovario del fiore (Cerrato *et al.*, 2016). L'habitat è rappresentato da prati umidi e torbiere, dominati da *Molinia* Schrank, generalmente al di sotto dei 1000 m s.l.m. (Corezzola *et al.*, 2012), in cui la pianta nutrice è abbondante (Berezki *et al.*, 2005; Küer & Fartmann, 2005).

Phengaris alcon è associata a diverse specie di formiche del genere *Myrmica*: *M. ruginodis* (Nylander, 1846) rappresenta l'ospite principale in molte regioni, ma vengono utilizzate anche *M. scabrinodis* (Nylander, 1846) e *M. rubra* (Linnaeus, 1758) (Maes *et al.*, 2024). In Italia la distribuzione è limitata alla Pianura Padana, margine meridionale del suo areale, con poche popolazioni residue: sono segnalate 30 popolazioni, di cui una probabilmente estinta, 15 da confermare e 14 confermate, 8 delle quali in Piemonte (Corezzola *et al.*, 2012; Cerrato *et al.*, 2016). Questo complesso sistema ecologico, basato su interazioni altamente specializzate tra farfalla, pianta nutrice e formiche ospiti, rende la specie particolarmente vulnerabile alla frammentazione degli habitat di prateria umida e agli effetti del cambiamento climatico, che incidono sia sulla fenologia della genziana sia sulla disponibilità idrica dei siti.

Nel 2019 è stata scoperta una nuova popolazione di *P. alcon* e *G. pneumonanthe* all'interno del Parco Nazionale Val Grande, situato nel Piemonte nord-occidentale (R. Dellavedova, A. Antonietti, A. Mosini, S. Basalini). Tale evento ha dato avvio a un progetto di ricerca triennale con l'obiettivo di valutare l'impatto del cambiamento climatico e della gestione del sito sulla sopravvivenza della farfalla e della sua pianta nutrice. Per affrontare la complessità del sistema oggetto di studio, è stato adottato un approccio integrato che ha compreso la cattura-marcatura-ricattura degli adulti di *P. alcon*, il censimento e l'analisi fenologica e fisiologica di *G. pneumonanthe* con particolare attenzione al potenziale idrico, il rilievo fitosociologico della vegetazione presente nel sito, nonché il censimento dei nidi e la determinazione delle specie di *Myrmica* spp. presenti nel sito.

I dati raccolti tra il 2022 e il 2024 hanno mostrato forti fluttuazioni della popolazione di *P. alcon*: N = 105 individui marcati nel 2022, N = 25 nel 2023 e N = 74 nel 2024. La disponibilità della pianta nutrice è risultata limitata, con circa 200 individui distribuiti in modo discontinuo e sottoposti a forte competizione con le specie dominanti come *Pteridium aquilinum* (L.) Kuhn, *Calluna vulgaris* (L.) Hull e *Molinia arundinacea* Schrank. Le misurazioni del potenziale idrico effettuate nel 2023 non hanno rilevato stress severi, con valori al di sopra della soglia critica (-1 MPa). Inoltre, è stata osservata un'asincronia fenologica di circa 13 giorni in media tra la curva di volo della farfalla e il numero di boccioli idonei alla deposizione delle uova. Infine, sono state identificate *M. sabuleti* e *M. scabrinodis* come specie presenti nell'area di studio, con una densità di nidi più elevata nelle aree sottoposte a sfalcio (0.18 nidi/m²) rispetto a quelle non sfalciate (0.11 nidi/m²).

I risultati indicano che la popolazione in esame di *P. alcon* è soggetta a forti fluttuazioni ed è a rischio di estinzione locale, ma suggeriscono anche che *G. pneumonanthe* mostra una certa tolleranza alla recente diminuzione delle precipitazioni medie nel periodo estivo. Da questi dati emerge la necessità di un piano di gestione dinamico, mirato e da mantenere nel tempo. Per questa ragione, sono state eseguite prove di gestione su quadrati sperimentali, che comprendono lo sfalcio periodico della vegetazione di competizione, semina *in-situ* della genziana e trapianti di esemplari localizzati in aree sottoposte a calpestio e di plantule ottenute da crescita *ex-situ*. Ad oggi, i risultati appaiono promettenti e confermano come la sopravvivenza di *P. alcon* sia legata a un equilibrio ecologico delicato e complesso. Allo stesso tempo, evidenziano come

interventi di gestione dinamica possano fornire strumenti concreti per preservare nel tempo la farfalla, la sua pianta nutrice e l'habitat prativo umido che li sostiene, contribuendo anche a mitigare gli effetti del cambiamento climatico.

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Contrastare la perdita di biodiversità nel comparto avicolo attraverso la valorizzazione zootecnica di Razze Avicole autoctone: il progetto BRAvi

Abstract. *In Italy, small populations of local breeds still exist, and conservation programmes have been carried out since year 2000, but the impact of local breeds on poultry product market is still negligible. The BRAvi project, funded by Regione Lombardia within the National Strategic Plan of PAC 2023-2027 - Action SRH04 - Communication, is aimed to promote rural breeding of local breeds through informative activities for breeders and agents of the food sector. The objectives are: spreading knowledge on conservation programmes through reports and podcasts published on pollitaliani.it; developing efficient communication strategies to promote local breed rearing and enhance the value of products; organizing informative events for breeders in Lombardia.*

Un'ampia variabilità genetica negli animali di interesse zootecnico è indispensabile sia per diversificare i prodotti e soddisfare nuove esigenze del mercato, sia per garantire l'evoluzione dei sistemi produttivi. In avicoltura, la selezione ha promosso l'esclusiva diffusione di ibridi commerciali altamente produttivi, escludendo completamente le razze locali. Tuttavia, le linee genetiche commerciali sono caratterizzate da elevata omozigosi e studi scientifici hanno quantificato una perdita del 90% del patrimonio allelico presente in polli autoctoni. Le razze italiane di pollo e tacchino rappresentano ancora oggi un importante patrimonio di biodiversità ed è urgente contrastare la progressiva riduzione numerica delle popolazioni in atto da decenni a causa della loro totale esclusione dal comparto produttivo.

A partire dall'anno 2000, programmi di conservazione di razze avicole italiane sono stati condotti a livello prima regionale e poi nazionale, con il contributo indiretto e diretto di istituzioni universitarie. Le attività di conservazione hanno migliorato la conoscenza relativa alle caratteristiche fenotipiche e genetiche delle razze avicole italiane, oltre ad avere prodotto strumenti utili a migliorare la gestione riproduttiva delle popolazioni. Tuttavia, il contributo delle razze locali al comparto zootecnico rimane irrilevante, come mostrato anche da un recente censimento condotto su tutto il territorio nazionale che ha individuato 121 allevamenti di razze avicole autoctone, dei quali solo 68 ad indirizzo produttivo (carne e uova da consumo).

In questo contesto, si inserisce il progetto BRAvi ammesso a finanziamento nell'ambito del Complemento per lo sviluppo rurale del Piano strategico nazionale della PAC 2023-2027 della Regione Lombardia - Intervento SRH04 - "Azioni di informazione" a giugno 2025. BRAvi ha l'obiettivo di svolgere

un'articolata attività di informazione allo scopo di promuovere la diffusione territoriale dell'allevamento di razze italiane di pollo e tacchino in sistemi rurali a indirizzo produttivo, condizione indispensabile per contrastare la costante perdita di biodiversità del comparto avicolo.

Il progetto BRAvi si rivolge a un nucleo di destinatari variegato e mira a creare un legame dinamico tra valore biologico della biodiversità, valore economico del prodotto e valore ecologico del sistema produttivo integrato. Gli allevatori, gli operatori del settore alimentare (produzioni su piccola scala) e di quello turistico potranno beneficiare dei risultati attesi dal progetto.

Il progetto si articola in tre Obiettivi Specifici. Il primo intende promuovere conoscenza diffusa, non solo accademica, relativa alle attività di conservazione sviluppate a livello nazionale e alle caratteristiche delle risorse genetiche autoctone disponibili nel comparto avicolo. L'obiettivo è perseguito mediante diversi mezzi di comunicazione: a) il portale www.pollitaliani.it, creato per la divulgazione delle attività dei centri di conservazione di razze italiane, continuerà ad essere aggiornato sulle attività dei centri e sulle caratteristiche morfologiche, produttive, riproduttive e genetiche delle popolazioni di razza in conservazione (schede tecniche di razza); b) reports tecnico-divulgativi saranno pubblicati online per evidenziare le potenzialità di utilizzo zootecnico delle razze avicole; c) podcast mirati ad una più facile e immediata divulgazione del significato di conservazione di biodiversità zootecnica saranno prodotti per sensibilizzare il consumatore sulle attività di conservazione e valorizzare i prodotti avicoli da razze locali.

Il secondo obiettivo specifico intende identificare strategie di comunicazione efficaci per promuovere l'allevamento di razze avicole autoctone e valorizzare i loro prodotti. Un'analisi di mercato è pianificata allo scopo di comprendere la percezione del consumatore rispetto al fenomeno della perdita di biodiversità e quali messaggi siano necessari da trasmettere per comunicare l'importanza della conservazione delle razze autoctone.

Il terzo obiettivo specifico intende promuovere l'allevamento di razze avicole autoctone a scopo produttivo sul territorio attraverso incontri informativi con allevatori e aziende agricole dei distretti rurali di Regione Lombardia e dei territori di montagna. In particolare, incontri informativi con allevatori del territorio lombardo saranno pianificati e realizzati con il supporto di Enti rappresentativi di comunità territoriali, come il Distretto Neorurale delle Tre Acque di Milano, il Distretto Agricolo della Bassa Bergamasca e l'Università di Montagna UNIMONT, polo UniMi di Edolo.

BRAvi ha durata annuale ed è realizzato da un gruppo di lavoro interdisciplinare che associa competenze zootecniche ed economiche per offrire strumenti di sviluppo concreti al mondo produttivo.

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Hidden aliens: the unseen expansion of non-native conures in Italy

Abstract. *I conuri, pappagalli sudamericani introdotti in Europa tramite il commercio di animali domestici, sono presenti in diverse aree urbane italiane ma poco documentati. Studi condotti tra il 2000 e il 2025 indicano popolazioni riproduttive confermate di *Psittacara leucophthalmus* a Firenze e possibili presenze di *Thectocercus acuticaudatus* a Roma. L'uso di piattaforme di citizen science e osservazioni dirette ha evidenziato una probabile sottostima delle loro popolazioni. I risultati suggeriscono che i conuri possono stabilirsi in ambienti urbani italiani e potenzialmente impattare le specie native, richiedendo quindi monitoraggi sistematici e, eventualmente, strategie di gestione.*

The global movement of people and goods has facilitated the spread of non-native species, with temperate regions providing favorable conditions for establishment (Abellán *et al.*, 2017). Among vertebrates, parrots are widely traded (Cardador *et al.*, 2017): the international pet trade has introduced them worldwide, especially in urban and suburban areas where mild winters and anthropogenic food sources allow survival (Chan *et al.*, 2021, Sánchez-Mercado *et al.*, 2021). Conures, South and Central American parrots encompassing five genera – *Aratinga*, *Cyanoliseus*, *Eupsittula*, *Thectocercus*, and *Psittacara* (Remsen *et al.*, 2013) – are popular pets due to their colorful plumage, social behavior, and adaptability to captivity (Menchetti & Mori, 2014). Despite their widespread ownership, scientific knowledge of conure populations in Italy is scarce, limiting conservation and management strategies (Mori *et al.*, 2013).

To address this gap, we gathered data on the presence, reproductive success, and habitat preferences of non-native conures in Italy from 2000 to 2025. A systematic literature review was conducted using Scopus, Web of Science, and Zoological Record, complemented with unpublished observations, citizen-science platforms (iNaturalist, Ornitho), social networks (Facebook, Instagram), image-hosting websites (Flickr, Pinterest), and YouTube. Observers were contacted to verify sightings and provide geographic coordinates. Additionally, monthly local sunset counts during the breeding season (March-May) were conducted to assess population trends.

Findings reveal that conures are present but underreported. The only peer-reviewed record documents a single breeding event of the blue-crowned conure (*Thectocercus acuticaudatus*) near Rome in 2013 (Mori *et al.*, 2013). Other observations include Nanday conures (*Aratinga nenday*) in Naples, Vecchiano, and Milan, a *Cyanoliseus patagonus* in Ladispoli in 2022, and a sun conure (*Aratinga solstitialis*) in Rome in 2024, likely escaped pets. Small groups of blue-crowned conures were observed in Rome, without evidence of reproduction, whereas in Florence the white-eyed conure (*Psittacara leucophthalmus*) has established a confirmed breeding population in the urban park “Le Cascine”, increasing from nine individuals in 2022 to 14 in 2024, reflecting a slow but steady population growth (Fig. 1). Globally, blue-crowned conure populations establish near abundant alien parrot species, suggesting facilitation mechanisms that may similarly support survival in Italy (Ancillotto *et al.*, 2016). Frequent misidentifications on citizen-science platforms indicate that conure populations may be more widespread than currently recognized.

These observations underscore the previously overlooked presence of conures in Italy and highlight the need for systematic monitoring. The establishment of breeding populations in urban environments demonstrates that conures can sustain and expand under favorable conditions. Potential ecological impacts include competition with native species, habitat alteration, and disease transmission (Pruett-Jones, 2021; Radford & Penniman, 2014). Proactive management strategies are recommended to prevent uncontrolled expansion. Future research should focus on long-term population trends, interspecific interactions, and ecological consequences of conure establishment in Italy.

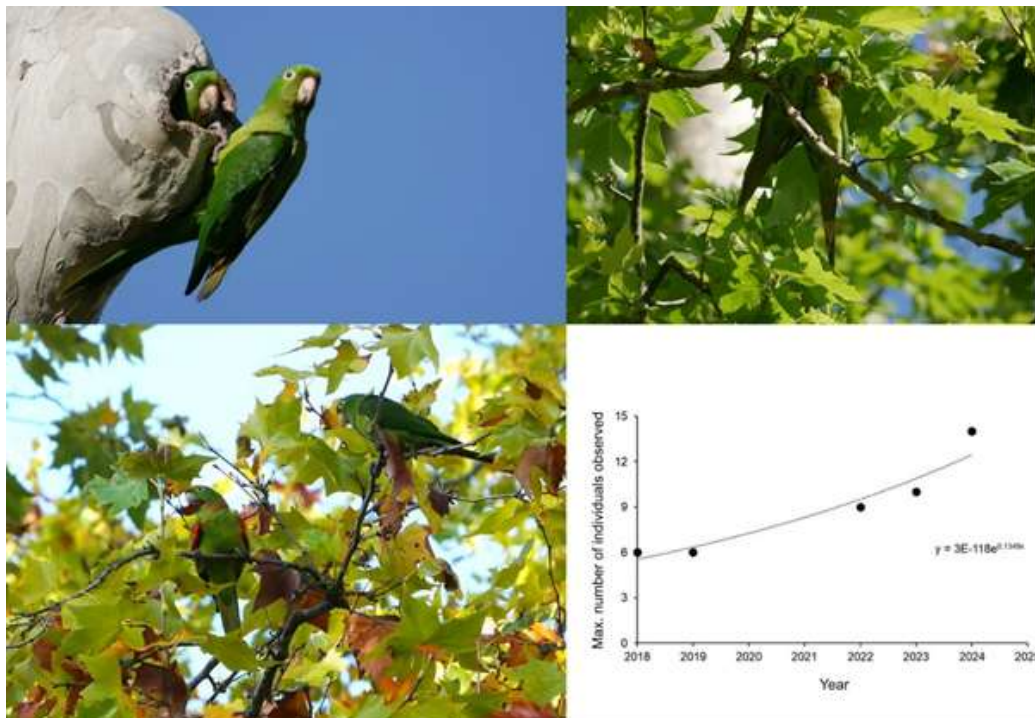


Figure 1 - Breeding white-eyed conures in Florence (photo Giovanni Ciattini) and local population trend, based on local bird counts

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Strumenti partecipativi per la restaurazione ecologica: il ruolo della citizen science nella Nature Restoration Law

Abstract. *The EU Nature Restoration Law (2024/1991) sets binding targets to restore degraded ecosystems. Citizen science is a key tool to support data collection and public engagement. In 2024, the Citizen Science Giovani group launched a national survey targeting young people (ages 25-35) to assess knowledge, needs, and interest in citizen science. With 108 responses, the results reveal high awareness, strong motivation, and key barriers such as lack of funding, training, and institutional support. Findings highlight the role of youth in participatory research and the need to formally recognize citizen-generated data as valuable for ecosystem monitoring under the new EU law.*

La Nature Restoration Law (Regolamento UE 2024/1991), approvata nel 2024, rappresenta un pilastro del Green Deal europeo e delle strategie comunitarie per contrastare la perdita di biodiversità e mitigare gli effetti del cambiamento climatico (Council of the EU, 2024). Essa definisce obiettivi vincolanti per il ripristino degli ecosistemi degradati, la tutela di habitat naturali e agricoli, l'aumento della biodiversità urbana e la resilienza complessiva degli ecosistemi europei. Per raggiungere traguardi tanto ambiziosi sono necessari strumenti capaci di fornire dati capillari e affidabili, ma anche di coinvolgere direttamente i cittadini in un percorso di consapevolezza e partecipazione attiva. In questo contesto la Citizen Science si

configura come strumento essenziale, in grado di implementare e contribuire alla ricerca scientifica attraverso la sua pianificazione, la raccolta e l'analisi dei dati, promuovendo al contempo cambiamenti culturali e sociali mediante l'adozione di buone pratiche e comportamenti virtuosi.

Per comprendere il ruolo che le nuove generazioni possono giocare nello sviluppo della Citizen Science in Italia, il gruppo *Citizen Science Giovani*, parte di *Citizen Science Italia*, ha realizzato un questionario online indirizzato a studenti universitari e giovani ricercatori compresi tra i 25 e i 35 anni. Nel 2024 è stato sviluppato un questionario online, diffuso tramite reti universitarie, associazioni e canali social, con l'obiettivo di raccogliere informazioni su conoscenze, percezioni e fabbisogni dei giovani nei confronti della scienza partecipata. Il questionario era rivolto a studenti universitari, dottorandi, neolaureati, giovani ricercatori e volontari, ma aperto anche a cittadini non direttamente coinvolti in progetti di ricerca. Alla data di settembre 2025 sono state raccolte 108 risposte, che costituiscono uno dei primi dataset organici a livello nazionale su questo tema.

I risultati preliminari mostrano un campione con età media di circa 35 anni e una distribuzione di genere equilibrata: 48.1% donne, 47.2% uomini, 3.7% non binario, 0.9% preferisce non rispondere. Il livello di istruzione è particolarmente elevato, con il 41.7% in possesso di una laurea magistrale, il 31.5% di un titolo post-laurea (master o dottorato), il 12% di una laurea triennale e l'8.3% di un diploma di scuola superiore. L'ambito di formazione prevalente è quello delle scienze naturali (47.2%), seguito da ingegneria e tecnologia (10.2%), discipline umanistiche e artistiche (6.5%), scienze agrarie e veterinarie (4.6%) e scienze sociali (2.8%). Dal punto di vista della conoscenza, oltre il 90% dei rispondenti ha saputo identificare correttamente la definizione di Citizen Science e circa il 72% la considera utile per le proprie attività di ricerca o per quelle delle associazioni di appartenenza. Il 65% ha espresso disponibilità a partecipare a progetti futuri. Gli ambiti di maggiore interesse comprendono la biodiversità, la conservazione, il monitoraggio ecologico e la tutela della fauna selvatica, con un interesse crescente anche verso applicazioni in contesti urbani, sanitari e sociali.

Tra le barriere segnalate, il 60% ha indicato la scarsità di finanziamenti come principale ostacolo, il 55% la necessità di formazione specifica e il 50% la mancanza di affiancamento da parte di esperti. Ulteriori criticità riguardano la difficoltà di integrare i dati raccolti dai cittadini nei sistemi ufficiali di monitoraggio e il limitato riconoscimento istituzionale delle iniziative partecipative. Per quanto riguarda gli strumenti di comunicazione, i più richiesti risultano podcast, webinar e social media, a conferma della centralità dei canali digitali per raggiungere e coinvolgere efficacemente i giovani.

L'alto livello di istruzione e la prevalenza di background scientifici tra i rispondenti, indicano la necessità di divulgare maggiormente la funzionalità della Citizen Science anche ad ambiti umanistici. In secondo luogo, l'interesse verso la Citizen Science appare diffuso e accompagnato da un chiaro desiderio di partecipazione, ma rischia di rimanere inespresso se non supportato da risorse adeguate, percorsi di formazione strutturati e piattaforme di coordinamento. Infine, emerge la necessità di riconoscere formalmente il valore dei dati prodotti dai cittadini, affinché possano contribuire agli indicatori di monitoraggio richiesti dalla Nature Restoration Law.

L'indagine presenta inevitabili limiti: il campione non è rappresentativo dell'intera popolazione giovanile italiana, la raccolta delle risposte online ha favorito la partecipazione di persone già collegate a reti accademiche o associative, e la natura esplorativa del questionario limita la generalizzabilità dei risultati. Tuttavia, questi limiti sono compensati dal valore pionieristico dello studio, che fornisce una base conoscitiva inedita e apre la strada a ricerche più ampie e rappresentative.

Il confronto con altre esperienze europee è illuminante. In Germania, Olanda e Spagna la Citizen Science è stata integrata nei programmi nazionali di monitoraggio della biodiversità e della qualità ambientale, con benefici sia scientifici sia educativi. A livello globale, la scienza partecipata contribuisce direttamente a diversi Obiettivi di Sviluppo Sostenibile dell'Agenda 2030, in particolare quelli dedicati alla lotta al cambiamento climatico (SDG 13), alla vita sott'acqua (SDG 14) e alla vita sulla terra (SDG 15). Anche l'Unione Europea, attraverso la Biodiversity Strategy for 2030 e il Green Deal, ha ribadito l'importanza di mobilitare tutte le risorse disponibili, incluse quelle derivanti dalla partecipazione civica (Council of the EU, 2024). In questo contesto, la Citizen Science si configura non solo come uno strumento complementare alla ricerca scientifica istituzionale, ma anche come un elemento chiave per promuovere una governance ambientale più inclusiva e resiliente, in linea con i principi della Restoration Law.

In conclusione, i risultati dell'indagine promossa da *Citizen Science Giovani* offrono una fotografia inedita del rapporto tra giovani e Citizen Science in Italia. Essi evidenziano un bacino giovanile ampio, motivato e competente, ma anche fabbisogni concreti che devono essere affrontati per trasformare l'entusiasmo in un contributo stabile e strutturato. Investire in formazione, mentoring, piattaforme digitali e risorse economiche non significa soltanto adempiere agli obblighi previsti dalla Nature Restoration Law, ma anche consolidare una cultura della partecipazione e della responsabilità condivisa, indispensabile per garantire la tutela della biodiversità e la resilienza degli ecosistemi europei nel lungo periodo.

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The ice has gone, and now?

Ground beetle colonisation after a glacier disappearance

Abstract. La fusione dei ghiacciai è una delle conseguenze più evidenti del cambiamento climatico. Dopo il loro ritiro, le piane proglaciali vengono colonizzate da diversi organismi. Tuttavia, la loro fusione rappresenta, al contempo, una minaccia per le specie criofile che vivono al margine di ghiacciai e nevai. Questo lavoro analizza la colonizzazione dei coleotteri carabidi lungo la piana proglaciale dell'ex Ghiacciaio del Trobio, estinto nell'estate del 2023. Durante l'estate 2025, utilizzando trappole a caduta e ricerche a vista, abbiamo investigato le comunità di carabidi nei diversi stadi di ritiro del ghiacciaio e monitorato la distribuzione di *Nebria tresignore*, specie criofila e stenoendemica delle Alpi Orobie. I dati verranno confrontati con quelli di Tampucci *et al.* (2015).

As a consequence of climate change, most alpine glaciers are facing a severe reduction in their extension, leaving behind them large ice-free areas, called glacier forelands. These forelands are progressively colonized by several micro and macro-organisms, either dispersed from similar nearby environments (e.g. by the wind, flight or walking) or already present for historical and ecological reasons (Hågvar *et al.*, 2020). A so-called colonisation gradient is defined from the almost barren soil recently freed by the glacier, to the quite well-structured ecosystem of the most ancient moraine, that of the Little Ice Age (LIA, ended around 1850 A.D. in the Alps) (Ficetola *et al.*, 2021; Nigrelli *et al.*, 2015). On the other hand, Alpine glaciers' retreat is threatening a wide range of organisms, from bacteria and unicellular algae to arthropods like springtails and beetles, inhabiting glaciers and glaciarets: the so-called "cryophilic species". These species are found only at the immediate proximity of the glacier front and are often endemic of limited sectors of the Alpine Chain (Bonelli *et al.*, 2025). Examining the colonization patterns along glacial forelands is therefore of great ecological, biogeographical and conservational importance. In this context, the peripheral mountain areas, such as the Orobie Alps, are of great interest because of the few remaining glaciers and the high rate of endemism (Lohse *et al.*, 2011; Tampucci *et al.*, 2015).

The present study is focused on the Trobio Glacier foreland, which is located in the Orobie Alps, in the peripheral southern part of the Alpine Chain. The Trobio Glacier has been declared extinct in 2023 (Chiarle

et al., 2024); however, thanks to the oceanic climate and the abundant winter precipitations (Caccianiga *et al.*, 1993), the area is partially covered by residual snow patches during the summer season.

The aim of our work is to provide a more comprehensive view of the establishment and succession of carabid beetles along the Trobio Glacier foreland and compare our data with those previously collected by Tampucci *et al.* (2015) before the complete extinction of the glacier.

We focused on carabid beetles because of their relatively well-known taxonomy and ecology, and for their efficient use as bioindicators of climate and environmental changes (Gobbi, 2020). Insect sampling was performed every three weeks, from July to September 2025. Due to the presence of a micro-endemic ground beetle (*Nebria tresignore*) we performed a different type of sampling, depending on the stage of the glacier chronosequence. A total of eight plots were selected, five of which were previously sampled by Tampucci *et al.* (2015). Each plot corresponded to a specific date of the glacier retreat, encompassing the area from the LIA moraine to the last 2023 ice patch. In six plots out of eight, five pitfall traps, consisting of a plastic cup half-filled with salted water and buried up to the edge, were placed. Due to the marmots and ibexes' disturbance reported by Tampucci *et al.* (2015), we avoided filling the pitfall traps with vinegar. As a complementary survey to that of pitfall trapping, we did 20 minutes long sessions of capture by hand using an entomological aspirator or soft tweezers. The hand capture was performed in all the plots and was the only methodology used in the youngest two, due to the potential presence of the cryophilic and micro-endemic *N. tresignore*. When possible, hand-captured ground beetles were visually identified at the species level and suddenly released. This enabled us to reduce sampling impact on their populations. A specific separate survey was performed near snow patches to check the presence of *N. tresignore*. The hand-capture was used, and the specimens released after the *in-situ* identification. Soil samples were taken for chemical (pH, carbon and nitrogen content) and physical (soil texture) analysis. Specimens were stored in ethanol (EtOH) and will be identified to the species level using a stereomicroscope and dichotomic keys.

Some of the collected species, like *Carabus castanopterus* and *Pterostichus lombardus*, were endemic to the Southern Alps (Grottolo *et al.*, 2016), which is probably due to their high-elevation distribution, low dispersal abilities, and the restriction to an Alpine region only marginally affected by quaternary glaciations. Following the results of Tampucci *et al.* (2015), we do not expect changes in the type of colonisation pattern (i.e., addition vs. persistence model); however, further analyses will be performed. Indeed, we hypothesize that not all species colonising a given stage are replaced by those arriving later; rather some may persist throughout the glacier foreland.

During the whole sampling period, we observed only two specimens of *N. tresignore* in the two most recent deglaciated plots, characterised by long-lasting snow patches. By comparing these data with those collected by Tampucci *et al.* in 2015 and considering the particularly restrictive ecological niche of the species, we might suppose a general decline of its population, caused by the drastic reduction of the suitable habitat. From preliminary field observations (hand-capture), in the oldest plots of the glacier chronosequence

(from 115 to more than 150 years old) also granivorous species like *Amara quenseli* were present, suggesting a more complex ecosystem structure occurring in the oldest stages of the glacier foreland.

Our preliminary results on the presence and abundance of carabid beetles along the Trobio Glacier foreland allowed us to visualise the concept of “space for time substitution”, and they will be useful to identify possible shifts in the expected colonisation dynamic and pattern. Additionally, our study provides preliminary insights on the current situation of high-elevation beetles facing climate change. Indeed, for some species the glacier retreat will not represent a threat, providing new suitable habitats. However, for few pioneer cold-adapted organisms, it can represent a severe obstacle for survival, with local population extinction to be expected, as could be the case of *N. tresignore* (Gobbi, 2020).

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The concept of stakeholders applied to natural resources: human-wildlife coexistence as a case study

Abstract. *Attraverso la revisione di 136 articoli scientifici pubblicati tra il 2000 e il 2025 sul tema della coesistenza uomo-fauna selvatica, si è tentato di verificare la legittimità dell'adozione del termine "stakeholder", coniato nell'ambito del business management, all'interno del lessico inerente alla gestione delle risorse naturali.*

Efforts towards sustainable management of natural resources should integrate society's concerns and expectations (Kessler *et al.*, 1992) by shifting the perspective on decision-making processes from mere interest-based participation towards collective feelings of responsibility, care, and legitimacy regarding both individuals' and communities' roles and rights (Brosius *et al.*, 1998). It has already been argued that utilising the original attributes of *property* and *action* (Mitchell *et al.*, 1997) to decide whose economic "stake" is relevant enough to be considered a "stakeholder" can undermine the democratic management of natural resources by facilitating the prioritisation of certain people's interests over others' (Matulis, 2014). Moreover, even the definition of the interest itself is still up for debate, with both policymakers and academics arguing in favour or against the inclusion of values other than the strictly economic ones (Pearce, 1989). Thus, we decided to analyse the evolution of the stakeholder concept using the scientific literature on human-wildlife conflicts as a case study, since wildlife is an emblematic example of a good with both consumptive and non-consumptive values, to catalogue the interpretations of "stake" adopted by academia and how they directly influence the identification and involvement of people.

Our main assumptions concern, first of all, the relation between the categories of stakeholders and the geographical and socio-economic context, and, most importantly, the theoretical transformation of the concept itself, morphing from a discipline-specific term used in business management (Freeman, 1984) to an ever-present buzzword with general agreement on the abstract notion it represents but unresolved disagreement about its practical application (Cornwall, 2010). Indeed, at present, no unambiguous definition of stakeholders in relation to natural resources exists. By discussing the semantic progress observed in the literature, we hope to highlight the need for a definitive cementation of the concept, with well-established and codified criteria to ensure transparent and objective decision-making processes.

A scoping review was performed following the protocol defined by Hagen-Zanker and Mallet (2013) and the PRISMA-ScR guidelines (Tricco *et al.*, 2018). Starting from 1794 records, two screenings were performed following specific criteria. Descriptive statistics of the use of the word “stakeholder”, stakeholder categories, geographical locations, protection status of the study area, wildlife, type of conflict, and mitigation strategies were performed on 136 papers using IBM SPSS Statistics 29.0.1.0.

The term “stakeholders” was used on average 21 times per paper, with a maximum of 145 times and a minimum of 1, up to ten times more often in the main body of the articles than the abstract and twenty times more than keywords and title. Fig. 1 represents the frequencies in the papers and the relative sections.

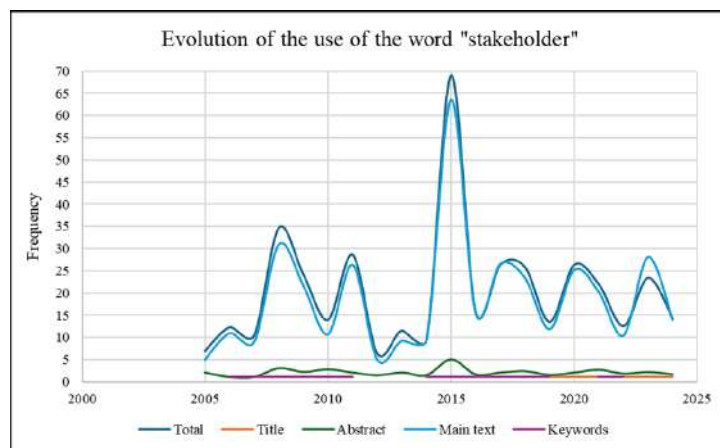


Figure 1 - Trends in the use of the word “stakeholder”

The peak in 2015, corresponding to 69 times on average among three papers, is due to the overzealous use of the term in two of them (115 and 84 times) that have no similarities in terms of authorship, study area, methodology, or any other characteristics. The use of the term across the continents followed non-linear trends, with peaks and valleys alternating with intervals different in both number and duration, comparing, for example, Europe and America, and periods during which no use was recorded, like for Oceania and Africa (Fig. 2).

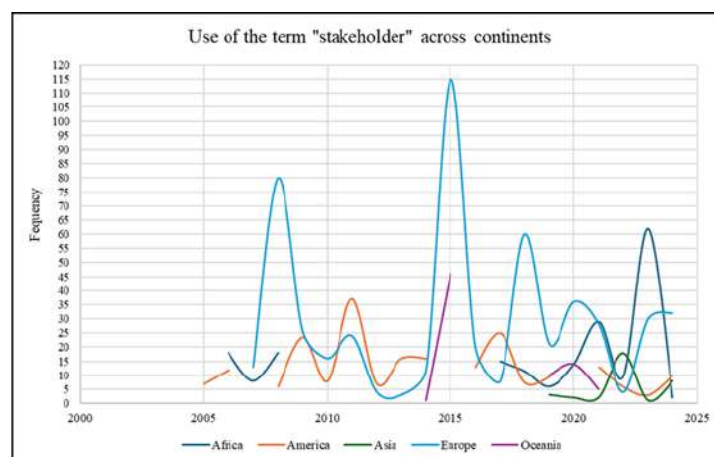


Figure 2 - Trends in the use of the word “stakeholder”

Only 48 of the 136 papers included an explicit definition of “stakeholders”, ranging from a simple clarification of the type of economic interest held by the identified categories to complex and references-rich paragraphs debating the meaning of “stake” in that specific context, with one even including the animals themselves. Studies conducted in Europe and America both contained more definitions than the other continents combined. Noteworthy is also the fact that the majority of them were concentrated in papers published from 2011 on, possibly indicating the need to reiterate the meaning of the term after a period in which it had been taken for granted after being absorbed in the lexicon, or, more coherently with recent developments in wildlife management, to explicitly express values other than the canonical ones.

A detailed textual analysis, including word frequencies and associations, will be performed following a rigorous protocol (drawing inspiration from the works of Di Bona *et al.*, 2023 and Hallberg & Salimi, 2020) to measure the definitions’ semantic distance from Freeman’s. Overall, 17 categories of stakeholders were identified, summarised in Tab. N 1.

Table 1 - Frequency of involvement in the studies and sample size of the stakeholder categories

Stakeholder categories	Africa		America		Asia		Europe		Oceania		Total	
	n° papers	n° subjects	n° papers	n° subjects	n° papers	n° subjects	n° papers	n° subjects	n° papers	n° subjects	n° papers	n° subjects
Activists	9	429	15	39	4	19	20	618	3	20	51	1125
Animals	0	0	0	0	0	0	1	0	0	0	1	0
Crop farmers	6	115	11	1230	3	483	13	1990	0	0	33	3818
Hunters/fishers	5	1241	20	1960	3	611	24	2394	4	46	56	6252
International authorities	0	0	0	0	0	0	1	0	0	0	1	0
Land/wildlife managers	8	47	23	77	2	35	20	991	5	48	58	1198
Landowners	1	597	7	11	2	918	11	847	1	0	22	2373
Livestock/fish farmers	6	108	18	757	3	24	17	676	3	32	47	1597
Local authorities	3	6	13	41	1	4	12	19	3	0	32	70
Rural areas residents	10	1163	29	5691	6	1018	18	4089	3	126	66	12087
National authorities	5	27	12	15	1	0	12	20	1	0	31	62
Native peoples	1	0	5	155	2	292	3	26	0	0	11	473
Policymakers	1	0	2	1	1	0	1	0	0	0	5	1
Scientists/researchers	2	2	10	24	2	12	7	28	2	0	23	66
Tourism professionals	4	42	5	8	1	3	5	72	4	23	19	148
Tourists/recreationists	3	26	7	2531	0	0	2	443	0	0	12	3000
Urban residents	1	1608	12	3605	2	0	8	1977	0	0	23	7190
TOTAL	65	5411	189	16145	33	3419	175	14190	29	295	491	39460

Globally, rural residents were the most considered stakeholders, with 12,087 (31%) subjects, followed by urban residents, with 7190 (18%) individuals (23), and hunters and fishers, with 6252 (16%) subjects. The least featured stakeholders were scientists/researchers and national authorities, with only 66 and 62 (>1%) subjects. In terms of collective sample size, urban residents (1608) and hunters (1241) predominated in Africa, parallel to rural (5691) and urban (3605) residents in America, rural residents (1018) and landowners (918) in Asia, rural residents (4089) and hunters (2394) in Europe, and rural residents (126) and land managers (48) in Oceania. Fig. 3 represents the changes in sample size for each category.

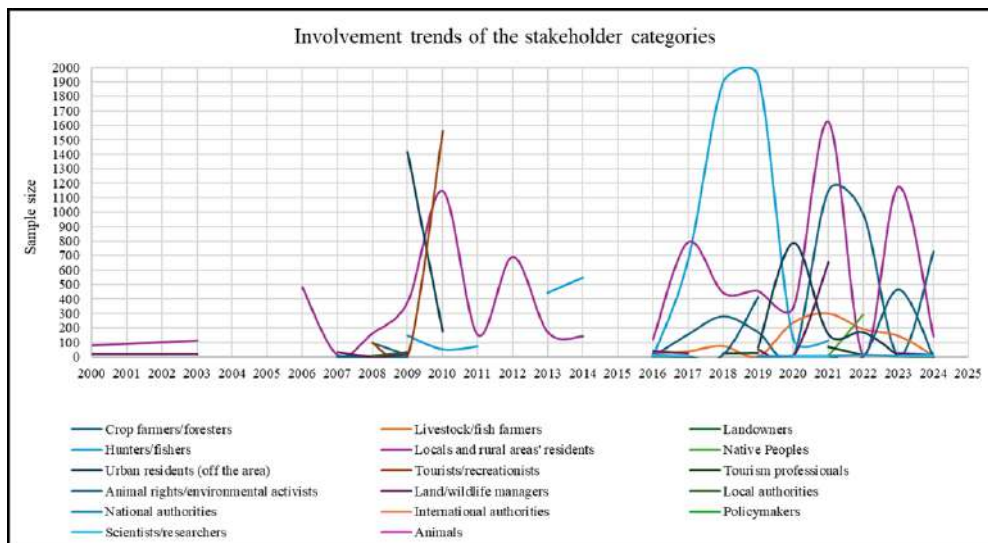


Figure 3 - Involvement of the different stakeholders

Given the ongoing status of the study, we were able to draw only some preliminary considerations. First of all, the inclusion of categories like policymakers and academics in the last 25 years' literature already shows a tacit evolution of the concept towards a less strictly economic meaning, de facto considering other aspects, or at least straying from the fixed attributes of damage/financial gain. Secondly, both time and geographical location appear to significantly influence the types of subjects identified, due, on one hand, to the social, economic, environmental, and political peculiarities of each conflict hotspot, and, on the other hand, to the current debate on the stakeholder theory. Further analyses will be performed to understand the effect of location, protection status of the study area, wildlife, type of conflict, and mitigation strategy on stakeholders' involvement. The primary aim of this research is to establish if the term "stakeholder" is still the most appropriate for the context of natural resources management, given that some alternatives have already been proposed (Decker *et al.*, 2019), at the same time contributing to the discourse about the long-term repercussions of appropriating a specific discipline's lexicon into the common language and the risk of scientific terminology becoming a buzzword.

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EPT taxa in glacier-fed streams: insights from Western Italian Alps

Abstract. Lo studio ha analizzato tre ordini di macroinvertebrati acquatici (Efemeroteri, Plecotteri, Tricotteri) in torrenti alpini dal 2010 al 2022, classificando i siti in 4 classi in base alla percentuale di copertura glaciale sul bacino idrografico. Le comunità appartenenti ai corsi d'acqua maggiormente influenzati dai ghiacciai sono risultate ben distinte dalle altre e associate ad altitudini elevate e basse temperature. Con la riduzione dell'influenza glaciale, è emerso un aumento degli Efemeroteri e un calo della ricchezza dei Plecotteri. I risultati forniscono informazioni utili per una migliore comprensione delle comunità di insetti come sentinelle del cambiamento globale negli ecosistemi fluviali alpini. I prossimi step di ricerca estenderanno la scala temporale e la lista faunistica.

The study focuses on a subset of the macroinvertebrate taxa considered among the most sensitive, Ephemeroptera, Plecoptera, and Trichoptera (EPT), which inhabit glacier-fed streams of the Aosta Valley Region (AVR). The study uses a 13-year monitoring dataset (2010-2022) from the regional environment agency (ARPA AVR). The aim was to compile an inventory of the taxa and then investigate their richness, abundance, composition and distribution across different classes of glacier-fed stream. The study also aimed to identify richness surrogates and indicator taxa in this context. A total of 102 sites belonging to 24 glacial rivers were involved, for a total of 721 observations. These sites were classified using the Catchment Glacier Cover (CGC) method, as described by Bert *et al.*, 2024. Analyses and graphs were processed using R and the following packages: vegan (Oksanen *et al.*, 2022), ggplot2 (Wickham, 2016), the lmerTest R package (Kuznetsova *et al.*, 2017), indicpecies (De Cáceres *et al.*, 2009) and biomonitoR (Laini *et al.*, 2022). The EPT communities comprised a total of 34 taxa: 9 genera were classified for the order Ephemeroptera, 13 for the Plecoptera while 12 families were detected for the Trichoptera. There is evidence of an increase in total family richness as glacial cover decreases, therefore from GH1 to GH4 class (Fig. 1). Instead EPT Family richness and EP genus richness did not show significant differences between classes. Trends in family richness values for each EPT order showed differences among glacial classes with more marked patterns when focusing on Plecoptera (decrease) and Trichoptera (increase) towards streams with less CGC. The community composition analysis *via* nMDS (Fig. 2) showed glacial class as an important factor for the EPT

community. The GH1 class is separated from the others and is associated with highest altitude and lowest temperature. The points of the GH3 and GH4 classes overlapped, stressing some similarity.

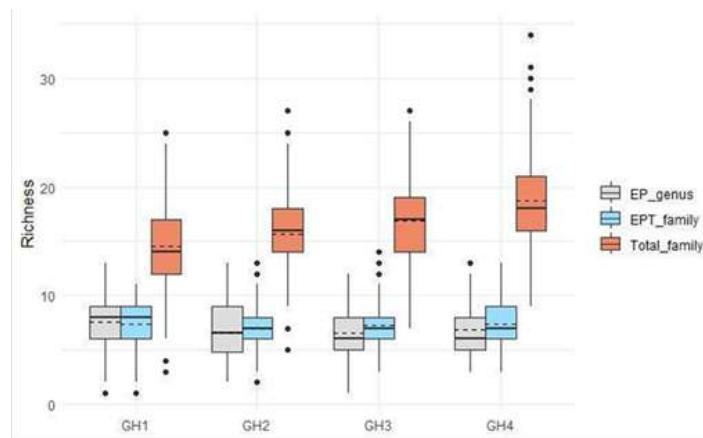


Figure 1 - Box plots showing different richness metrics analysed by glacial class (x-axis): total family richness (in salmon), EPT family richness (in light blue) and EP genus richness (in grey). Median values are represented by a bold horizontal line and mean values by a dashed line

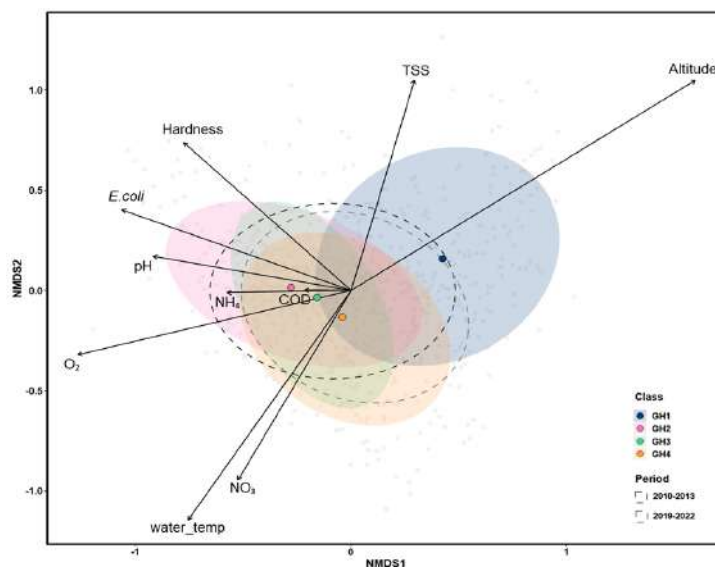


Figure 2 - nMDS plot and envfit output based on glacial classes (GH1 in blue, GH2 in pink, GH3 in green and GH4 in orange). Centroids (bold points) and ellipses (with 80% of the data) are also displayed; dashed ellipses represent the first period (2010-2013, in black) and the second period (2019-2022, in grey)

Indval test (Tab. 1) stressed *Dictyogenus* Klapalek, 1904 (Plecoptera) in streams with higher CGC, whereas the roles of Ephemeroptera and Trichoptera emerged in the other three classes. No indicator taxa have been stressed for the most recent years (2019-2022), except for GH4. This suggests that some EPT assemblages are probably evolving towards more similar communities among glacial classes.

Table 1 - Results of the Indicator taxa analysis for each glacial class; taxa, Stat values and p-values are displayed

Glacial Class	Taxa	Stat value	p-value
GH1	<i>Dictyogenus</i>	0.698	0.001
GH3	<i>Habroleptooides</i>	0.270	0.001
GH4	Philopotamidae	0.385	0.001
	Sericostomatidae	0.306	0.001
	Goeridae	0.206	0.002

When exploring for surrogates, it emerged that Plecoptera family richness generally showed the highest correlation value with EPT family richness, while Trichoptera family richness exhibited the highest values with remaining richness. Both should be stressed as potential indicators for EPT taxa and invertebrate richness, respectively, and considered when looking for regions as richness hotspots.

The results indicated that as the glacial influence decreases, an increase in the total number of invertebrate families is appreciable, this is primarily due to milder environmental conditions and the potential arrival and colonization of diverse taxa. This is also confirmed in other studies by other authors in different geographic contexts (e.g., Brittain & Milner, 2001; Jacobsen *et al.*, 2012; Milner *et al.*, 2017). However, this increasing value (at higher taxonomic level, such as family richness) may mislead environmental conservation policies as it fails to account for the potential “silent” loss of genera and species of significant conservation concern. EPT from GH1 would benefit from specific in-depth research, given their well-defined cluster separation and association with specific environmental factors (e.g., temperature and altitude). Overall, these findings provide a valuable starting point for better integrating and understanding EPT communities as sentinels of global change in alpine stream ecosystems. Future research and challenges should necessarily focus on periodically and constantly updating this information while simultaneously obtaining robust information at genus and species level. This approach will help identify specific indicators and enhance biodiversity inventories for these fragile and rapidly changing ecosystems. Most of these results have been recently published (July 2025) in *Aquatic Insects* (<https://doi.org/10.1080/01650424.2025.2525220>). The research is ongoing and will consider an additional two years of monitoring (2010-2024), attempting to identify temporal trends by considering the seasonal effect and all available taxa of macroinvertebrates. Preliminary results suggest a decline in abundance values, in particular for aquatic insects. Moreover, further taxonomic and functional metrics will be tested.

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MOBICOS: The Out-of-the-Box mesocosm facility for aquatic ecology

Abstract. *La comprensione dei meccanismi alla base di processi ecosistemici fondamentali nei fiumi è spesso limitata dal fatto che gli esperimenti di laboratorio mancano di realismo ambientale, mentre in campo è difficile isolare relazioni causa-effetto a causa della co-presenza di molti fattori. Per superare questi limiti, il Centro Helmholtz ha realizzato la struttura sperimentale MOBICOS nel bacino del fiume Bode (Germania). L'acqua del fiume viene convogliata in delle canalette che simulano piccoli corsi d'acqua e che vengono rapidamente colonizzati dai microrganismi. La struttura è stata utilizzata per oltre dieci esperimenti atti alla comprensione delle alterazioni nei meccanismi di funzionamento del biofilm bentonico e iporreico quando esposto a vari stressori antropici.*

Our understanding of the mechanisms underlying essential ecosystem processes in streams, such as nutrient attenuation, is often limited by the investigative approaches we use. On the one hand, experiments conducted in laboratories often lack realistic field conditions making it difficult to upscale findings. On the other, cause-effect relationships can be difficult to infer in field conditions because of the simultaneous occurrence of multiple factors. To address this challenge and conduct more realistic experiments, the Helmholtz Center for Environmental Research established the MOBICOS experimental facility. The MOBICOS facility consists of six containers located in the Bode catchment area (Harz, Germany) that function as stream bypasses. Submerged pumps draw water from the stream and direct it into the containers, which contain artificial channels designed to replicate small streams. By receiving flowing stream water, these channels are rapidly colonized by microorganisms from the stream. The facility has served over 10 manipulative experiments covering various subjects related to microbial stream ecology.

The major advances have been in mechanistically understanding:

1. The effects of anthropogenic stressors on nutrient dynamics in the benthic and hyporheic zone. Specifically, fine sediment generally reduced benthic-hyporheic exchange but had limited impact on NO₃⁻ and DOC dynamics in flumes mimicking agricultural stream conditions (Sunjiiidmaa *et al.*, 2022). In contrast, in flumes mimicking reference conditions, fine sediment likely stimulated denitrification in the hyporheic zone (Pasqualini *et al.*, 2024). In both studies, nutrient cycling was

primarily constrained by low DOC availability, with molar ratios indicating strong carbon limitation for nitrogen uptake and partial limitation for phosphorus uptake.

2. The effects of light and biofilm age on nutrient and DOM dynamics, with notable differences between day and night. Daytime nitrate uptake by younger biofilms increased with light but ceased in darkness. Older biofilms showed greater nitrate uptake during both day and night, though less at night. They also released SRP and humic-like DOM during the day. In contrast, protein-like DOM fractions were consistently consumed by both biofilm ages, regardless of light or time. These results highlight the critical role of nighttime nutrient and DOM processing and the combined influence of light and biofilm development stage on stream biogeochemistry (Sunjidmaa *et al.*, 2025).
3. The effect of short- and long-term phosphorus (P) loading on benthic biofilms P entrapment. Short-term P inputs are mainly handled through intracellular uptake. In contrast, long-term or high P inputs reduce intracellular uptake and increase extracellular P entrapment, lowering overall P removal efficiency. This shift may weaken the ability of aquatic ecosystems to manage P inputs and increase the risk of eutrophication (Perujo *et al.*, 2024).
4. The effect of bioavailable dissolved organic carbon on biofilms P entrapment. Low DOC limits biofilm growth, bacterial density, P entrapment, and alkaline phosphatase activity. Higher DOC increases biofilm biomass and bacterial density, enhancing intracellular P entrapment and enzyme activity at moderate P levels. Extracellular P entrapment is not affected by DOC. These findings show that DOC availability plays a key role in benthic P cycling and river ecosystem functioning (Perujo *et al.*, 2024).
5. The effect of C:N:P stoichiometry on substrate metabolism in the benthic and hyporheic zone. Main results indicate that when resource C:N:P ratios approached those of microbial biomass, functional diversity in substrate metabolism increased – most notably in hyporheic biofilms. These biofilms shifted toward using more N-rich and fewer P-rich substrates, especially during early biofilm development. Although hyporheic biofilms were not directly affected by light, autotrophic activity in benthic biofilms indirectly influenced them: light altered bacterial density and the metabolism of phenolics, amino acids, and carbohydrates in the hyporheic zone. In benthic biofilms, only carbohydrate use was light-sensitive. These findings highlight strong benthic-hyporheic coupling and suggest that changes in nutrient supply and light (e.g. from clear-cutting) can significantly affect microbial nutrient cycling in streams (Große *et al.*, 2025).
6. The effect of different stoichiometric ratios (350:940:1 vs. 73:40:1) and light (20 vs. 90 $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$) on benthic and hyporheic biofilms (C:N:P). The biofilms composition shifted in response to altered water chemistry and light conditions. Benthic nitrate-N uptake increased with labile DOC and P additions, while light had minimal effect. Despite increased nitrate-N uptake under more balanced DOC and P supply, nitrogen was more rapidly lost from biofilm biomass, resulting in similar N retention times across treatments. Macronutrient stoichiometry in the water column – not light

availability – is the dominant control on nitrate-N cycling in stream biofilms, with implications for managing N retention in anthropogenically impacted streams (Große *et al.*, 2025).

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Il recupero degli habitat palustri: un modello di conservazione della biodiversità vegetale nella Riserva Naturale Torbiere del Sebino (Lombardia, Italia Settentrionale)

Abstract. *The restoration of wetland habitats in the Torbiere del Sebino Nature Reserve (Lombardy, Italy) has proven effective in reversing a long-term decline in plant biodiversity. Between 2023 and 2024, ponds and ditches were restored, followed by floristic monitoring in 2024-2025. A total of 21 wetland species of conservation interest were recorded, including three new site reports and nine reappeared taxa, some spontaneously and others reintroduced. Compared to a drop from 25 taxa in 1998 to only 7 in 2020, conservation measures have led to a marked recovery, confirming the ecological responsiveness of wetlands and the strategic role of the reserve in safeguarding plant biodiversity.*

La riqualificazione degli ecosistemi, con particolare attenzione al ripristino delle zone umide, rappresenta, a fronte di pressioni e minacce crescenti, un elemento fondamentale per la salvaguardia della biodiversità. Tale obiettivo è sostenuto da interventi di conservazione e gestione attiva degli ambienti palustri presenti all’interno della Riserva Naturale Torbiere del Sebino (Lombardia) - ZSC/ZPS IT2070020.

Nel periodo compreso tra ottobre 2023 e febbraio 2024, sono stati ripristinati stagni e fossi precedentemente interrati nell’area protetta. A seguito degli interventi gestionali, sono state condotte campagne mirate di monitoraggio floristico (specie vegetali vascolari e alghe caroficee) nel periodo primaverile-estivo 2024-2025, indagando i siti di ripristino e le fasce palustri adiacenti caratterizzate da substrato torboso. La nomenclatura delle specie vascolari è conforme alle checklist italiane di Bartolucci *et al.* (2024). La nomenclatura delle caracee è conforme a Bazzichelli & Abdelahad (2009).

Il trend di conservazione delle specie vegetali palustri è stato ottenuto analizzando, per il periodo 1998-2018, la bibliografia disponibile (Ramsar Informations Sheet, Formulario Standard e report botanici annuali), e per il periodo 2019-2025, i risultati dell’attività diretta di monitoraggio botanico ordinario.

Le specie vegetali palustri considerate di interesse conservazionistico sono state individuate sulla base di differenti criteri, al fine di delineare con maggiore precisione le priorità di tutela. In particolare, sono state incluse: (A) le specie inserite nella Lista Rossa Nazionale; (B) le specie rare a livello nazionale o regionale, la cui presenza è oggi limitata a pochi siti; (C) le specie considerate di particolare valore per il contesto

geografico planiziale a diffusione maggiore nelle aree montane ed alpine, in quanto testimonianze residue di comunità vegetali tipiche attualmente fortemente frammentate o in regressione nella pianura lombarda. Questo approccio ha permesso di attribuire un valore ecologico differenziato alle entità floristiche rilevate, rafforzando le basi scientifiche per la gestione e il monitoraggio a lungo termine degli habitat palustri.

Complessivamente, a seguito degli interventi conservazionistici, sono state rilevate nel biennio 2024-2025, 21 specie palustri di interesse conservazionistico: 2 alghe caroficee e 19 piante vascolari (Tab.1). Di queste si sottolinea la presenza di 3 taxa di nuova segnalazione per il Sito (*Carex flava*, *Nitella capillaris*, *Tolypella intricata*) e la ricomparsa 9 taxa precedentemente scomparsi: 5 spontanei (*Carex panicea*, *Gratiola officinalis*, *Hottonia palustris*, *Ludwigia palustris*, *Ranunculus flammula*) e 4 reintrodotti (*Butomus umbellatus*, *Jacobaea paludosa* subsp. *paludosa*, *Nymphaea alba*, *Sagittaria sagittifolia*) (Fig. 1).

Tabella 1 - Checklist delle specie vegetali palustri di interesse conservazionistico rilevate nel periodo 2024-2025

Taxa	Specie	Famiglia	Gruppo
Alghe caroficee	<i>Nitella capillaris</i> (Krocker) J.Groves & Bullock-Webster	Characeae	B
	<i>Tolypella intricata</i> (Trentepohl ex Roth) Leonhardi	Characeae	B
Piante vascolari	<i>Alisma lanceolatum</i> With.	Alismataceae	B
	<i>Butomus umbellatus</i> L.	Butomaceae	B
	<i>Carex flava</i> L.	Cyperaceae	C
	<i>Carex panicea</i> L.	Cyperaceae	C
	<i>Carex riparia</i> Curtis	Cyperaceae	B
	<i>Cladium mariscus</i> (L.) Pohl	Cyperaceae	B
	<i>Eleocharis palustris</i> (L.) Roem. & Schult.	Cyperaceae	B
	<i>Gratiola officinalis</i> L.	Plantaginaceae	B
	<i>Hottonia palustris</i> L.	Primulaceae	A
	<i>Jacobaea paludosa</i> (L.) G.Gaertn., B.Mey. & Scherb. subsp. <i>paludosa</i>	Asteraceae	B
	<i>Ludwigia palustris</i> (L.) Elliott	Onagraceae	B
	<i>Nuphar lutea</i> (L.) Sm.	Nymphaeaceae	B
	<i>Nymphaea alba</i> L.	Nymphaeaceae	B
	<i>Persicaria amphibia</i> (L.) Delarbre	Polygonaceae	B
	<i>Ranunculus flammula</i> L.	Ranunculaceae	B
	<i>Rorippa amphibia</i> (L.) Besser	Brassicaceae	B
	<i>Sagittaria sagittifolia</i> L.	Alismataceae	B
	<i>Thelypteris palustris</i> Schott	Thelypteridaceae	A
	<i>Utricularia australis</i> R.Br.	Lentibulariaceae	A



Figura 1 - Specie vegetali palustri di interesse conservazionistico: *Ludwigia palustris* (a), *Ranunculus flammula* (b), *Tolypella intricata* (c), *Utricularia australis* (d), *Persicaria amphibia* (e), *Thelypteris palustris* (f), *Hottonia palustris* (g), *Cladium mariscus* (h)

Tutte le specie osservate nel 2024 sono state confermate nel 2025 ad eccezione di *Sagittaria sagittifolia*, tale dato tuttavia non può essere correlato con certezza ad un'estinzione locale, potendo riflettere variazioni interannuali legate alle oscillazioni dei livelli idrici delle zone umide. I risultati hanno evidenziato una significativa inversione del trend ventennale di impoverimento floristico dell'area, che precedentemente alle azioni di conservazione aveva portato da un massimo di 25 taxa (1998) a un minimo di 7 (2020) (Andreis, 2014; Patera, 2024) (Fig. 2). Tale dinamica suggerisce un incremento della ricchezza specifica correlato agli sforzi di conservazione e monitoraggio, evidenziando come il recupero mirato degli habitat palustri favorisca non solo la ricomparsa di specie precedentemente considerate estinte per l'area, ma anche l'ampliamento delle popolazioni di specie vegetali di rilevanza conservazionistica già presenti. Le zone umide rappresentano infatti ecosistemi particolarmente recettivi agli interventi di conservazione, mostrando una notevole capacità di risposta ecologica in tempi brevi. Tale reattività è attribuibile alla natura dinamica di questi ambienti e alla presenza di specie pioniere, che facilitano la ricolonizzazione e il ripristino di comunità vegetali, contribuendo al recupero della funzionalità ecologica.

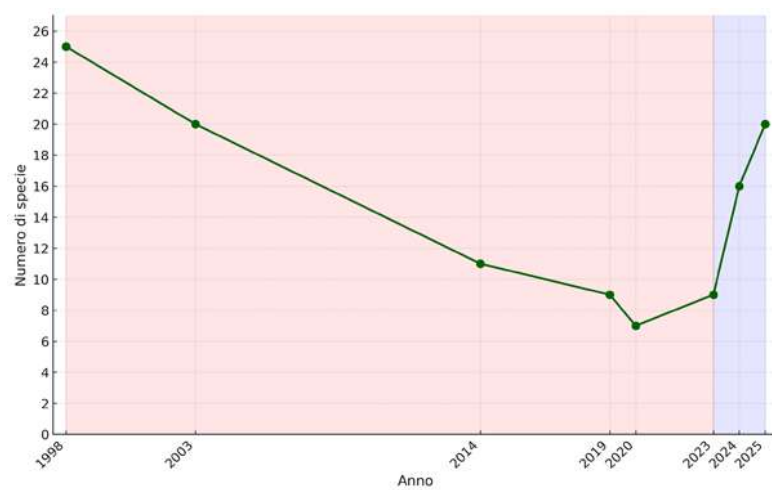


Figura 2 - Trend di conservazione delle specie vegetali palustri di pregio all'interno del Sito (1998-2025); la fascia rossa indica il periodo pre-intervento conservazionistico, la fascia blu il periodo post-intervento

Questo risultato dimostra l'efficacia delle azioni messe in atto nel contrastare la regressione degli ambienti acquatici e sottolinea il ruolo strategico della Riserva Naturale Torbiere del Sebino come area chiave per la conservazione della biodiversità vegetale delle zone umide del bacino pianiziale padano.

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Substrate type and light intensity determine lampenflora concentration on paleontological remains in show caves

Abstract. *Le grotte sono ecosistemi fragili che ospitano fauna unica e resti paleontologici, e contemporaneamente rappresentano anche una risorsa economica per il turismo. Tuttavia, l'illuminazione artificiale favorisce la proliferazione di biofilm fotosintetico (lampenflora) composto principalmente da cianobatteri, diatomee e alghe verdi, creando un danno fisico, chimico ed estetico ai resti fossili e al substrato roccioso. Questo studio ha esaminato l'influenza della luce e del substrato sulla colonizzazione di lampenflora sui reperti paleontologici della stanza "Cimitero degli Orsi" all'interno della grotta di Toirano (Nord Italia). I risultati mostrano che la luce artificiale è il principale fattore di proliferazione, e che le ossa fossili sono particolarmente vulnerabili alle diatomee. La gestione della luce artificiale può essere un primo passo per bilanciare la conservazione ecologica con il valore economico del turismo.*

Caves are among the most fragile ecosystems on Earth. They offer stable microclimatic conditions, strong oligotrophy, and total darkness, supporting unique and often endemic fauna, as well as irreplaceable paleontological and archaeological remains (Bastian & Alabouvette, 2009; Romano, 2019). At the same time, caves represent a major economic resource: more than 1,400 show caves worldwide attract millions of visitors each year, generating substantial revenues (Chiarini *et al.*, 2022; Cigna, 2016). This dual value creates tension determining management challenges between tourism and ecosystem conservation. Tourism sustains local economies, but also introduces profound disturbances, from CO₂ and heat released by visitors to the installation of artificial lighting. The latter favours the development of photosynthetic biofilms (*lampenflora*), which cause aesthetic, chemical, and physical damage, particularly critical when affecting palaeontological remains exposed in situ (Baquedano Estévez *et al.*, 2019; Mulec, 2019).

In this study, we investigated how substrate type and light intensity affect *lampenflora* colonization within the "Cimitero degli Orsi", an exceptional fossil deposit of cave bear *Ursus spelaeus* bones (Figure 1)

located in the Toirano show cave (NW Italy). We measured in situ chlorophyll-*a* concentration of cyanobacteria, diatoms, and green algae on bones, rocks, and soils using a Pulse-Amplitude Modulated (PAM) fluorimeter (BenthoTorch®) (Figure 1f). Local light intensity (lux) was also recorded, and generalized linear models tested the effects of light and substrate. In addition, we projected *lampenflora* concentrations under -30% and -50% light reduction scenarios to simulate possible management interventions.

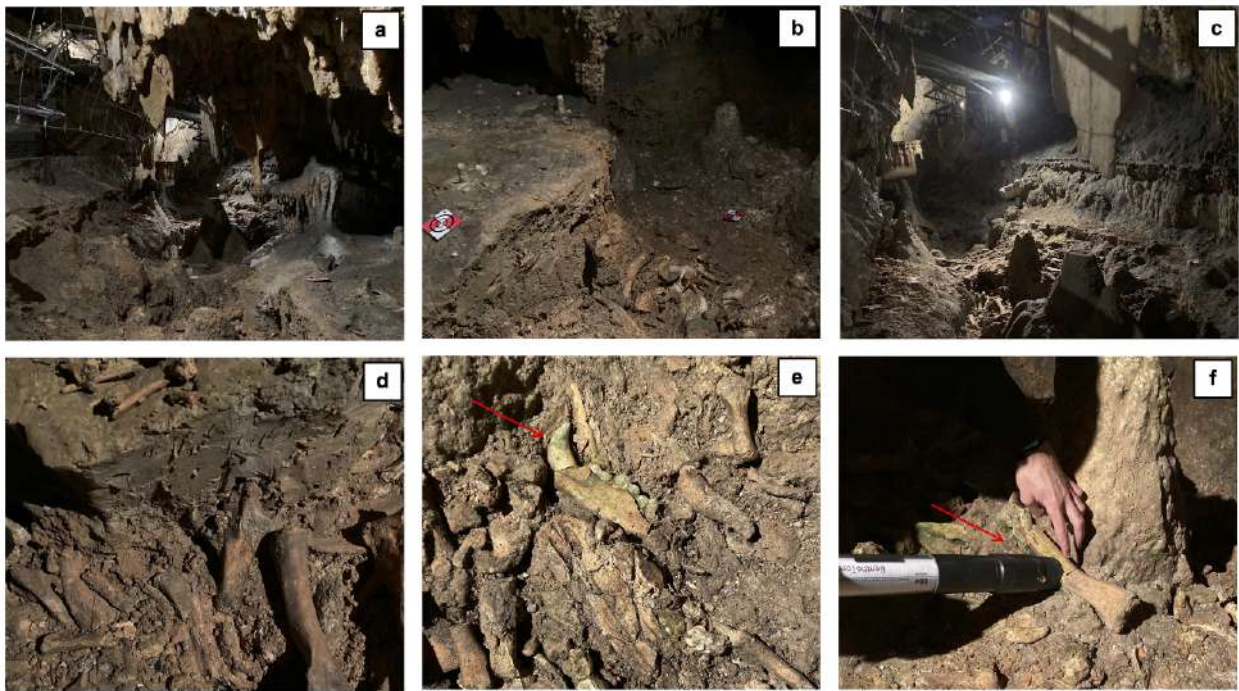


Figure 1 - “Cimitero degli Orsi” in the Toirano show cave (NW Italy)

Our findings revealed that artificial light is the main factor enhancing *lampenflora* proliferation within the “Cimitero degli Orsi”. Cyanobacteria density showed a clear positive response to increasing light intensity, but no preference for a particular substrate, indicating their ability to colonize different surfaces as long as illumination is sufficient. Diatoms, by contrast, displayed a striking substrate affinity: their concentrations were consistently higher on fossil bones than on rocks or soils, even after accounting for light effects. This suggests that the porous structure and nutrient composition of bones provide a particularly favourable environment for diatom colonization. Green algae exhibited a different pattern: they were more frequently found on rocks and soils than on bones possibly because of a lower competition with diatoms; and their presence increased sharply under high light levels, especially above 20 lux. When modelling scenarios of light reduction, the predicted concentration of cyanobacteria and green algae decreased markedly under both -30% and -50% illumination, while diatoms on bones were only marginally affected, confirming their strong association with this substrate.

Artificial light is the primary driver of *lampenflora* in show caves, but substrate properties further shape colonization patterns. Fossil bones are particularly vulnerable to diatom proliferation, which is problematic because cleaning treatments effective on speleothems cannot be safely applied to palaeontological remains (Addesso *et al.*, 2023). Thus, light management emerges as the most effective conservation strategy, including lowering bulb intensity, avoiding direct illumination of fossils, or installing motion-activated lighting.

Beyond technical considerations, this study raises a broader question: how should show caves be conceptualized and managed? Should they be regarded primarily as economic resources for tourism, or as fragile ecosystems and refugia with intrinsic scientific and conservation value serving as tools for education and public awareness? We argue that these perspectives are not mutually exclusive. With appropriate management, show caves can both sustain local economies and preserve subterranean biodiversity and heritage. Striking this balance, however, requires placing ecological integrity at the center of management decisions. Even seemingly minor interventions – such as the positioning or intensity of artificial lighting – can determine whether caves remain functional ecosystems or degrade into compromised attractions.

Ultimately, show caves should be approached as places of coexistence between human appreciation and natural conservation. Sustainable tourism that integrates ecological research can ensure that these extraordinary subterranean environments remain both economically valuable and biologically unique.

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Balancing energy and biodiversity: soil arthropod responses to shading in agrivoltaics

Abstract. *L'agrofotovoltaico permette l'uso integrato del suolo per produzione agricola ed energetica. In questo studio, condotto nell'ambito del progetto PRIN-PNRR SUNRISE, abbiamo analizzato l'effetto di due livelli di ombreggiamento da pannelli elevati a inseguimento solare su comunità di artropodi del suolo in colture di frumento e pomodoro. L'ombreggiamento ha modificato leggermente le condizioni microclimatiche e chimiche del suolo, ma non influenzando significativamente la biodiversità edafica. I collemboli sono risultati favoriti in ambienti più umidi e ombreggiati. I pannelli non hanno ridotto la qualità biologica del suolo, mostrando che l'APV è compatibile con la conservazione della biodiversità edafica, in modo coltura-specifico.*

The rising global demand for food and energy is driving substantial land-use changes, with natural habitats increasingly converted into croplands and renewable energy infrastructures. Currently, agriculture occupies nearly half of the terrestrial surface, while solar photovoltaics (PV) represent the fastest-growing renewable energy technology. This expansion has led to widespread installation of solar power plants on arable land, often generating competition between energy production and food cultivation (Walston *et al.*, 2022). Agrophotovoltaic (APV) systems – integrating solar panels with agricultural production – have emerged as a promising strategy to mitigate this land-use conflict by enabling dual land use.

Soil microclimate and chemical properties – such as temperature, moisture, pH, and organic matter – are modified beneath PV panels, potentially affecting the diversity and abundance of belowground fauna. Previous studies have documented altered arthropod community composition and reduced densities under ground-level PV arrays (Menta *et al.*, 2023), yet data on the effects of elevated APV installations on soil invertebrates remain limited.

Soil arthropods are considered key bioindicators of soil health due to their sensitivity to edaphic and climatic conditions. Among these, Collembola are widely used in biological soil quality indices, such as QBS-ar and QBS-c, due to their responsiveness to a broad range of environmental variables (Menta & Remelli, 2020). Despite their ecological importance, assessments of soil biodiversity in APV systems remain scarce.

This study, conducted within the PRIN-PNRR SUNRISE project, investigates the effects of elevated APV systems on soil arthropod communities in tomato and wheat fields. Specifically, it examines how

shading from PV panels alters soil conditions and arthropod diversity and evaluates the role of adjacent grassland strips as reservoirs of biodiversity in agrophotovoltaic landscapes.

Research was conducted in Borgo Virgilio (Northern Italy) at an APV site equipped with dual-axis solar trackers providing two levels of shading: “standard” (13%) and “expanded” (41%). Four treatments were established: STV1 (standard trackers), STV2 (expanded trackers), FS (full sun), and Control (uncultivated grassland). Wheat and tomato were selected as model crops and sampled at two phenological stages each (autumn and spring for wheat; spring and summer for tomato).

Soil sampling included measurements of soil respiration (EGM-5 gas analyzer), pH, soil organic matter (SOM, via loss on ignition), and soil arthropods (extracted using Kempson funnels). Arthropods were identified to order level; Collembola were further identified to family, and these data were used to compute QBS-ar and QBS-c indices. Statistical analyses included Factorial Analysis of Mixed Data (FAMD) to explore associations among qualitative and quantitative variables, Kendall’s tau-b correlations, and non-parametric comparisons (Wilcoxon and Mann-Whitney tests). Arthropod community structure was visualized using non-metric multidimensional scaling (NMDS) based on Bray-Curtis dissimilarities.

Correlation analyses revealed positive associations among the number of arthropod orders, QBS-ar, CO₂ emissions, soil temperature, and organic matter content. These variables generally declined with increasing soil pH. Total arthropod abundance correlated positively with CO₂ flux, moisture, and SOM. Biodiversity indices increased with higher CO₂ and temperature but showed negative correlations with moisture and organic matter. Seasonal effects were evident: soil temperature generally rose between wheat sampling stages, except under full sun. Moisture was highest in grassland control plots. Soil pH and SOM varied with treatment and crop development stage. Soil respiration peaked during warmer periods (late wheat and early tomato stages) and was consistently higher in grassland than in cropland. Arthropod abundance varied across crop stages, with the highest densities in grassland. In wheat, order richness remained stable across treatments. QBS-ar increased from early to late wheat stages under full sun and standard shading, but not under expanded shading. QBS-c differences were mainly observed under full sun.

Previous studies suggest that PV panels may reduce air temperature and increase humidity, although more recent assessments of elevated panels show minimal microclimate alteration (Zhang *et al.*, 2023; Zou *et al.*, 2025). In this study, soil chemical conditions were shaped by both crop growth and treatment. In tomato fields, shading increased soil moisture, likely due to reduced evaporation – relevant in light of rising water scarcity. Organic matter and pH were also affected by shading. Elevated panels increased SOM during specific wheat phenophases, diverging from studies reporting SOM depletion under PV (Moscatelli *et al.*, 2022). Soil pH trended towards acidification under elevated panels in wheat (approaching grassland-like values), whereas early-stage tomato soils became more alkaline under shading.

Soil ecosystems – comprising mesofauna and microbial communities – regulate critical processes such as respiration and greenhouse gas emissions. These results corroborate findings from other studies that link

higher CO₂ fluxes with greater arthropod diversity and soil quality, reinforcing biodiversity's role in ecosystem multifunctionality (Shi *et al.*, 2020).

Elevated APV systems with dual-axis trackers influenced soil arthropods primarily through microclimate and edaphic modifications, rather than direct shading. Crop type had the strongest impact, with grasslands hosting higher biodiversity and biological quality compared to wheat, but not tomato. Arthropod abundance and richness were influenced by crop phenological stage, particularly in wheat. Shading by PV panels increased arthropod density during warm seasons, possibly by mitigating thermal stress. In wheat, panel shading enhanced taxonomic richness during warm periods, consistent with literature reporting that PV arrays buffer temperature extremes (Choi *et al.*, 2023). QBS-ar values remained unaffected by shading but were consistently higher in permanent grassland, underlining the ecological value of continuous vegetation cover. In tomato fields, overall arthropod diversity was not significantly altered by panels, but Collembola richness increased under shading and in grassland, aligning with prior studies.

Community composition was mainly structured by crop type and phenological phase. Temperature emerged as a key seasonal driver, with some taxa favoring wetter winter conditions. For example, Thysanoptera increased under panels during early wheat growth, likely benefiting from cooler and moister conditions. Collembola showed clear preferences for shaded and moist environments under trackers in hot seasons, highlighting APV-driven microclimate effects.

This study demonstrates that variation in soil arthropod communities is primarily driven by crop species and phenological stage. Elevated dual-axis APV systems do not exert direct negative impacts on soil fauna. Instead, they influence soil communities through microclimatic alterations. In wheat, panels supported soil temperature during early development and increased SOM, while in tomato, they improved soil moisture, favoring moisture-sensitive taxa such as Collembola. These findings indicate that elevated APV systems are compatible with the conservation of soil biodiversity and illustrate how panel-induced microclimatic modifications can shape soil ecological dynamics in a crop-specific manner.

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Biodiversity loss in highly urbanized marine environment: an integrated study along the Italian coastline

Abstract. L’urbanizzazione costiera rappresenta una crescente minaccia per gli ecosistemi marini, alterandone la biodiversità e di conseguenza le importanti funzioni e i servizi che questi ecosistemi svolgono. Per analizzare gli effetti su scala regionale, nel 2023 è stata realizzata una campagna di campionamento lungo le coste italiane in 21 siti con crescente grado di urbanizzazione. Lo studio ha integrato approcci tassonomici tradizionali e molecolari (eDNA) valutando la composizione tassonomica, funzionale e il metabolismo bentonico. I risultati mostrano una consistente riduzione di diversità e di produzione di biomassa nei siti urbani, suggerendo un processo di selezione legato all’aumentare della pressione antropica che altera la struttura delle comunità compromettendone importanti servizi ecosistemici.

Urbanization is a global phenomenon that is increasingly impacting natural environments, from terrestrial to aquatic ecosystems. During the last decades, urbanization has impacted 1.5% of global exclusive economic zones, and the demand for space and resources is increasing (Airoidi *et al.*, 2021). Coastal marine ecosystems have a substantial social, ecological, and economic value, providing critical goods and services. However, the extensive development of coastal and marine infrastructures, known as “ocean sprawl” is leading to an alteration and degradation of marine habitats. (Heery *et al.*, 2017). Artificial structures could lead to an alteration of the coastal environment, changes in hydrodynamics, eutrophication, toxic contamination, as well as species interactions and community dynamics (O’Shaughnessy *et al.*, 2023). These changes have significant consequences for the diversity and structure of benthic communities, affecting ecosystem functioning and human services.

Developing monitoring programs to understand what ecological forces and processes shape biodiversity in increasingly urbanized marine systems is fundamental to guide better planning and management solutions.

This research addresses a critical gap in our understanding of the ecological consequences of marine urbanization considering regional-scale dynamics. The study focuses on assessing biodiversity across different urbanized marine areas, highlighting changes in community composition, structure, and ecosystem functions combining traditional and molecular taxonomic approaches. Between September and October 2023, we conducted a mobile campaign, spanning about 2000 km of the Italian coastline. Seven locations were selected to cover different biogeographic sectors (Bianchi, 2004) and maximize the regional species pool. For each location, we sampled three sites along a gradient of urbanization (Airoldi *et al.*, 2021): Urban (U, artificial rocks inside the marina), Periurban (PU, breakwaters a little further from the urban center), and Natural (N, natural rocky shore) for a total of 21 sites. The community composition and structure were analyzed integrating environmental DNA (eDNA) samples (5L of seawater filtered with with 0.45µm filters) with photographic and destructive sampling of the shallow benthic community associated to artificial and natural hard substrata on horizontal surfaces. Key ecosystem functions, such as biomass production and oxygen production, were assessed performing an in situ benthic chamber experiment (Fig. 1).

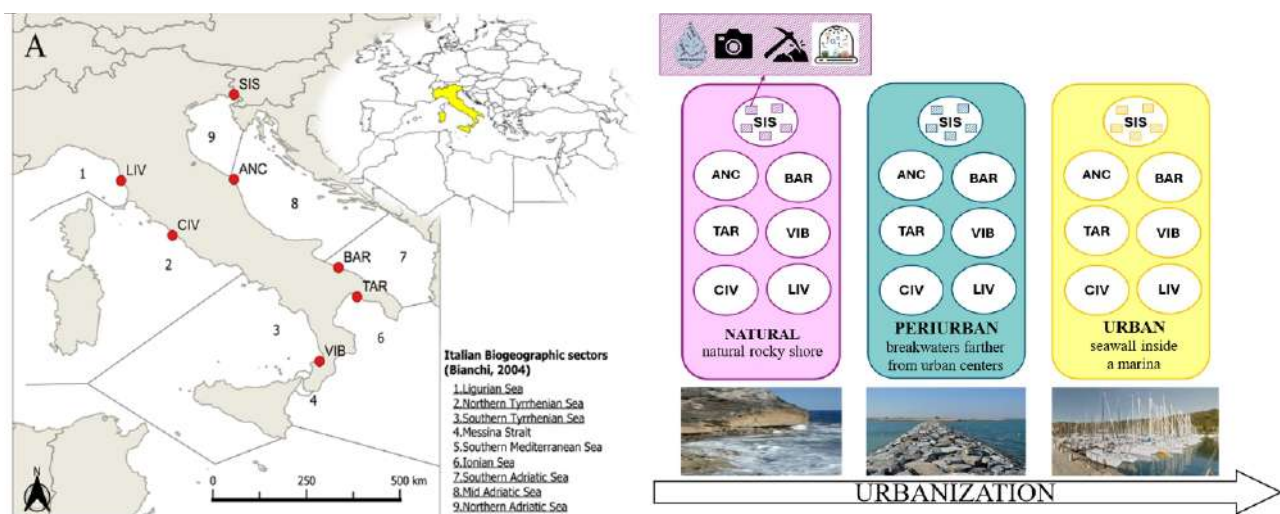


Figure 1 - Map of the study area with the seven locations, distributed along the Italian coastline (one location per biogeographic sector: Sistiana (SIS), Ancona (ANC), Bari (BAR), Taranto (TAR), Vibo Marina (VIB), Civitavecchia (CIV), Livorno (LIV)); on the right, scheme of the sampling design: 21 sites were sampled in total, 3 habitats (i.e. natural rocky shore, breakwaters and artificial substrate inside marinas) per 7 locations, 5 sub-replicates per site (105 samples in total); samples of eDNA, photoquadrats and scrapings of the sessile benthic communities and in situ measurements of benthic metabolism were collected

A total of 348 taxa (241 invertebrates and 107 algae) were identified with the destructive sampling and classified according to six functional traits (feeding mode, life strategy, growth form, size, calcified

structures and mobility) to evaluate the functional composition of the benthic community. Regarding eDNA samples, a total of 1466 Operational Taxonomic Units (OTUs) have been identified: 360 from the amplification of the COI region targeting metazoans, 1051 from Euka02 targeting eukaryotes and 68 from Tele02 targeting fishes (Leray *et al.*, 2013; Taberlet *et al.*, 2018). 610 OTUs were identified at species level and 884 at genus level. Algae represented the most diverse group (763 OTUs), followed by invertebrates (427 OTUs), Chordata (118 OTUs), Protozoa (81 OTUs), Fungi (61 OTUs), and Plant (1 OTU).

Both taxonomic and molecular analysis found a consistent decrease in the species and OTUs richness, respectively, from natural (~240 species and ~510 OTUs) to urban sites (~175 species and ~452 OTUs). The same negative relationship was found for the functional and phylogenetic richness, which would suggest environmental filtering in urban habitats. However, according to the multivariate analysis, urban communities don't seem to be a selected subsample of regional species pools; indeed, a high turnover of species was found, with distinct communities characterizing urban habitat compared to nearby natural ones. This suggests that other ecological processes may concur to shape the community structure, such as habitat connectivity patterns mostly driven by human activities (e.g. ship traffic), or different biotic interactions occurring in artificial habitats, or limitations in available niches.

The ecosystem biomass productivity, particularly of primary producers, shows a significant decline along the urbanization gradient. Measurements of benthic metabolism revealed null or negative net oxygen production in both natural and urban habitats, while significantly positive values were observed in the periurban habitat. This pattern can be explained by differences in the relative composition of biomass. In both natural and urban habitats, the proportion of algae relative to animals is similar. In contrast, the periurban habitat is characterized by a much higher dominance of primary producers, with algae making up over 70% of the total biomass. This high relative abundance of algae likely acts as a source of net oxygen production, as algae contribute more to oxygen generation through photosynthesis than animals consume through respiration.

A large-scale approach and the combination of different methods with a standardized protocol across diverse biogeographic sectors allowed us to investigate spatial patterns and regional variations in response to urban stressors, confirming a consistent decrease in biodiversity in urbanized marine habitats with negative effects on key ecosystem functions. This research remarks on the importance of biodiversity monitoring study to understand how the ecosystem responds to anthropogenic drivers and supports successful restoration and conservation programs (Airoldi *et al.*, 2021; Alberti, 2015; Heery *et al.*, 2017). Further, this work highlights the effectiveness of a non-invasive method such as eDNA, in assessing biodiversity and providing a reliable representation of the communities present in these habitats.

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Exit latency as a proxy for boldness in the Eurasian red squirrel (*Sciurus vulgaris*)

Abstract. *Gli animali mostrano differenze comportamentali, note come personalità. In questo studio abbiamo valutato se l'exit latency, ossia il tempo impiegato da uno scoiattolo rosso, *Sciurus vulgaris* Linnaeus, 1758, per lasciare un'arena sperimentale, possa costituire un tratto di personalità. Sono stati testati 167 individui in arene con Open Field Test e Mirror Image Stimulation test misurando attività, esplorazione e socialità. L'exit latency è risultata ripetibile e gli scoiattoli delle aree suburbane hanno lasciato l'arena più rapidamente rispetto ai rurali. Inoltre, era negativamente associata ad attività e socialità, ma non all'esplorazione. I risultati supportano l'uso dell'exit latency come indicatore di audacia e il ruolo della personalità nell'adattamento agli ambienti urbanizzati.*

Animals exhibit consistent individual differences in behaviour, referred to as personality (Réale *et al.*, 2007). Studying these differences is essential to understand species ecology and adaptive strategies; personality traits can influence key aspects of individual fitness, including resource acquisition, survival, reproduction and interactions with the environment. They are therefore essential for understanding how individuals adapt to varying environmental conditions, including urban habitats. Human-induced environmental changes can create novel selective pressures, favouring individuals with more flexible or adaptive behavioural traits, highlighting the importance of investigating how urbanisation affects behavioural variability (Fingland *et al.*, 2022).

In this study, we investigated whether exit latency, defined as the time required for an individual to leave an experimental arena, can be considered a personality trait and used as a measure of boldness in the Eurasian red squirrel, *Sciurus vulgaris* Linnaeus, 1758. We further examined how exit latency correlates with other personality traits (i.e., activity, exploration and sociability) along an urbanisation gradient, including rural, suburban and urban areas (Tranquillo *et al.*, 2024). Exit latency is a promising behavioural indicator, as it could provide a measure of an individual's propensity to take risks, that is, boldness, reflecting adaptive responses to external stimuli (Näslund *et al.*, 2015). While exit latency has been previously employed as a behavioural measure in mice (Brehm & Mortelliti, 2023; Herde & Eccard, 2013), this study represents the first application of this measure to *S. vulgaris*.

We hypothesised that exit latency would be a repeatable, and therefore stable, personality trait, serving as a proxy for assessing boldness in red squirrels. In line with this, we predicted that squirrels living in urban and suburban areas would exhibit shorter exit latencies compared to those from rural ones, reflecting a behavioural gradient along the urbanisation continuum, with urban individuals displaying greater boldness, likely as a consequence of habituation to anthropogenic stimuli (Uchida *et al.*, 2020). Finally, we investigated potential associations between exit latency and other personality traits, including activity, exploration and sociability, predicting negative correlations with these traits.

A total of 167 red squirrels were captured and individually marked using a capture-mark-recapture (CMR) protocol. Individuals were tested in arena settings combining Open Field Test (OFT) and Mirror Image Stimulation (MIS) test, designed to assess activity, exploratory tendencies and social responses (Mazzamuto *et al.*, 2019; Santicchia *et al.*, 2021). During the experiments, behaviours were recorded and coded using the CowLog software (Hänninen & Pastell, 2009). Exit latency was measured as the time elapsed between the opening of the arena door at the end of the experiments and the voluntary exit of the individual, a measure that we interpreted to be an indicator of boldness (Näslund *et al.*, 2015). Behavioural data were analysed using linear mixed-effects models (LMMs) to assess the repeatability of personality traits and the relationship between exit latency, personality traits and area type (urban, suburban and rural).

A relatively high value of repeatability ($R = 0.21$), calculated as the proportion of variance attributable to consistent individual differences (Bell *et al.*, 2009), confirmed that exit latency is a stable individual characteristic, supporting its interpretation as a personality trait (Carter *et al.*, 2013). We found that squirrels from suburban areas exited the arena faster than those from rural ones, suggesting greater boldness in the suburban group. Additionally, exit latency was negatively associated with activity and sociability, indicating that more active and social squirrels exited the arena more quickly and were consequently bolder. The relationship between exit latency and personality traits depended on area type: exit latency was more strongly negatively associated with activity in rural areas and weaker, yet significant, in urban ones, whereas its association with sociability was similar across all area types. These findings support the use of exit latency as a proxy for boldness and reveal complex relationships among personality traits, suggesting that animal personality is best understood as a combination of interrelated characteristics rather than isolated traits (Carter *et al.*, 2013; Wauters *et al.*, 2019).

More broadly, these results contribute to the study of individual responses to anthropogenic pressures (Hogue & Breon, 2022). Urbanisation represents a significant selective force that can favour individuals with bolder or more flexible behaviours, directly affecting survival and reproductive success. Studies such as this provide tools to predict which individuals or populations are more capable of coping with rapid environmental change, which is particularly relevant under ongoing urban expansion and global environmental change (Lowry *et al.*, 2013).

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Hatching under heat: the impact of temperature on *Sepia officinalis* eggs in the Venice Lagoon

Abstract. *Sepia officinalis* è una risorsa chiave per la piccola pesca nell'Adriatico settentrionale. La temperatura influenza lo sviluppo embrionale e il successo della schiusa, l'obiettivo dello studio è di valutare gli effetti del riscaldamento climatico sulle uova. In questo studio, uova sono state sottoposte a esperimenti in laboratorio con temperature costanti 18, 20, 26 e 28 °C e ambientali. I risultati mostrano che l'aumento della temperatura accelera lo sviluppo, riducendo i tempi di incubazione da 50 giorni a 18 a 20 a 26 °C, mentre a 28 °C non si è verificata alcuna schiusa. In condizioni ambientali, con picchi oltre i 28 °C, il successo della schiusa è calato di oltre il 50%. Questi dati confermano che la temperatura è un fattore determinante per il reclutamento della specie.

The common cuttlefish *Sepia officinalis* is a key fishery resource in the northern Adriatic Sea. Its life cycle is characterized by rapid growth and a relatively short lifespan of about two years (Ghmati *et al.*, 2024; Guerra *et al.*, 2015). Cuttlefish are fished year-round with a variety of fishing gears. During autumn and winter, they remain offshore to grow, where they are mainly caught by bottom trawlers. In the reproductive season (spring-summer), they migrate towards coastal areas and into the Venice Lagoon for spawning and egg deposition, where they are primarily exploited by artisanal fishers using passive gears such as gillnets, pots, and fyke nets. Juveniles, which hold high economic value, are captured only a few months after hatching with the same gears (FAO GFCM, 2021; Grati *et al.*, 2018). Although small-scale fisheries are generally considered to have lower environmental impacts, in the case of cuttlefish the main concern arises from egg deposition on fishing gears, followed by their removal and consequent loss. Fishing gears deployed in coastal areas therefore exert a significant negative impact on cuttlefish eggs. In the Venetian area, it has been estimated that more than 3 million eggs may be discarded along less than 3 nautical miles of coastline (Melli, 2014). In addition to this pressure, we must consider the potential effects of climate change, as warming, acidification, and deoxygenation; the so-called “deadly trio”, play a central role in current ecosystem alterations. The reproductive strategy of *S. officinalis* shows considerable plasticity and geographical variation, mainly influenced by water temperature (Guerra *et al.*, 2015; Laptikhovskiy *et al.*, 2023). Among cephalopods, the most studied stressors are warming and acidification, often acting in combination (Borges *et al.*, 2023; Laptikhovskiy *et al.*, 2024). Warming accelerates embryonic growth, resulting in premature hatching (Domingues *et al.*, 2002; Palmegiano & d'Apote, 1983), while hatchling

mantle length is strongly affected by temperature, with higher temperatures reducing incubation times, consequently resulting in smaller hatchlings (Coelho *et al.*, 2023; Laptikhovsky, 2019).

This study aimed to test the hypothesis that temperature is a critical factor determining egg hatching success in *S. officinalis*, with a particular focus on the environmental conditions of the Venice Lagoon. The goal was to assess the resilience of the species and evaluate the potential effects of climate-driven warming on recruitment. Experimental temperatures were based on monitoring data from 2013 to 2021 from the SAMANET network (Venice Water Authority, 2008). The SAMANET network consists of ten continuous monitoring stations (with semi-hourly frequency) that measure the physico-chemical parameters of the Lagoon waters using multiparameter probes. With this data we calculated the monthly averages and daily maxima for April-May (first experimental period) and June-July (second experimental period). Two laboratory experiments were conducted under both constant temperature treatments and fluctuating environmental conditions. In the first experiment, constant temperatures of 18 °C and 20 °C were applied, while in the second experiment the constant temperatures were 26 °C and 28 °C. Eggs were collected from fishing gears in the Venice Lagoon and monitored for growth, incubation time, hatching success, and hatchling size. Egg growth was assessed every four days by sampling 25% of the total eggs. The sampled eggs were weighed and measured. The number of hatched eggs was also recorded, and newly hatched cuttlefish were measured and subsequently released. Incubation time was defined as the period between egg deposition and hatching.

Results showed that higher temperatures significantly accelerated embryonic development, reducing incubation time from ~50 days at 18 °C to ~20 days at 26 °C. However, no hatching occurred at 28 °C. Under environmental conditions, where temperatures fluctuated and peaked above 28 °C, hatching success decreased by more than 50% compared to the other treatments. Overall, this study confirms that temperature is a key driver of reproductive success in *S. officinalis*. Projected warming trends in the Venice Lagoon may compromise its role as a nursery habitat, reducing recruitment and potentially threatening local fisheries. These findings highlight the vulnerability of cuttlefish populations to climate change and underscore the need for sustainable management strategies in small-scale fisheries.

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Mapping Ecosystem Services into Life Cycle thinking: evidence from Mediterranean olive groves

Abstract. *Nel progetto SustainOlive è stata applicata una valutazione integrata di servizi ecosistemici (ES) e ciclo di vita (LC) negli oliveti mediterranei. Dodici aziende (6 Sustainable Technological Solutions - STS; 6 non-STS) in sei paesi sono state analizzate con un'unità funzionale (FU) di 1 ha·y⁻¹ (cradle-to-gate) applicando il framework LANCA e utilizzando un modello di Ecotope Formation (EF). I servizi del suolo – resistenza all'erosione (ER), filtrazione meccanica (MF) e fisico-chimica (PCF) – sono stati quantificati e monetizzati tramite costi di ripristino del suolo e trattamento delle acque reflue; EF descrive stabilità ecologica e biodiversità. Le STS tendono a ottenere MF/PCF ed EF più alti, ma la risoluzione dei raster GIS limita la specificità di sito. I risultati supportano l'implementazione di Payments for Ecosystem Services (PES) ed eco-schemi PAC e indicano la necessità di dati pedologici più fini e parametri gestionali espliciti.*

This work integrates the environmental and economic assessment of ecosystem services (ESs) with the Life Cycle (LC) Approach in Mediterranean olive growing, addressing a recurring limitation of conventional LC studies – namely, the only partial inclusion of ESs in sustainability assessments. The analysis was conducted on 12 farms participating in the SustainOlive project (De Luca *et al.*, 2023), organised into paired comparisons between systems applying agroecological principles (Sustainable Technological Solutions, STSs) and business-as-usual practices (non-STSs) across Italy, Spain, Greece, Portugal, Tunisia and Morocco (N01_PU_STS_IT; N02_PU_nSTS_IT; N01_DE_STS_SP; N02_DE_nSTS_SP; N02_CHR_STS_GR; N05_CHR_nSTS_GR; N06_SER_STS_PT; N02_EVO_nSTS_PT; N02_SID_STS_TU; N06_SID_nSTS_TU; N02_OUA_STS_MO; N01_SPI_nSTS_MO). The functional unit is 1 ha·y⁻¹, with a cradle-to-gate boundary centred on the agricultural phase. Regulation and support services (MEA, 2005) were quantified using the LANCA framework together with the Ecotope Formation (EF) model (Baitz, 2002; Bos *et al.*, 2016), so that biophysical indicators could be expressed alongside a monetary valuation suitable for designing Payments for Ecosystem Services (PES). Erosion Resistance (ER) was estimated as the opposite of the Revised Universal Soil Loss Equation (RUSLE), $ER = -(R \cdot K \cdot LS \cdot C \cdot P)$, adopting established formulations for the topographic factors (Renard *et al.*, 1991; Wischmeier & Smith, 1978) and updating soil erodibility (K) by accounting for stoniness (Panagos *et al.*, 2014). Crop management

affects factor C (e.g. grass cover and cover crops), while support practices influence factor P (Panagos *et al.*, 2015a; 2015b). The economic value of ER derives from the costs of restoring eroded soil (soil supply and levelling), translating preventative effects into monetary terms to enable consistent comparison across sites and management regimes. Mechanical Filtration (MF) and Physicochemical Filtration (PCF) quantify, respectively, the soil's capacity to filter water physically (infiltration, permeability k_f) and to adsorb cationic contaminants as a function of Cation Exchange Capacity (CEC) (Bos, 2019; Bos *et al.*, 2020; Saad *et al.*, 2013). In LANCA, MF depends on texture and distance to the groundwater table, whereas PCF is driven by texture and CEC. Monetisation is based on capital costs of primary (MF) and secondary/tertiary (PCF) wastewater treatment (Cao *et al.*, 2015), reflecting avoided treatment costs as a common metric. EF, a dimensionless indicator of landscape stability and ecological functionality, combines maturity (MC), naturalness (NC), diversity (D_{VAR} , corrected for cultivars), and anthropogenic influence (AI); associated costs are expressed as annual operational expenses for landscape maintenance (Baitz, 2002). Taken together, these metrics capture soil-process regulation and broader, landscape-level attributes linked to ecological resilience.

Results for ER do not indicate a generalised superiority of STS; outcomes vary with climate, soils and management. In Greece, the STS farm (N02_CHR_STS_GR) shows a very low minimum soil-loss potential ($-0.08 \text{ t ha}^{-1} \text{ y}^{-1}$) and lower minimum restoration costs ($\text{€}0.57\div60.16 \text{ ha}^{-1} \text{ y}^{-1}$) than the non-STs counterpart (N05_CHR_nSTS_GR, $\text{€}63.24\div107.75 \text{ ha}^{-1} \text{ y}^{-1}$), consistent with the reduction in factor C achieved by grass cover. In some Italian contexts, non-STs exhibits slightly better erosion values than STs, yet with non-negligible restoration costs. Measures such as temporary ditches – typical of STs configurations – can reduce erosion by up to 67% by acting on the LS factor (Francaviglia & Neri, 2020) underscoring how topography and management interact in controlling soil loss. For MF and PCF, the coarse resolution of the soil rasters employed (Harmonised World Soil Database (HWSD), $1\times 1 \text{ km}$; Nachtergaele *et al.*, 2012) tends to flatten differences between neighbouring farms and reduces site specificity. Despite this limitation, the monetary results highlight advantages for STs. In Italy, the STs farm (N01_PU_STS_IT) reaches MF of $2.77\cdot 10^5 \text{ m}^3 \text{ ha}^{-1} \text{ y}^{-1}$, higher than the non-STs farm (N02_PU_nSTS_IT, $1.16\cdot 10^5 \text{ m}^3 \text{ ha}^{-1} \text{ y}^{-1}$). In Tunisia, with similar environmental values, PCF economic value is substantially higher in STs (N02_SID_STS_TU, $\text{€}304.71 \text{ ha}^{-1}$) than in non-STs (N06_SID_nSTS_TU, $\text{€}132.69 \text{ ha}^{-1}$). These patterns are consistent with improvements in soil properties such as SOM and CEC associated with agroecological practices, which enhance purification potential and, consequently, the estimated economic benefits. EF averages around 10 Pt and reflects both crop diversity and ecological stability. In Tunisia, non-STs (N06_SID_nSTS_TU) scores 10.20 Pt, slightly above STs (N02_SID_STS_TU, 10.00 Pt), likely due to greater cultivar diversity; however, this comes with much higher maintenance costs ($\text{€}754.11$ vs $\text{€}302.13 \text{ ha}^{-1} \text{ y}^{-1}$). In Portugal, STs (N01_POR_STS_PT, 10.28 Pt) marginally exceeds non-STs (N02_EVO_nSTS_PT, 10.22 Pt), again with higher associated costs ($\text{€}555.69$ vs $\text{€}239.62 \text{ ha}^{-1} \text{ y}^{-1}$). Overall, annual landscape-maintenance costs tend to be higher in STs systems, reflecting the operational complexity of practices oriented toward landscape

resilience and biodiversity support. Expressing EF together with costs makes explicit the ecological-economic trade-offs that stakeholders need to consider when comparing management options.

The main methodological constraints concern the low spatial resolution of georeferenced data (1×1 km) used by LANCA for ER, MF, and PCF, and the limited inclusion of key management parameters (e.g., compaction, fertilisation), which reduces field-scale sensitivity (Bos, 2019; Bos *et al.*, 2016). In contiguous areas, farms sharing the same pixel may receive conservative estimates, attenuating management-driven differences. Nevertheless, coupling LANCA-based indicators with EF and a monetary valuation grounded in restoration and treatment costs provides consistent, comparable metrics across heterogeneous contexts. In practical terms, this integrated output facilitates the translation of bio-physical performance into decision-relevant signals for farm advisers and policy makers, without departing from the cradle-to-gate perspective and the chosen functional unit. From a policy perspective, EF aligns with CAP 2023-2027 Eco-scheme 3, which remunerates the maintenance of landscape olive groves with compensation of €220 ha⁻¹, while practices that improve ER and overall soil condition fall under Eco-scheme 2 (grass cover for tree crops) (MASAF, 2023).

By expressing ES outcomes in monetary terms, the approach helps align incentives with observed environmental benefits and supports PES calibrated to actual service provision rather than generic prescriptions. In summary, STS farms tend to deliver superior environmental and economic performance for filtration services (MF, PCF) and ecotope formation (EF), whereas ER responses are context dependent. Future work should prioritise finer-resolution soils data and more explicit management parameterisation, thereby increasing site specificity and discriminatory power, while remaining consistent with the LC perspective and the agroecological objectives pursued by SustainOlive.

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Risposta comportamentale dei girini di Rana temporaria ai segnali chimici dei predatori in relazione all'introduzione di pesci nei laghi alpini d'alta quota

Abstract. Abbiamo analizzato la risposta comportamentale dei girini di *Rana temporaria* al segnale chimico di predatori naturali per determinare se girini originati da popolazioni esposte ad una pressione predatoria maggiore, dovuta all'introduzione di pesci non-nativi per la pesca ricreativa in laghi d'alta montagna, mostrano una sensibilità aumentata ai segnali chimici rilasciati dai predatori. Sono state campionate diverse popolazioni delle Alpi occidentali, e sono state analizzate le risposte antipredatorie in presenza del segnale chimico di larve di odonati (genere Aeshnidae). Dall'analisi dati è emerso che l'esposizione alla presenza di pesci alloctoni modifica la risposta dei girini in condizioni sperimentali, aumentando il tempo di freeze.

The objective of this study is to investigate the relationship between predation pressure and the defensive behavior of tadpoles from different populations of European common frog *Rana temporaria* Linnaeus, 1758. Specifically, the study aims to determine whether tadpoles originating from populations exposed to novel predation pressures, due to the introduction of non-native fish for recreational fishing, exhibit stronger antipredator responses and heightened sensitivity to chemical cues released by native predators. We chose dragonfly larvae as predators because they are naturally present in alpine lakes and can feed on tadpoles of all stages of development.

To test this hypothesis, behavioral responses were recorded from 600 tadpoles collected from six high-altitude lakes (100 individuals per lake), located in areas both with and without the presence of introduced fish (Tab. 1). Tadpoles were exposed to varying concentrations of predator-derived olfactory cues, and their behavioral reactions were analyzed and compared. To assess the sensitivity of antipredator responses in relation to fish presence at a landscape scale, we also considered the occurrence of lakes with fish within an 800-meter radius of the egg collection site. This approach is based on the assumption that the presence of predators in nearby lakes may reflect either historical or current predation pressure, which over time could have selected for stronger defensive behaviors or increased behavioral plasticity. The 800-meter buffer was

chosen based on known adult amphibian mobility and typical dispersal distances observed in alpine environments (Lanza *et al.*, 2007).

Eggs were collected during the reproductive season of 2024 from 6 lakes within the Gran Paradiso National Park and the Mont Avic Natural Park. Clusters were collected shortly after deposition, to ensure similar development conditions. For each lake we collected 10 fragments maximising the distance between each one to minimize the chances of relatedness. Eggs were transported to the Laboratory of Zoology and Animal Behavior Ecology of the University of Pavia within 24 hours from the collection and each fragment was individually placed in a plastic container with 3 litres of clean tap water. Dragonfly larvae (family Aeshnidae) were kept individually in plastic containers filled with 250 mL of water to avoid cannibalism.

The experiment included five olfactory treatments: aged tap water, used as the control (C), and kairomone cues from fasting dragonfly larvae at four different concentrations: 1:1 (referred to as the "pure stimulus"; S1), 1:5 (50 ml of cue in 250 ml of water; S5), 1:10 (25 ml of cue in 225 ml of water; S10), and 1:20 (12.5 ml of cue in 237.5 ml of water; S20). The cues were prepared each testing day collecting 30 ml of water from 8 randomly selected fasted larvae containers; these were poured in a separate container used as the 1:1 reference for the dilutions. For each clutch of every population we tested the five stimulus with two replicates. To assess the activity levels pre- and post-stimulus each tadpole was placed in an opaque plastic container (15×10.5×5 cm) with 250 ml of aged tap water. The containers were placed in two tanks under a camera and left for 15 minutes to acclimatise. Each trial consisted of 10 minutes pre-stimulus and 10 minutes post-stimulus administration. The olfactory cue was administered using a disposable 8 ml syringe in a concentration of 1:125 consistent with previous studies (Gazzola *et al.*, 2018; Gomez-Mestre & Díaz-Paniagua, 2011; Scribano *et al.*, 2020).

A total of 600 tadpoles were tested, with 100 individuals per population. In each experimental session, two racks of 10 containers were used (Fig. 1), allowing for the simultaneous observation of 20 individuals (Guadin *et al.*, 2021; Scribano *et al.*, 2020). All trials were conducted indoors and recorded with a digital video camera. Video recordings were analyzed with the software ToxTrac (Rodriguez *et al.*, 2018), which allows automated tracking of tadpole trajectories. Activity levels were assessed using total freezing time, a variable provided by the software and considered a reliable indicator, as reduced mobility is interpreted as a fear response.

Table 1 - Characteristics of the six alpine lakes from which tadpoles were collected.

Code	Lake	Authority	Lat.	Long.	Elevation	Fish in lake	Fish in area (0-800m)
LES	L. Leser	PNMA	45.6577	7.6016	2020	Yes	Yes
BIA	L. Blanc	PNMA	45.6496	7.5849	2154	Yes	Yes
VLT	L. Vallet	PNMA	45.6499	7.5913	2173	No	Yes
RAT	L. Raty	PNMA	45.6247	7.5720	2284	No	No
LOS	L. Losere	PNGP	45.4757	7.1570	2568	No	No
TRB	L. Trebecchi	PNGP	45.5020	7.1443	2727	No	Yes

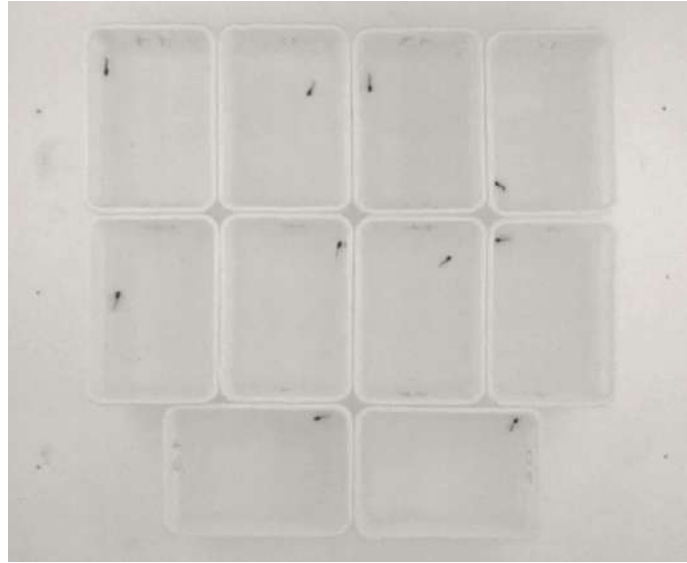


Figure 1 - Experimental arena consisting of 10 opaque containers used for the simultaneous observation of tadpoles during behavioural tests

All statistical analyses were performed in R version 4.4.2 (R Core Team, 2020). To analyse variation in tadpole activity levels in response to the olfactory cue, two separate models were built, using as the response variable the ratio between post-treatment and pre-treatment total freezing time. This variable was log-transformed to improve the normality of the distribution. In the first model (mod. 1), a linear model (LM) was applied to assess whether there were differences among populations in their response to the chemical cue. Cue concentrations (treated as an ordinal variable) and population of origin (treated as a factor) were included as fixed effects. In the second model (mod. 2), a linear mixed-effects model (LMM) was used, to evaluate the effect of predatory fish presence within an 800-meter buffer (treated as a factor) and cue concentration (treated as an ordinal variable). In this case, population (treated as a factor) was included as a random intercept effect, to account for variability among individuals from different populations.

In the first model a significant effect of predator cue concentration on total freezing time was observed ($F = 69.18$, $df = 4$, $p < 0.001$). The main effect of population was also significant ($F = 5.82$, $df = 5$, $p < 0.001$). In addition, a significant interaction between stimulus and population was found ($F = 2.13$, $df = 20$, $p = 0.003$). In the second model predator cue concentration had a significant effect on freezing time ($F = 56.01$, $df = 4$, $p < 0.001$). The main effect of predator presence was not significant ($F = 3.75$, $df = 1$, $p = 0.125$), but the interaction between stimulus and predator presence was significant ($F = 2.56$, $df = 4$, $p = 0.038$). Post-hoc analysis showed that in the absence of predators, only the highest concentrations (S1 and S5) significantly increased freezing time compared to the control (S1: $p < 0.001$, S5: $p < 0.001$). Lower concentrations did not show significant effects (S10: $p = 0.067$, S20: $p = 0.276$). In the presence of predators, all cue concentrations had a significant effect compared to the control (all $p < 0.001$), with an increasing effect as dilution decreased.

The results show that antipredator responses in *R. temporaria* tadpoles vary significantly both according to cue intensity and the geographical origin of populations. Different populations reacted consistently to the various concentrations, with higher freezing times at stronger cues, though with some differences among them (Fig. 2). Moreover, populations from lakes exposed to higher predation pressure displayed greater sensitivity even to highly diluted cues (Fig. 3), suggesting possible local adaptation or increased behavioral plasticity in contexts characterized by introduced predatory fish. Conversely, tadpoles from fishless environments responded significantly only to higher cue concentrations, indicating a higher threshold for triggering defensive responses. These behavioral differences may have important eco-evolutionary consequences at the landscape scale: increased freezing time reduces feeding activity and therefore slows growth, potentially delaying metamorphosis and affecting survival in alpine lakes, where the growing season is particularly short.

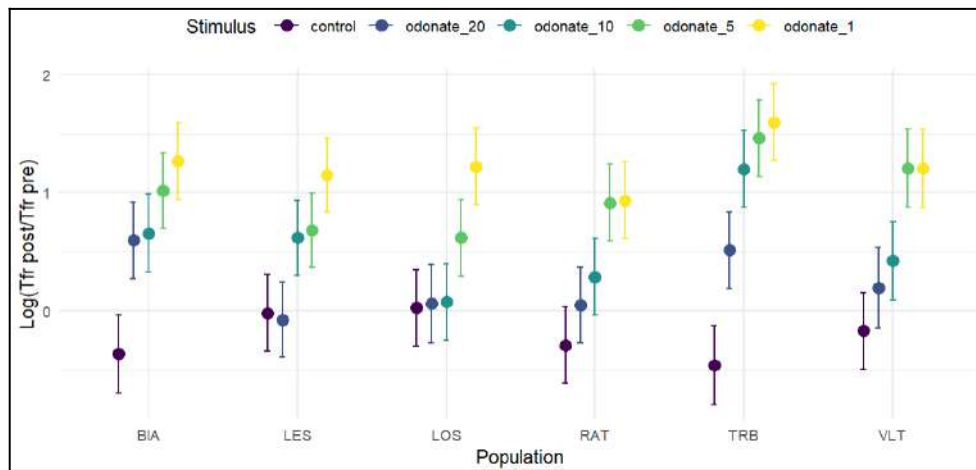


Figure 2 - Effects of olfactory cues and population on Total Freezing Time

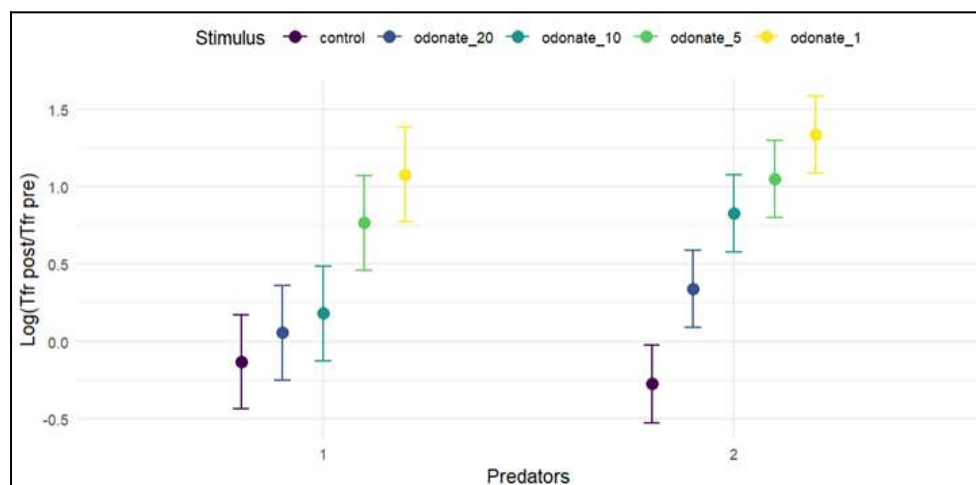


Figure 3 - Effect of stimulus and predator presence on Total freezing Time

These results have important implications for conservation: the introduction of non-native fish not only alters ecological communities but also amphibian survival strategies. Further studies should investigate metamorphosis timing and body size at metamorphosis in populations with and without introduced fish, to better understand the trade-off between predation risk, growth, and post-metamorphic survival.

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Comparing Global Fishing Watch data sets with the Information Imbalance method to model biodiversity and social trends

Abstract. Utilizziamo i metodi “Information Imbalance” e “DII” per confrontare la qualità informativa di diversi dati sulla pesca. Analizziamo le attività di pesca con i dati di Global Fishing Watch derivati da sistemi distinti: trasmissioni AIS (Automatic Identification System), radar satellitare Sentinel-1 SAR e immagini ottiche Sentinel-2 MSI. Confrontando queste fonti e modelli derivati, valutiamo quale rappresenta meglio le attività di pesca nei vari ecosistemi. I dati ottimali vengono messi in relazione con biodiversità marina e indicatori socio-economici (PIL, HDI, Human Footprint) per capire l’impatto sulla natura e sulle comunità costiere. Il progetto, in corso, mira a fornire nuovi strumenti per monitorare la sostenibilità della pesca globale.

The Information Imbalance method (Glielmo *et al.*, 2022) and its differentiable variant (DII, Wild *et al.*, 2025) are feature selection approaches that compare the informativeness of different feature spaces. Informally, the idea is: if feature space A is informative about another, then nearest-neighbor relationships in A serve as reliable proxies for those in the other space, which is not necessarily true vice versa. This relationship is quantified by the Information Imbalance, which approaches 0 when A is highly informative and 1 when A provides no information. The framework enables comparisons between feature spaces of any size, from single variables to thousands of dimensions, and assesses their relative informational quality. The Differentiable Information Imbalance can also automatically assign weights to input feature spaces to balance units of measure and importance.

In this ongoing project, we apply these methods to fishing effort data from Global Fishing Watch, derived from several distinct observation systems: Automatic Identification System (AIS) transmissions, which depend on compliance and may suffer from intentional disabling or coverage gaps; satellite-based Sentinel-1 synthetic aperture radar (SAR), which provides independent observations of vessel presence regardless of transponder use but detect only vessels larger than 20 m reliably; and satellite-based Sentinel-2 MultiSpectral Instrument (MSI) data, which can reveal fishing activities through high-resolution optical imagery under suitable atmospheric conditions. By systematically comparing AIS, SAR, MSI, and model-derived

indicators, we evaluate which of these sources provides the most informative representation of fishing activities across different countries and ecosystems.

Using the optimally derived fishing activity ground truth, we explore how patterns of fishing activity relate to ecological and socio-economic outcomes. First, we analyze the relationship between fishing intensity and marine biodiversity trends, explicitly accounting for confounding drivers such as climate variability, using global environmental databases (e.g. Copernicus and The Sea Around Us). A key distinction is drawn between overall biodiversity change, for instance as monitored by MEDITS surveys of demersal species in the Mediterranean, and the dynamics of exploited stock species, which may show contrasting temporal trends relative to non-target species. By disentangling these relationships, we aim to improve our understanding of how different fishing pressures impact ecosystems under varying climate and management regimes.

We also assess the connection between fishing activity and the socio-economic wellbeing of coastal communities. These analyses use similar quantitative frameworks and integrate international socio-economic indicators such as the gross domestic product (GDP) and the Human Development Index (HDI) with higher-resolution proxies such as Human Footprint (terrestrial; Mu *et al.*, 2022) and Human Impact (marine; Halpern *et al.*, 2019), which offers fine-scale information about human economic activity. Integrating night-time satellite light intensity is planned in the future. The dual perspective, ecological and socio-economic, provides an opportunity to evaluate not only the sustainability of fishing activities, but also their broader implications for human communities that depend on marine resources.

The combination of novel methodological tools (Information Imbalance and DII), multiple observation systems (AIS, SAR, MSI, and model-derived data), and integrative analyses across ecological and socio-economic domains makes this project a unique step toward more comprehensive monitoring of global fishing activity. The project is still in an early stage.

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