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BOOK OF ABSTRACTS

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Ecologia e sostenibilità:
strategie per affrontare le sfide del terzo millennio

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Parte I

Relazioni su invito

The current polycrisis and foresight in sustainability: A need for a new ecology?

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The recent foresight study on planetary health and human wellbeing conducted jointly by the International Science Council and the United Nations Environment Programme highlights that, as global crises join forces, the world must adopt a forward-looking approach to protect human and planetary health. Possibly, the most significant contribution of the study is to draw our attention to the underlying causes of change, which in some cases may seem remote from modern ecology. This important shift in the conceptual framework of how such drivers influence ecosystem benefits and human wellbeing is needed and will have implications for methods of study, and for guiding strategies and interventions. In this context, the world community of ecologists is confronted inter alia with the following questions: Are the principles of ecology still valid in the era of the 'Anthropocene'? Is the next generation of ecologists being trained in an adequate manner and what is the role of transdisciplinarity therein?

Regenerating soil organic matter for the benefit of climate and food production: A systemic multifaceted approach

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Soil organic matter (SOM) provides critical agroecosystem services. Its stewardship, including its preservation and further accrual, is key to increasing resilience of food production to a changing climate, and to avoid an irreversible climate crisis. Recently our understanding of the processes and drivers of SOM formation and persistence has advanced within a coherent framework. Applying this framework can support the design of integrated measurement-modeling platforms to inform best agriculture management practices for the stewardship of SOM. I will present our latest framework to conceptualize SOM structure, formation, and persistence, and a coherent measurement-modeling approach we implemented and use. I will illustrate how SOM may affect soil properties which in turn determine the soil's capacity for functioning and ability to provide desired outcomes including supporting plant productivity, and climate adaptation and mitigation. Finally, I will provide examples of applications of our approach to quantify and forecast SOM changes under regenerative agriculture.

Enhancing marine conservation through better marine spatial planning: Science gaps, practical solutions, and recommendations

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Marine spatial planning is an integrated marine governance process aiming to balance sustainability and exploitation objectives, but despite this, it does not yet have a clear capacity or set of widely accepted methods to help achieve EU and global environmental policies. As yet many European MSP and marine protected area (MPA) designation processes are currently uncoordinated. In this presentation I will give a quick overview of how MSP should support conservation goals and provide examples of marine spatial plans that have conservation objectives. Further I will detail the science and knowledge needed to assess potential benefits of marine spatial planning with offshore wind, fisheries, and conservation targets. Finally, I will show how the newly developed MarinePlan decision support system can guide both a better alignment of MSP and conservation planning processes and standardised process to define marine protected areas that account for MSP.

Parte II

Comunicazioni orali

Reti trofiche ed ecologia di comunità

1

Glaciers' ecological networks: Insights from two Italian glaciers

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Glaciers are increasingly recognised as ecosystems in their own right, yet the ecological processes underpinning life on ice remain poorly understood. In particular, we lack detailed knowledge of supraglacial biodiversity, population structures, trophic interactions, and the fluxes of energy and matter that sustain these extreme habitats. Here, we present the first insights into the ecological networks of two Italian glaciers: Forni (in Stelvio National Park) and Mandrone (in Adamello Regional Park), both located in the Central Alps. Using an integrated suite of morphological and molecular tools—including DNA barcoding, environmental DNA (eDNA) metabarcoding, population genetics, and stable isotope analysis—we characterised community composition and reconstructed food web structures. To date, we have identified over 683 taxa on Forni and more than 656 on Mandrone, encompassing bacteria, protists, fungi, mosses, tardigrades, and arthropods. Our results reveal simple but structured ecological networks, driven by allochthonous organic inputs and local primary production, mainly by Cyanobacteria. In both glaciers, tardigrades (e.g., *Cryobiotus klebelsbergi*) dominate the communities of cryoconite holes (small ponds on the glacier surface). On Forni, a more complex trophic cascade connects springtails (*Collembola*) to predatory beetles (*Nebria* spp.) and spiders (*Linyphiidae*, *Pardosa* spp.), besides non-biting midges (Chironomidae) in the bedieres, highlighting the emergence of higher-order interactions. In contrast, Mandrone supports a less articulated supraglacial web. These findings underscore both the ecological value and the vulnerability of glacier-associated networks, which are rapidly shrinking under climate change. The results have direct implications for conservation planning: glacier ecosystems are listed among priority habitats under the EU Habitats Directive (92/43/EEC, code 8340), and our data contribute to defining conservation targets and future monitoring strategies for these vanishing environments.

First survey of epibenthic diatom assemblages on marine seagrasses in the Arabian Gulf

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Microphytobenthic assemblages are fundamental components of shallow coastal marine environments, contributing significantly to primary production, nutrient cycling, and mediating biogeochemical interactions between sediments and water column. Although all microalgal classes are represented in these communities, diatoms (Bacillariophyceae) are the most dominant. Epiphytic diatoms, in particular, are able to colonize the leaf surfaces of marine seagrasses, forming highly dynamic habitats. Despite their high productivity and recognized sensitivity to environmental changes, these communities are frequently underrepresented in ecological monitoring efforts. Studying them is particularly crucial for understanding ecosystem stability and response to stress in extreme and sensitive regions like the Arabian Gulf, known for high salinity, high temperatures, and increasing anthropogenic pressure. This study explores the diversity and relative abundance of epiphytic diatom communities associated with three seagrass species (*Halodule uninervis*, *Halophila stipulacea*, and *Halophila ovalis*) along the Saudi Arabian coast of the Arabian Gulf, with sampling conducted during both winter and summer seasons. Through scanning electron microscopy (SEM), we identified dominant taxa and evaluated seasonal and spatial variation in assemblage composition. Diatoms were confirmed as the most abundant epiphytic group, with the genus *Cocconeis* comprising 96.2% of total diatom abundance and represented by four major species. During the winter, the highest abundance was observed at the central sampling site, while in summer, it peaked in the northern location. *Halodule uninervis* showed higher abundance of epiphytic diatoms in winter, while *Halophila ovalis* was the most colonized during summer. The composition of the diatom communities was predominantly influenced by seasonal variation, whereas site-specific differences had a limited impact. These findings enhance our understanding of diatom-seagrass associations, particularly in extreme environments such as the Arabian Gulf, and underscore their potential value as bioindicators in future monitoring programs.

Plankton food webs as indicators of the ecosystem status to support the Marine Strategy Framework Directive: a case study from Campania region (Italy)

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The European Union's Marine Strategy Framework Directive (MSFD) aims to assess a "Good Environmental Status" (GES) based on the analysis of 11 Descriptors. Among them, investigating the food webs (Descriptor 4) helps to evaluate the impact of anthropogenic and climate change on the functioning of marine ecosystems. The present study analyzed, with specific ecological indicators, , how environmental conditions (e.g., river inputs) can affect the structure and functionality of planktonic food-webs. An ecological-network modeling approach (based on *Ecopath*) was conducted along the coast of the Campania Region (central Tyrrhenian Sea, NW Mediterranean) in the three main gulfs (Gaeta, Naples, and Salerno), during two seasonal snapshots (autumn 2020 and summer 2021). The results revealed clear seasonal structural diversity of the planktonic food web, with autumn 2020 showing less network organization, especially in Gaeta, than summer 2021. Specifically, in autumn, Gaeta's microbial food web was primarily dominated by detritivores (e.g., doliolids, appendicularians and salps), whereas in summer, it was centered around primary production and herbivorous processes. Integrating the analysis from satellite data, it was possible to attribute this autumn trophic condition to increased inputs of organic matter of terrestrial origin, transported by the main rivers present in the Gulf of Gaeta. The proposed approach is designed as a tool to inform marine policies and coastal planning, supporting the role of planktonic food-webs in highlighting those coastal marine sectors whose ecosystems are more vulnerable to anthropogenic and natural disturbances.

Ecological community succession on plastic panels in a polluted marine environment

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This study investigated the ecological succession of prokaryotic and eukaryotic communities colonizing pristine polystyrene panels, used as model substrate, deployed for 25 weeks in an anthropogenically impacted environment, such a harbor. Using the eDNA metabarcoding targeting the 16S and 18S rRNA genes, we tracked the temporal dynamics of communities, highlighting shifts in biodiversity and community structure on plastic surfaces. The microbial biofilm assemblages demonstrated relative temporal stability, with *Rhodobacteraceae* (16.97%) and *Flavobacteriaceae* (17.99%) consistently dominant, confirming their ecological roles as pioneer and persistent taxa in biofilm formation on plastics. Eukaryotic colonization patterns reflected more pronounced succession, shifting from Alveolata (63.39%) and Stramenopiles (23.53%) during early stages to communities enriched in Chlorophyta (20.14%) and Opisthokonta (94.32%) over time. Alpha diversity, based on ASV richness, ranged from 1,875 to 2,481 for eukaryotes and 159 to 405 for prokaryotes, indicating dynamic succession of communities as part of natural processes. Notably, putative plastic-degrading prokaryotes were detected suggesting microbial adaptation and potential functional roles in polymer degradation. Finally, trophic profiling of the eukaryotic assemblages revealed a heterotroph-dominated system. The observed temporal changes reflect ecological succession modulated by local environmental stressors. Our findings underline the role of plastic debris as a different ecological habitat that harbor diverse microbial and eukaryotic assemblages including invasive or potentially harmful species, which could influence local biodiversity patterns and alter trophic interactions in marine ecosystems. These dynamics pose ecological risks and highlight the urgent need for improved plastic waste management strategies, particularly in semi-enclosed coastal systems, such as harbors, where limited water circulation promotes plastic accumulation with ecological implications.

New insights on *Acanthaster plancii* outbreak in the Gulf of Oman (United Arab Emirates)

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The crown-of-thorns starfish (*Acanthaster plancii*) is one of the most effective coral predators in Indo-Pacific coral reefs. Its biological traits, such as high fecundity, pelagic larval dispersal, and opportunistic feeding, enhance its capacity to form dense and ecologically disruptive aggregations. Furthermore, by preying on reef-building corals, particularly fast-growing species, it can trigger widespread coral mortality and structural degradation. The Gulf of Oman, particularly the reef sites of Hole in the Wall and Martini Bay (Khor Fakkan), experienced a first outbreak in January 2024 and remains particularly vulnerable to recurring infestations. This study aimed to investigate the population dynamics, feeding preferences, and genetic identity of individuals of *Acanthaster* spp. resembling different species morphologically, and evaluate the short-term effectiveness of targeted culling as a control measure. Fieldwork was conducted between January and June 2024 using a multi-method approach. Coral cover and benthic composition were assessed through photo-quadrat surveys and analysed with Coral Point Count with Excel. Roving diver observations provided data on prey selectivity, individual size distribution, and relative abundance. Tissue samples from collected individuals were processed for molecular and phylogenetic analysis to assess haplotype diversity. Manual culling operations were carried out in June 2024 to reduce population density and assess potential ecological response. Results revealed a genetically homogeneous *A. plancii* population with low haplotype diversity. Coral cover was dominated by *Porites*, which showed clear signs of feeding avoidance. Selective predation on other taxa and a predominance of adult individuals were observed. Notably, culling efforts resulted in an 86% reduction in starfish density, indicating their immediate efficacy as a mitigation strategy. This study presents the first comprehensive assessment of *A. plancii* outbreaks in the Gulf of Oman, underscoring the importance of ongoing monitoring, genetic surveillance, and targeted management, including controlled culling, to enhance coral reef resilience in the face of increasing ecological pressure.

An ecological model to investigate how specialization shapes abundance, persistence and rarity in plant-pollinator networks

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The functioning of plant-pollinator mutualistic networks is crucial for ecosystem service provisioning and biodiversity maintenance. These communities are, however, heavily affected by both global and local scale environmental and human-induced changes, as shown by the alarming rate at which wild pollinators' abundance and richness are declining worldwide. We propose an ecological, process-based mathematical model describing the dynamics of pollinators and plants, properly mediated by reward resources. Our model explicitly accounts for the main interactions of both facilitative and competitive nature that occur both within and between the two guilds. In this study, we focus on fragmented landscapes, akin to those that can be observed in urban and peri-urban environments. We contrast the outcomes from a novel ecological model with empirical evidence to investigate how the degree of specialization (and the resulting niche width) can determine a species' temporal persistence and abundance at the community level, and its rarity at landscape level. Our results suggest that few generalist pollinators form a core of abundant, persistent and widely distributed species, while increasing specialization is generally associated with low abundance, low persistence and high turnover between patches. Specialists, however, are crucial to maintaining high levels of biodiversity within the community. This finding highlights the importance of ecological connectivity, through which local extinctions can be counter-balanced by recolonizations. Our analysis shows how a mechanistic model accounting for the interplay between the species traits and the structure of plant-pollinator networks can serve as a tool to investigate important ecological mechanisms driving community composition, dynamics and the resulting biodiversity patterns.

Influence of spring conditions on the distribution and abundance of ichthyoplankton in the Southern Tyrrhenian Sea (Western Mediterranean)

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It is now widely recognized that the study of ichthyoplankton ecology in the marine ecosystem can provide important data on the life cycle of adult individuals and, consequently, for a rational use of fishing resources. Despite a good knowledge of the adult stages of these fish species, scarce information is available on the ichthyoplankton community and its response to environmental variables. The aim of this study was to define the major composition patterns and the community structure of the ichthyoplankton assemblage in the southern Tyrrhenian Sea and to assess the influence of environmental factors which control these patterns. A multidisciplinary survey was carried out in a wide coastal area of Sicily during early spring (April 16-24, 2007). At 24 stations, ichthyoplankton was sampled, using a Bongo net (diameter, 60 cm; mesh size, 500 µm). The temperature profiles highlighted relatively higher superficial values to the western area rather than to the eastern one. Highest oxygen values were found at depths between 30 m and 70 m, while the DCM (Deep Chlorophyll Maximum) was found between 60 m and 75 m. Larval fish community consisted of 2073 individuals, further to 2750 fish eggs. Thirty-three species belonging to seventeen families were identified. *Myctophum punctatum* was the most abundant species (20.9%), followed by *Cyclothone braueri* (11%), *Lampanyctus pusillus* (10.2%), *Lampanyctus crocodilus* (9%), and *Hygophum hygomii* (4.6%). The family most represented was Myctophidae (61.6%, 13 identified species), followed by Gonostomatidae (12.4%, 2 species). From NMDS analysis it is evident that some species are clearly distributed in some areas that show different environmental characteristics, as showed by comparisons of *Arnoglossus laterna*, *Notoscolepus elongatus*, *Capro aper* which prefer more temperate waters, versus other species (*Lobinchia gemellarii, Boops boops,* and others) which prefer waters with higher salinity and fluorescence.

Supraglacial algae biodiversity in an alpine glacier (Forni Glacier, Lombardy)

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Glaciers and ice sheets are particularly threatened by the loss of biodiversity due to the widespread melting induced by climate warming. Assessment of the biodiversity in these endangered ecosystems is timely and critical. However, few studies have characterized the algal communities in alpine supraglacial environments, despite their importance for surface albedo, carbon cycle, and global biodiversity patterns. Here, we present the first study of algal biodiversity at a high precision level in the Forni Glacier (Lombardy, Italy) based on microscopic observations of terrestrial and aquatic supraglacial habitats. We identified different supraglacial habitats on the glacier surface, characterized by "terrestrial" substrates (dirt cones, cryoconite sediment, sparse cryoconite) and "aquatic" substrates (bedieres, snow, bare ice, water of cryoconite holes). Biovolume, diversity, and community composition have been assessed at the beginning (July) and the end (August-September) of the ablation season for two consecutive years (2023 and 2024). Our results revealed that the algal biovolume, diversity, and community composition varied spatially and temporally in the Forni Glacier. More specifically, we demonstrated that each supraglacial habitat hosts a distinct community, highlighting the significance of microlocal factors in shaping algal assemblages. By expanding our knowledge of glacier biodiversity, this study constitutes a significant step in forecasting the incidence of algal blooms and anticipating the effects of biodiversity loss in alpine glaciers.

Fish Community Structure and Condition Across Three Nigerian Lakes: Implications for Biodiversity and Conservation

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The fish communities of three Nigerian lakes (Ureje, Egbe, and Ero) were assessed to understand biodiversity status, community structure, and condition, with implications for conservation and sustainable management. Data were collected over a period of seven months (April–October 2024) using a combination of biodiversity metrics (species richness, diversity indices, and relative abundance) and population health indicators (length–weight relationships and condition factors). Water quality parameters were also measured to evaluate their influence on fish communities. Across the three lakes, a total of 12 fish species were recorded, with six species common to all sites. Species richness varied slightly, with Ureje supporting seven species, Egbe eight, and Ero nine, representing 4, 6, and 6 families respectively. Ero Lake exhibited the highest species richness and diversity, supported by a statistically significant Margalef index ($P < 0.05$). Oreochromis niloticus was the most abundant species overall, while rare species such as Heterotis niloticus were only found in Ero Lake. Analysis of growth patterns revealed that all specimens exhibited allometric growth, with fish from Ero Lake predominantly showing positive allometric growth ($b > 3$), suggesting favorable ecological conditions. The condition factor ranged from 0.48 (Parachanna obscura in Ureje Lake) to 3.01 (Tilapia zilli in Ureje Lake), with no significant differences between lakes ($p > 0.05$). While fish abundance showed a positive correlation with dissolved oxygen and temperature, no significant relationship was found between water quality variables and growth coefficients or condition factors. This integrated study highlights the role of local environmental variables in shaping fish community composition and health. The findings provide updated baseline data crucial for community-level conservation strategies and management actions aimed at preserving the ecological integrity and biodiversity of these freshwater ecosystems.

DNA metabarcoding of the gut microbiota in an Italian alpine dung beetle community

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Dung beetles (Coleoptera: Scarabaeoidea) play a key role in several ecological processes and services, including dung removal, maintaining soil fertility, nutrient cycling, and reducing greenhouse gas emissions. The gut microbiota of dung beetles is involved in many of these ecological services. In the present study, we analysed the gut microbiota of 12 species belonging to five different tribes and different functional groups based on their nesting strategies. Ten wild individuals per species were collected from cattle dung in the Western Alps. We analysed the prokaryotic and fungal communities using high-throughput sequencing of the 16S rRNA gene and the ITS2 region, respectively. To assess microbiota variation, we applied distance-based redundancy analysis (db-RDA) using Bray-Curtis dissimilarity and conducted envfit analyses to determine which factors best explained microbial community composition. For prokaryotes, host species identity accounted for the greatest variation (R^2 = 86.6%, p = 0.001), followed by tribe (R^2 = 60.6%, p = 0.001) and functional group (R^2 = 52.6%, p = 0.001). A similar trend was observed for fungal communities, with host species again explaining the most variance (R^2 = 78.1%, p = 0.001), though tribe (R^2 = 28.3%, p = 0.001) and functional group (R^2 = 27.6%, p = 0.001) had lower explanatory power. Interestingly, db-RDA results showed that dung beetle species differed more in their prokaryote than fungal composition. Furthermore, species accumulation curves indicated that microbial diversity increases with the number of dung beetle species included, highlighting the importance of taxonomic breadth in microbial studies. These results suggest that when dung beetles have a uniform diet, host phylogeny is the dominant factor shaping the gut microbiota, with significant implications for understanding gut microbial diversity of dung beetle communities.

Spatial and temporal trends of macroinvertebrates communities in small Alpine catchments

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Freshwater environments are globally recognised as biodiversity hotspot, hosting 10% of all known species in just 1% of Earth's surface. These ecosystems are not only important for aquatic species but also surrounding environments, providing vital ecosystem services. However, Alpine freshwater environments are both fragile and under pressure by climate change and human activities. For instance, aquatic insects make up a significant portion of freshwater biodiversity, but due to their sensitivity to habitat alterations, such as channelization and loss of longitudinal connectivity, and the rigid life cycle, species that were once common in Europe have now disappeared locally or have become extinct. In our study, we investigated spatial and temporal trends of freshwater macroinvertebrates across 120 sampling points located in small alpine catchments in the Autonomous Province of Bolzano (Italy). Sites were selected considering the entire stream and river network in the area, including catchments smaller than 10 km^2, which are not considered within the EU Water Framework Directive (2000/60/EC), and classified in different categories based their water origin, elevation, slope, geology of the riverbed and discharge. Firstly, we analysed the benthic communities, observing differences in their abundance and composition between the different stream categories. Thus, we examined the influence of environmental and chemical variables on the macroinvertebrate community structure. Finally, we'll present preliminary results of four years temporal trends of a selection of 24 different sites, aimed to investigate the response of macroinvertebrates communities to different environmental conditions across the study area. Given the key role of macroinvertebrates in these ecosystems, it is crucial to characterize and understand the freshwater community dynamics in the context of climate change and human impacts. Our study provides relevant information about distribution and trends of macrobenthic diversity, helpful to build and promote innovative and more efficient water quality biomonitoring and management policies.

Investigating phenological mismatches between bumblebees and their brood parasites in a bumblebee-diversity hotspot

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Cuckoo bumblebees (*Bombus*, subgenus *Psithyrus*) are obligate social parasites of other bumblebee species. Although they share habitats with their hosts, their parasitic lifestyle imposes additional ecological and phenological constraints, such as a dependence of the temporal window to host development and activity patterns. A delayed emergence is thought to be adaptive, yet phenological mismatches between hosts and parasites remain largely unquantified, and the extent to which these dynamics are modulated by the environmental context remains unclear. With this study we examine whether mismatches in host–parasite timing are consistent across parasite species and how these coevolved phenologies may be affected by environmental changes. To this end, we analysed phenological patterns of multiple host–parasite pairs naturally co-occurring in a southern Mediterranean hotspot of bumblebee diversity. As expected, cuckoo bumblebees exhibited narrower and more temporally restricted flight periods compared to their hosts, suggesting a constrained phenological strategy tightly aligned with host colony cycles. However, we found distinct patterns of asynchrony depending on the examined host–parasite pair. These results suggest that phenological mismatches are not fixed traits but are shaped by species interactions and ecological contexts. Still, host phenology displayed a significant and strong association with temperature, particularly preseason warming, while parasite responses were weaker and more variable, suggesting limited ability to cope with temperature changes. This different response to temperature may compromise coevolved synchrony under climate change, which deserve consideration in conservation initiatives applied to pollinator communities.

Metabolic responses to climate warming scenarios in the Adriatic Sea

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The unprecedented climate warming is profoundly altering all aspects of life. Metabolic rate, a key physiological and ecological trait, mediates the effects of climate change, providing significant predictive power for forecasting its impact. Understanding and accurately predicting metabolic responses to changing temperatures is therefore essential for anticipating species' vulnerabilities, adaptive capacity, and broader ecosystem consequences. This is especially relevant for invertebrate communities, which play critical roles in ecosystem functioning and are particularly sensitive to thermal shifts. The urgency is heightened in the semi-enclosed Adriatic Sea, where pronounced changes in invertebrate populations and community composition have recently been observed. Here, we aimed to assess how the standard metabolic rate (SMR) of invertebrate species in the Adriatic Sea responds to temperature changes and to project its change under various IPCC climate emission scenarios by 2100. We measured the individual SMRs of nine invertebrate species collected from locations spanning the southern to northern Italian coast of the Adriatic Sea, across two acclimation temperature levels. Our findings indicated a shallower-than-expected dependency of SMR on body mass, and on temperature. We further showed that metabolic rates in Adriatic species are projected to increase by ~ 10–30 %, from the most conservative to the most severe climate change scenarios. This finding provides a baseline for understanding elevated minimum energy costs under expected temperature increases, enabling predictions of higher-order, metabolism-related ecological processes

Reassessing the ontogenetic trophic shift in *Caretta caretta*: insights from a systematic review and stable isotope analysis

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The loggerhead turtle (*Caretta caretta*) is one of the most iconic, yet vulnerable, species of marine megafauna. A well-established concept in marine turtle ecology is that *C. caretta* migrates between oceanic and neritic habitats, changing its foraging strategies throughout its life history. This study aims to shed light on the diet of *C. caretta* in the Mediterranean Sea by combining a systematic review with a stable isotope analytical approach. Data extracted from sixteen original articles were analysed using multivariate techniques revealing high variability in the feeding habitat (benthic vs. pelagic), while life-stage-based dietary segregation did not occur. This unexpected result may reflect publication biases in the definition of life-stage thresholds and associated dietary shifts, or perhaps the need to revise the classic pelagic–benthic ontogenetic shift paradigm. To explore this further, we analysed stable isotope data from multiple tissues with different turnover rates, collected from juvenile to adult loggerhead sea turtles stranded along the Sicilian coasts from 2021 to 2025. These data suggest, in contrast, a gradual dietary and trophic-level shift with growth, with juveniles relying more on low-trophic level pelagic prey and adults on high-trophic level benthic prey. Sub-adults also appear to change their dietary patterns over time, consistent with ontogenetic dietary transitions. Moreover, differences in isotopic results among tissues with different turnover rates emerged, with interesting implications for the understanding of recent versus past dietary patterns. Overall, these findings highlight critical knowledge gaps and biases in the existing literature and emphasize the need for additional empirical data to strengthen current knowledge on sea turtle trophic ecology and inform effective conservation strategies for *C. caretta* in the Mediterranean Sea.

Trophic relationships among microarthropods along a vertical gradient

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Soil microarthropods, through their feeding habit, are widely recognized as responsible for organic matter turnover and energy flow. A species-level approach is essential to reveal fine-scale ecological patterns and spatial organization within their communities. The present research, combining species-level identification with trait-based analysis, investigated the distribution of the main groups of microarthropods such as Oribatida and Collembola according to the resource quality. The research was performed in a temperate beech forest in Southern Italy and the samples were collected in a 20x20 plot along a vertical gradient: fresh litter, fragmented litter, surface mineral soil (depth: 0–5 cm) and deep mineral soil (depth: 5–10 cm). Microarthropods were extracted by Berlese-Tullgren funnels, and Oribatida and Collembola were identified at species level. Body size and metabolic rate were measured individually, whereas the functional traits, such as feeding and reproduction strategies, were assigned based on the literature. Finally, the resource quality was estimated as C/N ratio. The results showed that fungal feeders, representing the 61% of the microarthropod abundance, dominated the deep mineral soil and the litter feeders, representing the 53% of the microarthropod abundance, dominated the fresh litter layer. The metabolic rate decreased along the vertical from 0.013 J h^{-1} in fresh litter to 0.003 J h^{-1} in the deep mineral soil. In conclusion, the vertical gradient filtered microarthropod communities based on their feeding strategies rather than selecting them according to taxonomic affiliation, promoting a spatial partitioning of energy sources. Indeed, organic substrates supported fast-living consumers with higher energy demands, whereas law-quality substrates favoured consumers with specialized feeding strategies and conservative life-history strategies.

Effetti del disturbo sui sistemi ecologici

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The principle of energy equivalence as a guideline for the implementation of closer-to-nature forest management.

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Human activity (e.g. harvesting) represents one of the most frequent disturbances in forest ecosystems. Recent documents from the European Commission (2023) states that future forest management in the Union should focus on practices that ensure the various contributions forests provide to humanity, with particular emphasis on biodiversity conservation and climate change mitigation. Furthermore, there is a recognized need to safeguard natural dynamics as much as possible and to draw inspiration from them in order to propose management systems that reduce the severity of disturbance caused by timber harvesting. The aim of this work is to propose a universal ecological principle—the Energy Equivalence Principle (EEP)—as a guideline for closer-to-nature silviculture. The principle states that the density of individuals in different size classes scales inversely with the resource consumption of that particular size class. Under this condition, each size class consumes a constant amount of resources. Using tools from statistical mechanics, it can be demonstrated that this distribution is the one that optimizes the overall use of available resources. This work presents some empirical tests showing that, in forests approaching old-growth conditions, community structure aligns with the predictions of the EEP, while forests that have experienced disturbances exhibit structures that deviate significantly from those of optimal resource use. It is therefore possible to offer forest managers a universal structural-functional model (i.e., one applicable to forests worldwide) that can guide interventions to minimize the impacts of human activity and help steer forest communities toward greater functional efficiency—and, consequently, greater stability.

A Bio-Based Alternative for Emerging Contaminants: The Promise of *Galdieria daedala*.

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In recent years, concepts such as the circular economy and the 3Rs (Reduce, Reuse, Recycle) have reshaped our priorities. Traditional wastewater treatment plants often fall short in terms of sustainability standards; they require a significant amount of space, time, and energy to remove contaminants. Moreover, they often are inefficient against emerging pollutants, such as pharmaceuticals, posing a risk for the environment. A promising alternative lies in the use of the extremophilic red alga *Galdieria daedala*, which thrives in high-temperature and low-pH environments. This alga is particularly resilient as it can exploit different metabolic strategies for its growth which can be autotrophy, heterotrophy, or mixotrophy, under aerobic and anaerobic conditions. All these characteristics make it suitable for a heterogeneous and dynamic context such as wastewater and eliminate the need for oxygenation, reducing operational costs and energy demands. Moreover, *G. daedala* is known for its ability to remove carbon, nitrogen, phosphorus, heavy metals, and pathogens from its media. Given its depurative potential, *G. daedala* may represent a promising tool for emerging pollutants removal, especially pharmaceuticals. In this study, data obtained from the adaptation of *Galdieria* to different pH values and different nitrate sources will be presented, followed by an evaluation of the toxicity of four different drugs on the microalga, in particular: two antibiotics (ciprofloxacin and amoxicillin) and two nonsteroidal anti-inflammatory drugs (diclofenac and ibuprofen). These data will allow a more precise evaluation on the depurative effectiveness of *G. daedala* to phytoremediate municipal wastewater in a single-step process, thus allowing the removal of multiple contaminants simultaneously in a more sustainable process. The findings will contribute to the development of nature-based solutions to mitigate chemical and biological disturbances in aquatic systems driven by anthropogenic activity.

The joint diversity of plant and springtail communities in Mediterranean urban ecosystems

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The extent to which green areas can preserve biodiversity and ecological functioning in urban ecosystems can depend upon factors acting at multiple scales, including their management. The complexity of terrestrial ecosystems, where above- and below-ground communities participate in joint dynamics, further limits our prediction of the effects of these factors, as well as our capability to develop sustainable management approaches. With a view to shed light on the joint variations in the biodiversity of above- and below-ground communities in managed urban ecosystems at small spatial scale, we studied the richness, composition and abundance of plants and of springtails in a Mediterranean urban lawn subjected to different land uses (pathways and tree rows), which was regularly irrigated, fertilized and, before the study, mowed. Plants were collected in 24 plots (25x25 cm^2), identified at the species level and quantified in terms of cover, number of individuals and dry mass. Springtails were collected through 2 soil cores (78,5 cm^3) next to each plant survey plot, extracted using MacFadyen funnels, identified at the species level and quantified in terms of number of individuals. Plant functional traits were obtained from literature, whereas those for springtails were obtained both through the analysis of calibrated photographs of each animal and from literature. Findings highlighted that land use explained a substantial proportion of the spatial variability in the diversity of plants and springtails. Changes in vegetation were observed primarily at the structural level, while the spatial variations in springtail communities were mainly recorded at the functional level. In terms of community interactions, results suggest that management directly controls vegetation diversity and indirectly affects springtail communities by acting on key plant species, which functionally couple above- and below-ground ecological dynamics, likely by affecting soil characteristics such as the pore-size distribution and the availability of resources.

The role of plant traits in shaping fire-prone communities

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Fire is a critical ecological disturbance with both ecological benefits and socio-economic implications. Across fire-prone ecosystems, different fire regimes can be found, reflecting a combination of climatic factors and of different plant species characteristics. While the role of plant characteristics such as fuel load and flammability has long been recognized, recent theoretical studies have emphasized how the composition of other plant traits linked to fire responses, but also to growth and competitive ability can be strongly related to the fire regime and to the resilience of whole ecosystems. Here we will focus on how plant traits related to flammability and fire responses, but also to growth and competitive ability, are related to the fire regime and the overall ecosystem resilience in different ecosystems and for various climates around the globe. To address this aim, we combined statistical and mathematical modelling. We expanded on an existing dynamical model representing vegetation succession and vegetation-fire feedback. We also analysed global datasets of plant traits (e.g., TRY, AusTraits, Flamits), community composition (from sPlot), climate data, and remote sensing fire data (from MODIS/VIIRS). We show that traits related to flammability are increasingly present in communities with more frequent fires, both for forests and for open ecosystems. Noticeably instead, trait related to fire responses (e.g. resprouting, bark thickness) display different relationship with fire frequency for forest and open ecosystems. The model results also show that plant trait syndromes were fundamental in determining fire regimes and the occurrence of different plant communities under the same climatic and environmental conditions. Our findings provide valuable insights for fire management, ecosystem restoration, and reforestation efforts by highlighting the complex influence of community functional composition on fire dynamics. These findings underline also the importance of including the plant fire response when modeling fire ecosystems, for example, to predict the vegetation response to invasive species or to global change.

Microplastic pollution in a lowland spring-fed watercourse of Northwestern Italy

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Microplastic (MP) pollution is increasingly recognized as a global environmental concern, both in marine and freshwater ecosystems, with the latter acting both as MP transport pathways and accumulation zones. Despite the growing interest and research, there is still a lack of information about MP pollution in freshwater systems, especially for lowland hydrological networks, where small spring-fed watercourses are particularly vulnerable, due to their proximity to human settlements and agricultural areas, where the risk of continuous MP input increases, leading to potential long-term environmental accumulation. Moreover, regarding the biotic compartment, organisms may exhibit different degrees of MP accumulation, depending on their feeding strategies, habitat use, and ecological roles. In this study, we investigate MP pollution in a lowland spring watercourse from Northwestern Italy (Sacchetti Ditch, Friuli Venezia Giulia), assessing temporal MP trends both in abiotic (water and sediment) and biotic compartments. For this purpose, the mollusk *Unio elongatulus* was chosen as it is widely distributed in the study area and may be heavily affected by MP contamination due to its filtering activity. Bimonthly sampling activities highlighted MP contamination both in abiotic matrices and mollusks, while polymer analysis identified different MP types, such as polyethylene terephthalate (PET), polypropylene (PP), polyethylene (PE), and polyamide (PA). No significant temporal trends were detected in abiotic/biotic matrices, suggesting continuous MP inputs from untreated wastewater discharge, runoff, and agricultural/industrial effluents. *U. elongatulus* showed close association with MP content in water, and the Strauss selectivity index showed that PP was preferentially ingested, while PE and PA were significantly avoided, suggesting that polymer properties (such as density) can affect bioavailability and uptake. Oure results reinforce the role of filter-feeding bivalves as bioindicators of MP pollution and highlight the need for targeted management strategies to mitigate MP pollution in small but highly contaminated water bodies.

Tracing Disease-X risk in Indonesia and India with high-resolution ecological and mobile data: from emergence areas to nodes of global spread.

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Projecting scenarios for the spread of emerging infectious diseases well ahead of a possible next "Disease X" pandemic is a critical global priority. To assess the spillover and diffusion risk of pathogens in source regions, a One-Health approach calls for the simultaneous monitoring of (*i*) key reservoir species to detect zoonotic emergence, and (*ii*) local human presence and mobility patterns toward large-scale spread hubs. We propose a data-driven framework to face both challenges, by innovatively estimating the risk of disease emergence and spread from high-resolution ecological and mobile-phone data. Indonesia and India were selected as focal case studies to demonstrate our method for Nipah (or a Nipah-like Disease-X) circulating in *Pteropodidae* bats, known reservoirs of WHO Blueprint viruses. Using a multicriterial framework, we couple the *hazard* – from IUCN spatial data on suitability and distributions of reservoir species - with the *exposure*, proxied through fine-scale mapping of human presence from a large World Bank dataset of mobile devices. In so doing, we show how the likelihood of zoonotic spillover correlates with key ecological stressors - such as extent and rate of deforestation - and how development drivers (like expanding tourism) may amplify the consequent spread potential. Building upon the estimated spillover risk, we assessed the threat of disease spreading to airports and ranked them by potential disease transmission risk (PDTR). Contrary to the common assumption that air traffic alone may satisfactorily capture PDTR, we find that minor yet crucially located airports can be pivotal to control strategies. Overall, our findings underscore the urgency of integrating key ecological drivers – such as habitat transformation – to improve the design of next-generation policy plannings. At the same time, our method provides decision-makers with an innovative tool to identify nodes and connections of greatest vulnerability at regional scales that must be prioritized to avoid international threats.

Cyanobacteria like it salty? A long-term study from Lake Trasimeno

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Lake Trasimeno is a closed lake known for its shallow waters and serves a valuable sentinel site for assessing climate-driven impacts. It is also a long-term ecological research (LTER) site and has been the subject of naturalistic and ecological research since the last century. The LTER network plays a pivotal role in tracking and forecasting ecosystem responses to environmental variability and anthropogenic pressures. Characterizing the phytoplankton community structure is essential for evaluating ecosystem status and detecting shifts in environmental conditions. This study focuses on the analysis of a continuous 50-year monthly time series of phytoplankton data. Our findings reveal significant long-term changes in phytoplankton dynamics, including shifts in species composition, community structure, seasonal succession patterns, and overall diversity. We observed a general shift in dominance toward Cyanobacteria, accompanied by a decline in other algal classes and orders, as well as reduced community evenness. Salinity and water column stability were identified as the main potential driving forces behind the observed seasonal succession changes. In contrast, temperature and water depth appeared to have an unclear influence, with no consistent or well-defined patterns emerging from the analysis. Additionally, this study applied the morpho-functional (MFG) groups index as a valuable tool for assessing phytoplankton community structure. Morpho-functional groups classify phytoplankton based on ecological and morphological features. Grouping phytoplankton species by functional traits enhances the understanding of community succession. Furthermore, using indices that consolidate taxonomic information into functional units provides deeper insight into the ecological assessment of the Lake Trasimeno ecosystem.

Sedimentary organic matter and meiofauna responses to a dystrophic event in a coastal lagoon (S'Ena Arrubia, Western Sardinia, Italy)

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Coastal lagoons provide important ecosystem services like biodiversity enhancement, nutrient cycling, and climate change mitigation. Despite their natural variability, lagoons are sensitive to climatic and human pressures, including eutrophication. Excess nutrient loads cause algal blooms, oxygen depletion and mass mortalities, occasionally resulting in dystrophic crises. Sedimentary organic matter (OM) attributes and meiofaunal communities can either detect environmental change or assess lagoons health. We investigated seasonal changes in meiofauna and sedimentary OM characteristics also intercepting the occurrence of a summer dystrophic event in the S'Ena Arrubia Lagoon (Western Sardinia). Three areas along a salinity–trophic gradient, each comprising two stations, were sampled seasonally and immediately after a dystrophic event caused by high temperatures and excess organic loads. Physical-chemical parameters were measured, and three sediment cores collected for the analysis of meiofauna and sedimentary OM quantity, biochemical composition, and degradation rates. The results revealed a response gradient across the lagoon, driven either by seasonality or the dystrophic event. The innermost lagoon was the most affected by the dystrophic event, with meiofaunal density and diversity dropped by 53% and a nematode-dominated community. OM contents and protein turnover time increased, indicating enhanced primary production and reduced microbial activity. After the event, meiofaunal abundance and diversity partly recovered, with pioneer taxa appearing, whereas OM composition shifted toward a more refractory composition. The outer lagoon area, less diverse, was much less affected. Our findings suggest that the dystrophic event made the innermost lagoon more vulnerable to future anthropogenic and climatic stressors, and highlight the need for prosecuting the lagoon monitoring. This study has been conducted within the framework of the project e.INS www.einsardinia.eu (Next Generation EU- PNRR - M4 C2 I1.5 CUP F53C22000430001) and attending PhD in Life, Environmental and Drug Sciences (UniCa, Cycle XXXVIII), funded by DM 352/2022 (Next Generation EU-PNRR) and IMC Foundation).

Machine learning-based framework for forecasting mass-mortality events in Mediterranean coralligenous habitats

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Global warming is triggering increasingly frequent mass-mortality events (MMEs) in Mediterranean benthic habitats. Documented MMEs involve coralligenous communities, reef-building assemblages that have recurrently collapsed since the 1980s. Occupying a narrow thermal range, these habitat-formers are highly susceptible to extreme marine heatwaves and environmental anomalies. Although inclusion within Marine Protected Areas (MPAs) reduces local pressures, their capacity to buffer climate-driven mortality is uncertain. Moreover, the environmental combinations that amplify or dampen coralligenous MME severity remain largely qualitative. Our primary objective is to elucidate the environmental drivers that either amplify or mitigate the transition towards severe mass-mortality events in Mediterranean coralligenous communities, and to assess the potential of protective measures in managing these induced changes. To this end we apply explainable artificial-intelligence methods, specifically eXtreme Gradient Boosting (XGBoost) models, and assess their classification skill to judge whether the resulting models can underpin an early-warning tool for the management and conservation of these habitat-forming organisms. Using the Mediterranean MME database provided by Carlot et al. (2025), we combined monthly oceanographic variables from Copernicus Marine Environment Monitoring Service and annual marine-heat-wave metrics with site descriptors such as depth, geolocation and MPA protection. We fit multiple XGBoost models using train-test partitions that combine complementary spatial-temporal validation strategies. Model behaviour is interpreted with SHapley Additive exPlanations (SHAP), which decompose each prediction into additive variable contributions. Performance metrics are employed to quantify explanatory power. Preliminary results indicate that the best XGBoost models, trained with cross-validated hyperparameter optimization, achieved robust discrimination of severe MME years (AUPRC: 0.78, F1: 0.69, LOYO validation). Predictive accuracy was higher under random KFold splits (AUPRC: 0.85), but declined when forecasting years not seen during training, underscoring the challenge of extrapolating to novel environmental regimes. These findings suggest that early-warning predictions are feasible and can identify a substantial proportion of severe events, although further validation on fully independent years and real-time scenarios remains necessary.

Marine plastic litter in mangrove forests: insights from the endangered ecosystems of the Maldives

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Mangrove ecosystems are among the most biologically, ecologically, and economically important coastal environments, offering critical services such as shoreline protection, biodiversity support, carbon sequestration, and fisheries enhancement. Their complex root structures and dense vegetation make them natural traps for marine debris, particularly plastics, with studies showing that plastic accumulation in mangrove forests can be up to four times higher than on sandy beaches. Nevertheless, mangroves remain understudied in the context of macroplastic pollution, with less than 5% of research on marine debris focusing on these habitats. In the Maldives, a Small Island Developing State, plastic pollution is an escalating concern due to a challenging waste management system. In 2020 alone, an estimated 1.6 kilotons of plastic waste entered the marine environment, largely due to landfill leakage, inadequate infrastructure on inhabited islands, and maritime activities. Although mangroves are present on 108 islands, no previous study has documented plastic accumulation in these ecosystems. During three MaRHE Center expeditions in 2024, as part of a national-level survey of Maldivian mangroves, we assessed 28 islands across ten atolls and recorded macroplastic debris in four mangrove forests (14% of sites). The most common items, single-use PET bottles, were found entangled in stands of *Ceriops tagal*, *Bruguiera cylindrica*, *Rhizophora mucronata*, and *Pemphis acidula*. Accumulations were typically observed in low-lying, wave-exposed embayments with dense vegetation and shallow depressions, suggesting that geomorphology and forest structure are key drivers of debris retention. Plastic waste may obstruct roots, hinder seedling development, and compromise overall forest health. These findings represent the first documented evidence of macroplastic pollution in Maldivian mangroves. Given their recent classification as critically endangered by the IUCN, this underscores the urgent need for targeted conservation measures, improved waste management, and integration of mangrove protection into national marine pollution strategies.

Microplastics trigger enhanced carbon degradation in oligotrophic coastal marine sediments

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Plastic pollution is a topical environmental threat, yet many aspects of its impact on ecosystem functioning remain poorly explored. In particular, the effects of microplastics (MP) on sedimentary organic matter (OM) degradation are still largely unknown. To provide insights on this, we investigated in mesocosm the short-term (after 10 and 20 days of exposure) effects of microplastics of different particle size ranges (210-500µm and 70-210µm) and polymer type (polyethylene, polyurethane and tire wear particles) on quantity, biochemical composition and enzyme-mediated degradation of OM in coastal marine sediments. Our results reveal that smaller microplastic particles, regardless of polymer composition, can trigger enhanced aminopeptidase activity, especially in the very short term (i.e., by 10 days from incubation). Furthermore, increased β-glucosidase activity was recorded after 10 and 20 days of exposure to each microplastic polymer and size. Notably, OM quantity showed polymer-specific changes. Tire wear-treated sediments showed significantly increased organic C quantity for the whole duration of the experiment, mainly because of the rise of (constitutive) lipid contents. These results resulted in a size-driven positive influence of microplastics on the OM degradation and turnover rates, pointing to the likely relevance of both chemical and physical MP properties in influencing sedimentary biogeochemistry. Our results, though based on a manipulation experiment in mesocosm, suggest that the effects of microplastics on sedimentary biogeochemistry are tightly dependent on the plastic particle size and polymeric composition. In particular, the observed positive effects on C degradation, if contextualized in warmer seas, where C degradation will be accelerated as well, pose concern about the exacerbated oligotrophic nature of the sea bottom, with potentially negative consequences on benthic trophic webs.

Global change experiments in mountain ecosystems: A systematic review

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Mountain regions are being affected by climate warming at a rate up to twice the global average, making them among the most rapidly changing ecosystems. These climatic shifts, along with altered precipitation regimes and increased nitrogen deposition, have rendered mountain ecosystems particularly vulnerable and important as early indicators of global change impacts. To improve mechanistic understanding of how environmental drivers influence mountain vegetation and ecosystem processes, a systematic review of three decades of manipulation experiments was conducted. Seven major global change drivers were assessed: temperature, water availability, nutrient addition, snow manipulation, radiation, atmospheric gases, and disturbance. Temperature was the most frequently manipulated driver (in 45% of studies), followed by nutrient addition (15%) and water availability (14%). Across 767 studies, consistent effects of warming were observed on plant life history traits, functional characteristics, and phenology. Phenological events were generally accelerated, and shifts in species composition were commonly recorded under experimental warming. Direct impacts on plant development and ecosystem function were also reported in relation to changes in water and nutrient availability. Soil microbial communities were found to respond rapidly to warming, with consequences for nutrient cycling and decomposition. Long-term studies indicated that interactions between warming and soil-vegetation feedbacks influence carbon and nutrient dynamics. In studies where temperature and water availability were manipulated together, soil moisture was shown to mediate the effects of warming on productivity and biogeochemical processes. However, biotic interactions were rarely studied (only 2% of responses), despite evidence suggesting that warming may disrupt plant–pollinator relationships and alter competitive dynamics. Although vegetation responses to global change drivers were well documented, major research gaps were identified—particularly in tropical and boreal mountains and in understanding adult tree responses. Integrated approaches combining long-term monitoring with multifactor experiments were recommended for future research.

Adapt or perish? Physiological and ecological strategies of brown algae *Dictyota dichotoma* along natural pH gradients at Fuencaliente (La Palma, Canary Islands)

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Climate change is accelerating ocean acidification, making it essential to understand the adaptive strategies enabling marine species to cope with the changing environment. In this context, natural acidification sites provide a unique opportunity to explore both short- and long-term responses of marine organisms. In this study, we examined, for the first time, the survival strategies of the brown algae *Dictyota dichotoma* along a natural pH gradient at Fuencaliente (La Palma, Canary Islands). Algal thalli were collected from three sites—acidified, transitional, and control—and analyzed for photosynthetic efficiency, pigment composition, antioxidant capacity, and key functional, anatomical and morphological traits. Additionally, algal cover at each sampling site was measured to assess responses at the population level. Results indicated that photosynthetic efficiency did not vary along the pH gradient, while thallus dry matter content and algal cover increased at acidified site, suggesting a potential benefit under elevated CO_2. In contrast as acidity increased, surface thallus area and total chlorophyll content decreased, and carotenoid concentration and antioxidant capacity increased, indicating a shift in metabolic investment likely associated with stress mitigation under acidification. Anatomical analysis provides first documented evidence of significant thallus thinning, likely due to a decrease in cortical cell thickness. Such structural changes, together with stable photosynthetic efficiency and strong antioxidant response, highlight the significant plasticity of *D. dichotoma*. Overall, our findings suggest that *D. dichotoma* have several adaptive traits—functional, structural, and biochemical—that may help its persistence in naturally acidified marine environments. This study contributes to understanding the resilience mechanisms engaged by macroalgae to counteract future ocean acidification scenarios.

Effects of grassland management practices on soil microbial functions and multifunctionality

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Grazing and mowing are among the most common grassland management practices, and they can significantly influence the belowground food webs, along with microbial biomass and activity and nutrient balance. The aim of this study was to investigate how different land uses, and therefore the associated management practices occurring along the year, affect soil functions and multifunctionality. To fulfil this aim, in the Matese mountain (Southern Italy), adjacent areas characterised by different land uses were selected: meadow-ME, pasture-PA and forest-FO (as undisturbed control). Soil samples were collected at four times along the year, corresponding to specific management practices: sowing, mowing, five months after mowing and, one year after sowing in ME; at the beginning, after one month of grazing, after six months of grazing and, and after spring-rest grazing in PA. Total S and P content, microbial biomass (dsDNA), and eight enzymatic activities were analyzed to assess soil functions related to C, N, P, and S cycles and decomposition. These functions were then used to assess soil multifunctionality using both the averaging approach (SMF index) and the threshold-based approach. Both individual soil functions and overall multifunctionality showed consistent patterns in PA and FO, with significantly higher values compared to ME. In PA, after six months of grazing, functions related to the C and S cycles, as well as soil multifunctionality, increased (by 38% for the C cycle and 6% for both the S cycle and SMF index) compared to FO. In contrast, in ME, during the mowing, S and P cycle functions and the soil multifunctionality decreased (by 22% for both the S and P cycles and 3% for SMF index) compared to FO. Our findings highlight the importance of adopting sustainable management strategies to enhance soil ecosystem functions and services and to fight ecosystem degradation.

Effects of Gadolinium on *Cyclops abyssorum* during Alpine Winters

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The increasing anthropogenic release of gadolinium (Gd), a rare earth element, primarily from medical contrast agents, raises concern about its environmental fate and ecotoxicological effects in freshwater ecosystems. Gd can reach remote alpine lakes through long-range atmospheric transport and deposition, leading to its accumulation in cold, oligotrophic environments. These ecosystems are particularly vulnerable due to their low buffering capacity, reduced biological productivity, and sensitivity to contamination. In this study, we investigated the effects of Gd exposure under winter conditions on the copepod *Cyclops abyssorum* (G.O. Sars, 1863), a cold-adapted zooplankton species commonly found in deep and high-latitude lakes. As a key component of pelagic food webs, *C. abyssorum* plays a crucial role in energy transfer and nutrient cycling. Individuals were sampled from an alpine lake in the Western Alps and exposed for 14 days to a gradient of environmentally relevant Gd concentrations (1–150 µg/L) under simulated winter conditions (low temperature and darkness). To evaluate sublethal effects, we measured four oxidative stress biomarkers: superoxide dismutase (SOD), glutathione peroxidase (GPx), glutathione S-transferase (GST), and malondialdehyde (MDA). Results revealed significant biomarker modulation across treatments. SOD activity showed a non-linear response with marked inhibition at intermediate concentrations, while GPx exhibited a concentration-dependent increase. GST activity decreased at the highest concentrations, and MDA levels rose significantly, indicating cellular membrane damage. Compared to existing literature, our results highlight species-specific responses, with *C. abyssorum* showing patterns distinct from those observed in standard model organisms. This study provides novel insights into the potential risks posed by rare earth elements in cold freshwater ecosystems and emphasizes the importance of including non-model and ecologically relevant species in environmental risk assessments.

Scaling ecological impacts of anthropogenic noise: a global review of knowledge gaps and future research priorities

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Anthropogenic noise is increasingly recognized as an environmental disturbance with significant implications for biodiversity and ecosystem processes. While its effects on individual organisms—such as altered behavior and physiology—have been well documented, how these impacts scale to broader ecological levels remains less understood. This systematic review compiles findings from 154 publications encompassing 1,321 case studies to evaluate how noise pollution affects populations, communities, habitats, and ecosystems across various taxa and habitat types. The analysis reveals a strong research focus on terrestrial settings, especially urban, forest, and grassland environments, with a pronounced taxonomic bias favouring birds. In contrast, taxa such as amphibians, reptiles, invertebrates, and aquatic species are considerably underrepresented. The literature is also geographically and temporally biased, with a majority of studies conducted in Europe and North America and over relatively short durations, limiting insights into long-term trends and generalisability. Most investigations concentrated on population and community-level metrics—such as changes in abundance, fitness, species richness, and diversity—while impacts at the habitat and ecosystem levels have been largely overlooked. Moreover, 61% of the studies relied on indirect noise indicators instead of direct acoustic measurements, potentially compromising the accuracy of exposure assessments. Despite these limitations, 45% of the case studies reported detrimental effects linked to noise exposure, particularly in marine systems where sound plays a fundamental ecological role. The findings highlight the urgent need for more comprehensive taxonomic and geographic representation, standardized methodologies for noise assessment, longer-term monitoring, and greater attention to higher levels of ecological organization to better understand and mitigate the ecological consequences of anthropogenic noise.

Exergy Analysis of a Mediterranean Forest Ecosystem: Insights into Energy Dynamics and Ecological Efficiency

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Plants are open, irreversible, non-equilibrium systems interacting continuously with their environment through mass and energy exchanges. As such, they are suitable for thermodynamic analyses and can be considered energy converters, transforming solar energy into chemical energy to sustain cellular metabolism and promote growth. This study presents a novel thermodynamic model based on mass conservation and the First and Second Laws of Thermodynamics, capable of calculating the efficiency of ecological systems. The approach centers on determining exergy inflows and outflows from a defined control volume. Exergy represents the quality of energy, quantifying a system's thermodynamic distance from equilibrium with its environment, and providing a combined qualitative and quantitative assessment of ecosystem energy content. Initially adopted in ecology as eco-exergy, it relates total exergy to total biomass, enabling analysis of ecological structure, function, survival capacity, energy-use efficiency, and regulatory interactions. However, eco-exergy departs from traditional thermodynamics by not adequately representing the actual work capacity of ecological systems. To address this limitation, this research defines the exergy of a Mediterranean forest ecosystem (Palo Laziale, Rome) over a five-year period (2018-2022), within the context of climate change. A simplified exergy model, treating the canopy as a single "big leaf," was applied using quantified CO_2 and H_2O fluxes combined with local climatic data. The exergy analysis highlighted solar radiation as the dominant incoming energy source, followed by energy from liquid water, with minimal contribution from assimilated CO_2. Outgoing exergy was mainly directed toward biomass formation and water diffusion, while considerable amounts were lost due to spontaneous irreversible processes. Exergy efficiency peaked in 2021 (0.0197%), coinciding with warmer mean temperatures (18.8°C) and moderate precipitation (639.6 mm), contrasting with lower efficiency years characterized by non-limiting conditions. The model enabled the determination of dynamic exergy efficiency over time, providing useful insights into energy resource management which can support the development of effective management practices and policies.

Assessing soil impacts in Mediterranean forest sites affected by wildfire disturbance

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Forest fires are a major ecological disturbance, increasingly influenced by anthropogenic activities, including land-use change and abandonment, and the effects induced by rising temperatures. These factors are altering global fire regimes, particularly threatening natural areas of conservation interest. According to the 2025 Report by the European Commission's Joint Research Centre (JRC), about 35 % of the total burnt area in the EU affected the Natura 2000 Network. In this context, the FLER_MeCoFor project aims to improve knowledge on the functional effects of fire disturbance in coastal pine forests in the Apulia region (Southern Italy). The research was conducted in the Special Area of Conservation (SAC-IT9130006), where several wildfires have occurred since 1960. This study specifically evaluated the fire severity impacts on soil following the most recent wildfires that occurred in 2017 and 2020, at two different sites (Galaso and Patemisco). Before sampling (April 2024), areas of different levels of fire severity were selected by the differenced Normalized Burn Ratio (dNBR) computed using pre- and post-fire Sentinel 2 images at 10 m spatial resolution. At plots representing three different fire severity levels and at paired unburned plots, organic (O-layer) and mineral soil (S-layer) samples were collected (depth 0-5 cm) to determine several soil properties. Results showed that fire severity differently influenced various physical, chemical, and biological properties. Notably, at both sites, the most marked effect was on the O-layer, particularly in Patemisco, where high-severity plots lacked this layer, suggesting a loss of this carbon pool. Data analysis further revealed that soil recovery may depend not just on time since fire but also on fire severity. Therefore, effective post-fire land management strategies are crucial to restoring soil properties, preserving carbon pools, and mitigating long-term ecosystem disturbances.

Listening to *Posidonia oceanica* meadows: temporal and spatial patterns of fish acoustic community in a Marine Protected Area and boat noise effects

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Marine acoustic monitoring is a non-invasive tool for studying marine biodiversity and ecosystem dynamics through the analysis of the underwater soundscape. This method enables the detection of cryptic species and behaviours not easily observed through traditional visual surveys. It also helps to assess anthropogenic disturbance, as noise pollution. *Posidonia oceanica* meadows, protected under the Habitat Directive 92/43/CEE, are vulnerable to such pressures, since noise can alter fish sound production and behaviour. This study aims to investigate the acoustic community of the *Posidonia oceanica* meadows in the Capo Gallo - Isola delle Femmine Marine Protected Area (MPA), by using acoustic indices, and analysing the differences among sites and between high and low touristic seasons. Additionally, the effect of boat noise on species acoustic occurrence was assessed. Six sites within the MPA were selected. Autonomous underwater recorders (RASP-URec384k-Nauta RCS) were deployed in mid-June and mid-August, recording 15 minutes every hour (6 hours/day). Recordings were analysed using Raven Pro 1.6 (FFT =8192, Hamming window, 50% overlap). All recordings were manually screened to detect fish sounds and boat noise. Acoustic abundance and richness were calculated to assess the habitat acoustic community. A total of 502 hours of recordings were collected, with three days per site analysed. Preliminary results revealed 9,247 fish sound occurrences, mainly at night. The dominant species were *Scorpaena* spp. (79%), *Sciaena umbra* (21%) and *Ophidion rochei* (0.01%). Punta Barcarello was the site with the greatest acoustic richness, and the highest acoustic abundance was observed during the high season. Boat noise was present in 57% of recordings, and its increased duration at night corresponded with a decreased fish sound occurrence. These results support the integration of passive acoustic monitoring into the management of MPAs, particularly for understanding ecological patterns and the effects of anthropogenic noise on vulnerable seagrass ecosystems.

Organic pesticide spatial and temporal variations in wildflowers – the role of plant diversity and the risk for wild pollinators in protected areas

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The widespread use of synthetic phytosanitary products poses serious threats to wild pollinator communities even outside of the agroecosystems where they are primarily used, especially when potential sources spatially coexist with areas whose primary goal is the protection of biodiversity and of ecological integrity. Funded by the "Cilento, Vallo di Diano e Alburni" National Park (Italy), this study was carried out to assess the ecotoxicological risk to wild pollinators posed by the contamination of wild plants with pesticide residues. To this end, and to overcome the limitations of the standard methods relying on honeybees, we embraced an approach focused on evaluating the variations in space and time in the contamination of the diverse species forming entomophilous plant communities. Specifically, the study encompassed 3 monthly field campaigns (April, May, June 2024) in 6 sites of the Park differing in land use, where floristic surveys were carried out. Here, samples of flowers from all the species with sufficient abundance were collected for the analysis of 375 pesticides in pollen and corollas, using a purposely optimized QuEChERS extraction and coupled GC-MS/LC-MS quantification. To better understand the contamination patterns, the functional diversity of plant communities was also evaluated in terms of morphological traits mediating the interaction with pollinators, and biochemical traits, including non-structural carbohydrates, lipids and proteins. Overall, 45 species were studied revealing the use of a few compounds, even in remote areas, potentially targeting different pollinator groups with non-lethal and lethal effects at the measured concentrations. The adopted approach proved particularly effective in tracking contamination even from traditional small-scale agriculture and in rural and remote areas. As a long-term monitoring strategy, it may provide valuable insights for precise ecotoxicological risk assessments of wild pollinators and for the planning of conservation and management actions in protected areas.

Influence of plastisphere on lake metabolism across diverse ecosystems

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Biofilms play a vital role in aquatic environments as a key form of microbial life and as fundamental chemical modulators. Beyond naturally occurring biofilms, increasing attention is being directed toward a novel form of "artificial" biofilm that develops on plastic surfaces, known as the plastisphere. The widespread presence of plastic debris in aquatic ecosystems provides abundant surfaces for microbial colonization; however, the ecological significance of this emerging habitat remains poorly understood. In this study, we investigated the impact of the plastisphere on the metabolism of aquatic ecosystems. We conducted in situ experiments along a geographical gradient, selecting lakes with diverse hydro-morphological features and trophic statuses. Plastic substrates of different polymer compositions were incubated in three lakes (Iseo, Italy; Tahoe and Castle, USA) to allow biofilm development. After 30 days, chlorophyll-a concentration was measured as a proxy for photosynthetic biomass. Additionally, a subset of plastic pieces was incubated in light/dark bottles to quantify changes in nutrient concentrations and dissolved oxygen. From these data, we estimated net ecosystem production (NEP), gross primary productivity (GPP), and community respiration (R). Our results showed that the magnitude of plastisphere effects on lake metabolism varies by lake type, with more pronounced changes in NEP observed in more eutrophic systems. The direction of change varied across lakes, indicating a shift toward more autotrophic conditions in samples from the meso-eutrophic Iseo and the oligotrophic Tahoe systems, while more heterotrophic conditions were observed in the alpine, pristine Castle Lake, although differences compared to controls were small in both Tahoe and Castle. Changes in nutrient dynamics were also evident, highlighting the potential for these microbial communities to influence multiple ecosystem processes. Overall, our findings suggest that plastic debris may contribute to primary productivity, especially promoting the 'greening' of littoral zones, although the extent of this effect varies on specific system characteristics.

Invasive alien species as emerging bioindicators of environmental pollution: potential, limitations, and perspectives

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Invasive alien species (IAS) are typically viewed as threats to biodiversity, but they may also serve a valuable role in environmental monitoring. Due to their high abundance, wide distribution, and resilience to environmental stressors, IAS offer practical advantages as bioindicators of pollution, particularly in ecosystems where native species are rare, protected, or declining. Their capacity to bioaccumulate a broad range of contaminants, including trace elements, persistent organic pollutants, and emerging contaminants such as PFAS and microplastics, makes them effective tools for assessing environmental quality. For example, bivalves like *Dreissena polymorpha* are efficient accumulators of mercury; crustaceans such as *Procambarus clarkii* have been shown to reflect microplastic pollution; and semiaquatic mammals like *Myocastor coypus* can help detect wetland contamination through fecal analysis. Importantly, using IAS can reduce ethical and legal concerns tied to sampling vulnerable native species. However, challenges remain. Physiological and ecological differences between IAS and native species can influence contaminant uptake and lead to inconsistent or misleading results. There are also regulatory and ecological risks, including the potential to unintentionally support the spread of invasive species through monitoring programs. To overcome these limitations, IAS should be used strategically, focusing on established populations and interpreting their data alongside that of native species. When applied carefully, IAS can complement traditional monitoring tools, offering a cost-effective, ethically sound, and ecologically informative approach to tracking environmental pollution and supporting conservation efforts.

Remove or not remove: a protocol for assessing the impact of abandoned fishing gear removal on coralligenous habitat

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Abandoned, lost, or otherwise discarded fishing gear (ALDFG) poses a significant threat to Mediterranean coralligenous habitats. Such threat stems from the gear's presence on the seafloor and the mechanical harm it causes during its persistence and removal. This is particularly concerning given the slow growth rate of coralligenous species, which limits the habitat's capacity to recover from extensive damages. This work describes a standardized monitoring protocol to assess the ecological impact of ALDFG removal on coralligenous habitats, first applied within the Capo Carbonara Marine Protected Area (SE Sardinia, Italy). Seven sites affected by ALDFG were surveyed using a BACI (Before-After/Control-Impact) design at three time periods: before, immediately after, and one-year post-removal. Data collection followed the STAR protocol (STAndaRdized coralligenous evaluation procedure) to apply the COARSE index (Coralligenous Assessment by Reef Scape Estimate) for the evaluation of changes in ecological status in the three structural layers (i.e., basal, intermediate, upper) of the coralligenous habitat. The results showed limited short-term impacts from ALDFG removal, with only two impact sites exhibiting a temporary decline in ecological status, followed by recovery after one year. Notably, the three layers of coralligenous habitat responded variably to the removal. The intermediate layer was the most affected, probably due to the loss of fast-growing species that colonized the ALDFG. The basal layer remained stable, while the upper layer exhibited localized declines in structural complexity with minimal recovery. Community composition analyses confirmed minor shifts attributable more to external environmental drivers than to the removal itself. This protocol offers a replicable framework for evaluating the consequences of ALDFG removal and supports the importance of careful, site-specific assessments prior to intervention. When the removal is carried out by trained personnel, it is recommended to recover the integrity and the aesthetic value of the seafloor.

Enhancing soil and plant biodiversity via marine waste-derived organic amendments

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In Mediterranean climates, soils are degraded by anthropogenic activities that deplete organic matter, reduce biodiversity and impair ecosystem functioning. Ecological restoration through organic amendments may counteract these trends and recover degraded soils, preventing the loss of ecosystem services. Indeed, organic amendments improve soil chemico-physical properties and microbial biodiversity, promote natural revegetation and accelerate community successions. In this context, and aligned with circular economy principles, the preliminary results on the effects of a novel lumbricompost (derived from *Posidonia oceanica* litter + fish market residues) compared to traditional sewage sludge, applied with or without zeolites from limestone quarry waste, are reported. The study, part of the EMBRACE project (PRIN PNRR 2022), aims to assess the potential of these organic and inorganic matrices in improving industrial soil functioning. To this end, a field experiment was conducted on a quarry substrate with 5 treatments, each replicated in three plots: lumbricompost, sewage sludge, their respective zeolite-enriched variants, and an untreated control. After three months from the amendments, soils were characterized for several chemico-physical (water content, organic matter, pH, electrical conductivity and water-holding capacity) and biological properties (seed germination, natural revegetation, community-level physiological profiling as well as enzymatic activities targeting major nutrient cycles, such as hydrolase, β-glucosidase, β-1,4-N-acetylglucosaminidase, phosphatase and arylsulfatase). Results obtained so far (spring sampling) showed functional shifts in soil microbial community across treatments, with compost-enriched soils generally exhibiting enhanced biodiversity and metabolic activity. In particular, hydrolase and β-glucosidase activities significantly increased, indicating improved soil biochemical functioning because of the amendments. Organic matter addition promoted revegetation in treated as compared to untreated soils, leading to structural and functional changes in plant diversity depending on the amendment applied. In addition, treatments did not elicit phytotoxic effects. Seasonal monitoring will further clarify the effectiveness of these sustainable strategies for restoring soils under climatic and anthropogenic pressures.

The Imbalance of Nature: The Role of Species Environmental Responses for Community Stability

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Understanding stability is crucial for predicting ecological responses to environmental fluctuations. While the diversity-stability relationship is well studied, the role of species' fundamental responses remains underexplored. We investigate how the distribution of species' fundamental responses, captured by a novel metric—imbalance—drives community stability through asynchrony and population stability. Using a protist microcosm experiment, we manipulated species richness and response distributions (defined as interspecific variation in species performance curves) under fluctuating temperature at different nutrient concentrations. Results show that lower imbalance leads to higher temporal stability, while richness has no effect. Structural equation modelling revealed that asynchrony and population stability explain 90% of the variation in stability. Imbalance estimated from monocultures predicted community stability, suggesting that fundamental species responses were the primary drivers of community stability. This study offers new insights into the responses of ecological systems to environmental change.

Host-parasite dynamics in a polluted world: behavioural responses of *Artemia parthenogenetica* to parasites and global pollutants

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Chemical pollution poses a growing threat to wildlife and ecosystems globally. However, wild organisms are also exposed to other challenges that might shape the way that they respond to environmental pollution. Parasites, for instance, are widespread across ecosystems and are known to affect their hosts differently depending on environmental conditions, such as resource abundance. Yet how global contaminants alter host-parasite dynamics remains largely unknown. To fill this gap, we tested the combined effect of a widespread organic pollutant (phenanthrene; $C_{14}H_{10}$) and cestode parasites (*Flamingolepis liguloides*) on ecologically relevant behaviours and life-history traits of wild-caught brine shrimps (*Artemia parthenogenetica*). We exposed individuals to realistic concentrations of phenanthrene – one of the most abundant polycyclic aromatic hydrocarbons in aquatic environments worldwide – and repeatedly assessed their swimming activity (i.e., distance moved and time spent swimming) and risk-taking (i.e., time spent near the water surface and escaping behaviour). These behaviours are key determinants of parasite transmission in brine shrimps and affect their predation risk by flamingos, the final host of the parasite. Our results show that phenanthrene exposure significantly reduced swimming activity, while parasite load explained variation in risk-taking, with infected individuals spending more time near the water surface compared to uninfected ones. Our evidence provides novel insights into the interplay between pollution and parasites, highlighting the importance of considering more realistic environmental conditions when evaluating the ecological consequences of contaminants.

Preliminary assessment of structural and functional variations in macrobenthic assemblages impacted by mechanical harvesting of bivalves in the Southern Adriatic Sea

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The harvesting of commercial bivalves through hydraulic dredges represents a critical disturbance for macrobenthic communities inhabiting shallow soft bottoms. However, the ecological responses of these communities are shaped by cumulative impacts, including fishing and environmental stressors. This contribution presents preliminary results on temporal variations in the functional diversity and traits occurrences in benthic assemblages impacted by the clam fishery (*Chamelea gallina*) in the Southern Adriatic Sea during the period 2019-2022. Biological data were collected through monitoring surveys conducted in two areas characterized by different fishing effort intensity levels (Lesina high and Barletta low). Standardized abundance data (N/100m^2) for 51 species were used to perform a Biological Trait Analysis. Eleven traits (6 response and 5 effect on the environment), encompassing 42 categories, were assigned to each species using a fuzzy coding approach (scores 0–3 based on affinity). Functional Dispersion index (FDis) and Community Weighted Mean (CWM) were calculated, and temporal and spatial differences were tested using univariate non-parametric test (Kruskall-Wallis test) and a multivariate ordination method (Principal Coordinate Analysis, PCoA) based on Gower's similarity matrix calculated on CWM values. Significant temporal increase and decrease in median FDis values, calculated for response traits, were observed in Barletta and Lesina, respectively (p

Fire refugia recovery trends and patterns across Mediterranean pine forest ecosystem

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Climate change, land cover changes, and fuel accumulation are altering the historical fire regimes in Mediterranean fire-prone ecosystems. Understanding the impacts of fire-regime modifications on post-fire recovery/regeneration is critical, but challenging across broad spatial scales. Within fire perimeters, "fire refugia" i.e. unburned or less severely burned areas, contain residual pre-fire vegetation and facilitate species persistence post-fire. Based on the reconstruction of the 1981 to 2020 fire chronology in a Natura 2000 Network site, within the PRIN 2022 FLER_MeCoFor Project, we identified fire refugia within burned patches of six *Pinus halepensis* Mill. stands. We used Landsat annual time-series of Normalized Burn Ratio (NBR) to assess vegetation recovery temporal trends and pattern, and climate variables which include maximum and minimum temperature (T_max, T_min) and precipitation (P) of four seasons, over the 43 years, to account for climate conditions. To test the influence of climate on NBR, we applied multiple linear regression analysis followed by cross-correlation analysis. Results showed significant increasing vegetation recovery trends for fire refugia of each fire event. Multiple linear regression results indicated that both summer minimum temperature and autumnal precipitation are likely the main drivers of fire refugia recovery. Cross-correlation analysis showed that the recovery trend significantly increased with high T_max of four seasons observed at first positive lags (years), while decreased due to its negative correlation with T_max at last lags. Conversely, for most cases, the minimum temperatures showed weak correlation with NBR, except for the 1982 fire, where a significant positive correlation between spring and summer T_min and vegetation recovery was observed at negative lags. These findings suggest that interannual climate variability may strongly modulate the rate of fire refugia recovery, hence affecting the speed at which these ecosystem legacies can perform important ecological functions in burned areas.

Whole transcriptome analysis of the coral *Pachyseris speciosa* subjected to intermittent and continuous darkness

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Coral reefs worldwide confront escalating threats, characterized by heightened sedimentation and diminished light penetration due to extensive land reclamation and coastal development. This critical issue is exemplified by the drastic reduction in underwater visibility, notably in Singapore, where levels have dwindled from over 10 meters in the 1960s to approximately 2 meters today. This study endeavours to explore the repercussions of intermittent light and complete darkness on the transcriptome of the common tropical coral *Pachyseris speciosa*. The research implemented a 4-week experiment involving three distinct light treatments: control, representing normal light conditions; intermittent light, with 5 days of normal light conditions and 2 days of total darkness (non-consecutive); dark, maintaining constant total darkness. Coral samples collected at the beginning and conclusion of the experiment underwent RNA sequencing via Illumina for whole transcriptomic analysis, enhancing the depth of understanding regarding molecular responses. Additionally, comprehensive photo-physiological data were recorded at the experiment's onset and conclusion. Post-experiment analysis revealed the resilience of all *P. speciosa* colonies, albeit with notable disparities in the transcriptome status. Coral's transcriptome under intermittent light showcased differential expression of genes involved in pathways like inflammation and immune system, suggesting a possible adaptation to these adverse conditions. On the other hand, the dark treatment transcriptomics responses highlighted a remarkable stressful state, with enhanced KEGG pathways involved in tissue damage and apoptosis. Notably, no corals resulted dead at the end of the experiment, underlying the resilience of this coral species. Overall, our findings suggest that *P. speciosa* may possess the molecular and photo-physiology capacity to adapt to intermittent light stress, positioning it as a promising candidate for use in restoration projects in low light environments affected by reduced light penetration.

A novel method for the assessment of plant reactions to environmental disturbances

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As an effect of climate change, several regions of the world are likely to suffer increasingly severe droughts. This will cause increasing stress to urban plants, which are often already affected by pollution, inadequate management and heat island effects. Droughts also pose a threat to food security. It is therefore fundamental to improve technologies and management practices to maximize efficiency in water uses. One possibility is to assess the water status of plants in order to irrigate them based directly on their needs, rather than on predetermined schedules or on proxy environmental variables. A promising technology to this end is to measure and interpret the electric potential (EP) in the vascular bundles. It is indeed well established that plants react to a variety of stimuli, including mechanical damage, burning and sudden air cooling, with specific variations of cells' membrane potential that propagate across the plant through the vascular bundles and affect the cells' metabolism. While EP variations associated to disturbance are elicited in response to sudden stimuli, more recent research is trying to detect a variety of stressors, including drought, nutrient deficiency or parasites, based only on a continuous measurement of the EP across time. In our study we analyzed EP data collected in two drought-stress experiments, on tomatoes and on apricots, respectively. Sixteen statistical features from the time and frequency domains were selected and evaluated on the EP signal. The results show that some time-domain features were significantly different between stressed and control apricots, while other frequency-domain features were significantly different among tomatoes. This preliminary study illustrates the potential value of (i) plant EP data, (ii) the statistical features derivable from those, and (iii) the possibility to develop models for the assessment of plant drought stress as part of management actions in both urban and agricultural systems.

Ecosistemi e cambiamento climatico

3

Vulnerable species mortality and warm-water species spread in a changing Mediterranean Sea

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The semi-enclosed nature of the Mediterranean Sea makes it particularly susceptible to rising temperatures, making it a recognised hotspot of climate change. A direct consequence is the increased frequency of prolonged periods of elevated temperatures, called 'heatwaves', which have been associated with an increase in mass mortality events among vulnerable marine species, as well as the spread of invasive species. This work presents the five-year (2019-2024) outcomes from the 'Mare Caldo' project, in collaboration with Greenpeace, aimed at assessing the effects of water warming on rocky reef communities along the Italian coast, including eleven Marine Protected Areas (MPAs) and one unprotected site at Elba Island. Seawater temperatures were monitored following the standardised protocol provided by T-MEDNet (a pan-Mediterranean network), which involves deploying temperature data loggers along reefs profiles from the surface down to 40 m depth. Underwater visual surveys were conducted to assess the ecological status of benthic communities and to collect data on the presence of warm-water species and on mortality events of the target species. Data revealed abnormally high temperatures, with multiple heatwaves over the past 5 years. Mortality events on target species were observed across all areas. Data on warm-water species show a latitudinal distribution aligned with temperature gradient; while these species are naturally abundant in southernmost regions, their presence is increasing also in colder and northern areas. The decline of native species and the spread of warm-water ones resulted in profound shifts in the structure and functioning of benthic communities. These findings highlight the ongoing changes of Mediterranean marine ecosystems under the influence of climate change. While MPAs provide valuable local conservation benefits, they alone are insufficient to mitigate the widespread impacts of climate change, emphasizing the urgent need for coordinated global efforts to protect marine biodiversity.

Biodiversity and ecosystem responses to climate change

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Climate change, causing a systematic and directional alteration on key abiotic niche dimensions, is resulting in individual level responses with cascading impact on populations, species and communities threatening the current adaptation, coadaptation and coevolutive equilibrium status of Earth ecosystems. Among individual level responses, those related to the cost of life (expressed as the metabolic costs) and to the overall individual energy budget are likely to have quantifiable metabolic theory-based implications both on other individual functional traits and on the higher levels of the ecological hierarchy. This includes influences on traits, such as individual perception of resource availability and related space use behavior, as well as on density and intensity of inter-individual interactions and competitive performances, species and communities carrying capacities, ecosystem processes and services. This ultimately challenges the benefits that humans derive from ecosystems processes and services. Deeper knowledge and lower uncertainty on the quantitative responses of biodiversity and ecosystems to climate change are crucial to design effective actions and strategies to lessen their negative impacts on our social and economic growth. Here, we discuss on the available data, their interconnections and implications at the highest level of ecological hierarchy. We propose a set of ecological indicators useful to detect early signs of ecological changes and to derive scenarios of change for both biodiversity and ecosystems and for the goods and services to our societies.

Wildfire effect on growth performance and ecophysiology of *Fagus sylv*atica and *Pinus nigra*

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In recent decades, both the number and severity of fires have significantly increased in Mediterranean forests thus affecting trees productivity, growth and vitality. Comparing tree growth before and after a fire event can be used as a proxy of tree resilience and resistance. Resilience can be defined as the capacity to return to pre-disturbance functioning and growth levels. However, resilience per se does not consider the impact of the disturbance; therefore, resistance, which is the reversal of the reduction in ecological performance during a disturbance can be included in the resilience analysis to avoid underestimating the resilience. This research aims to analyze the impact of a 2023 anthropogenic fire on two ecologically and economically important species, *Fagus sylvatica* L and *Pinus nigra* J.F.Arnold, growing in the Maiella Natural Park, in Abruzzi Region, Italy. We compared burned populations with unburned control trees to investigate the different responses of the two species to fire in terms of growth and ecophysiological performance. To achieve this goal, a multidisciplinary approach was adopted integrating satellite analyses to map the area affected by the fire with field investigations, including dendrochronological analyses and carbon stable isotope ratio measurements to gain information concerning changes in tree performance in response to environmental conditions. Our findings afford new insights into post-fire survival strategies of those species in an environment where fires are predicted to increase in frequency during the twenty-first century. Funded by project "BIOdiversita' Specifica e Funzionale per la Resistenza, Resilienza e Recupero ai disturbi ed al cambiamento climatico [BIOSFeR^{3}a]", in the framework of PNRR SPOKE 4 NATIONAL BIODIVERSITY FUTURE CENTER (NBFC)" CUP F83C24000360006.

Psychrophilic and psychrotolerant fungi: an exclusive club of extremophilic organisms

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Cold terrestrial habitats, defined by average temperatures below 5 °C, include over 80% of the Earth's terrestrial surface. These environments encompass polar regions (Arctic and Antarctica), high-altitude mountains across Asia, Europe, and the Americas, cold deserts, and deep-sea ecosystems. Despite the extreme abiotic stressors (e.g., low temperatures, limited water availability, high solar irradiations, etc.), these ecosystems harbor psychrophilic and psychrotolerant fungal communities, including both yeast and filamentous life forms. These organisms have evolved a range of adaptive strategies to maintain their metabolic functionality at low temperatures, namely reduced growth kinetics, production of cold-active enzymes, and accumulation of cryoprotective compounds (e.g., heat shock proteins, polyols, etc.). Furthermore, in response to reduced membrane fluidity caused by low temperatures, psychrophilic and psychrotolerant fungi typically enhance membrane fluidity by increasing the proportion of unsaturated fatty acids within their lipid bilayers. Climate change is exerting an increasing pronounced impact on cold terrestrial ecosystems, with evident effects, such as extended ice-free periods in Arctic and alpine regions. Consequently, the investigation on the diversity of fungal communities in polar and high-altitude cold ecosystems is of strategic relevance for improving our understanding of fungal ecology in these underexplored biomes. To characterize the taxonomic structure and ecological dynamics of these fungal communities, DNA metabarcoding approaches (involving next-generation sequencing of the ITS region followed by bioinformatics analyses) were applied to environmental samples, such as soil (including permafrost), brine, ice, and both epi- and hypo-glacial debris. Taxonomic assignment of operational taxonomic units (OTUs) revealed that Ascomycota dominated among filamentous forms, whereas Basidiomycota were more abundant among yeast taxa. Alpha- and beta-diversity analyses demonstrated high phylogenetic variability even at local spatial scales. Environmental parameters such as salinity, electrical conductivity, pH, and organic C were identified as significant (p

Late-winter warming and severe weather jointly advance grapevine phenology in Piedmont, Italy

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Climate-driven phenological shifts significantly influence ecosystem functioning and agricultural productivity, particularly in temperate regions. Grapevines (*Vitis vinifera* L.) represent economically and ecologically crucial species whose phenological timing impacts biodiversity and vineyard management. This study investigates how late-winter warming and increased frequency of extreme weather events jointly influence grapevine phenology in Piedmont, Italy. Using a 20-year dataset (2004–2023) of phenological observations for Cortese, Barbera, and Dolcetto cultivars, integrated with local meteorological records and severe weather data from the European Severe Weather Database (ESWD), we quantified climatic effects on budburst timing. February–March temperatures rose significantly (by 2.2 °C and 3.5 °C, respectively), correlating with an advancement of approximately 5 days per 1 °C warming ($\beta = -4.89 \pm 0.83$ days °C^{-1}, $z = -5.91$, $p < 0.001$). Additionally, springs with frequent extreme events ($\geq$2 events in February–March) advanced budburst by 18.13 ± 6.47 days ($z = -2.80$, $p = 0.005$). Together, these factors explained 62.5% of inter-annual variation. Our results underline the necessity of integrating extreme weather forecasting with traditional thermal indices to develop robust climate adaptation strategies for sustainable viticulture.

Impact of lake drying and nutrient inputs on greenhouse gas emissions in Arctic ecosystems

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Climate warming is affecting nutrient cycling in Arctic lake ecosystems, impacting global carbon emissions. Indeed, Arctic lakes are significant carbon sinks, where low temperatures and nutrient scarcity limit carbon release both from the soil and from waters. However, lakes are shrinking at approximately 1500-2000 Km^2 annually due to warming, while nutrient levels are rising due to reduced snow cover and growing herbivore populations. This study aims to elucidate the connections between lake drying, nutrient inputs, and greenhouse gas emissions, which is essential for accurate predictions and effective mitigation strategies. We designed a space-for-time experiment using stable isotopes, in-situ gas-flow measurements and remote sensing to understand the mechanisms linking changes in snow cover with terrestrial productivity, N inputs by migratory geese, CH_4, CO_2, N_2O, and H_2O emissions across nine Arctic lake ecosystems (Svalbard Islands). At each lake, measurements in lake waters, inundated, and dry soils simulated lake drying effects. In catchments where summer snowmelt occurred earlier, simulating a warmer climate scenario, grass productivity and geese abundance were higher. This led to increased N concentrations both in soil and in water, promoting carbon emissions and turning lakes from carbon sinks into sources. CH_4 emissions decreased while CO_2 emissions rose from lake waters to dry soil. On average, CO_2 equivalent emissions from dry soil were 19.2 g m^{-2} s^{-1} higher than from lake waters, with differences intensifying with N soil inputs by geese. Data indicate that the estimated economic impact of losing 1 km^2 of Arctic lake surface is nearly $32,000 annually due to rising carbon emissions. Our findings reveal positive feedback mechanisms linking climate warming, snow, herbivores, and greenhouse gas emissions, highlighting the ecological and economic implications of Arctic lake loss and enhancing Arctic-climate interaction predictions.

Influence of forest plant community biodiversity and fire on soil C and N cycling and related greenhouse gas fluxes

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The project BIOSFER^{3}A aims at exploring the relationship between biodiversity and functionality in natural ecosystems, with a particular focus on the role of forest ecosystems in the carbon and nitrogen cycles and greenhouse gas balance in the atmosphere. It also explores the role of climate change and fire in shaping the response of forest C and N cycles to fire disturbance. Here we present the results of the GHG fluxes (CO2, N2O and CH4) and related C and N mineralization and nitrification fluxes measured on soil sampled in November 2024 from the BIOSFER3A study sites, coniferous and broadleaved forest stands that have undergone strong wildfire in 2023 and in coniferous stands also in 2017, in Morrone mountain (Abruzzo, IRET site). Data show that coniferous forests has much lower N2O and CO2 fluxes and N losses compared with the broadleaved forest and comparable CH_4 sink. Fire impacts more significantly the coniferous site significantly increasing N losses and GHG emissions, although post-fire soil N and C losses in broadleaved sites remain higher than in coniferous sites. Data show that protection of forests from fire significantly contributes to limit GHG emissions during and in the post-fire period and limit forest soil degradation in mountain areas. *Project "BIOdiversita' Specifica e Funzionale per la Resistenza, Resilienza e Recupero ai disturbi ed al cambiamento climatico [BIOSFeR^{3}a]", funded by Italian Ministry of University and Research, "National Biodiversity Future Center - NBFC PROJECT", CUPB83C22002930006*

Assessing Marine Heatwaves and Cold Spells along the Italian coastline: implications for benthic mass mortalities

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The Mediterranean Sea is warming rapidly due to climate change, exposing marine ecosystems to increasing thermal stress. While Marine Heat Waves (MHWs) - prolonged and intense sea temperature anomalies - have been extensively studied, Marine Cold Spells (MCSs) - extreme cooling events that can also disrupt species distributions - have received far less scientific attention despite their ecological relevance. This study aimed to i) characterise the occurrence, frequency, duration and intensity of MHWs and MCSs along the Italian coastline, and ii) assess their potential role in documented Mass Mortality Events (MMEs) in benthic coastal marine communities. We integrated 15 years of *in-situ* temperature data from the ISPRA National Tide-Gauge Network with daily satellite-derived Sea Surface Temperature data from the Copernicus Marine Service, covering 31 monitoring stations along the Italian coasts. Thermal anomalies were identified, characterized and categorized according to Hobday et al. (2016, 2018), and then spatially and temporally correlated with recorded MMEs. The analysis revealed a consistent rise in sea temperature at all monitored sites, following a clear latitudinal gradient with stronger warming at higher latitudes. This warming trend coincided with a marked increase in the frequency and intensity of MHWs and MCSs over the studied period. Moreover, temporal and spatial overlap between extreme thermal events and MMEs was found, suggesting that both heat- and cold-related anomalies are pivotal drivers of the recent die-offs in Mediterranean benthic communities. Our findings underscore the urgent need to strengthen monitoring efforts and implement targeted mitigation strategies, as increasing thermal stress, both from heatwave and cold spells, continues to threaten Mediterranean marine biodiversity. This study also provides a valuable framework for assessing biological risks in a context of ongoing ocean warming.

Quantity and quality: how climate change can alter the environmental conditions of Alpine rivers

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In the context of global climate change, the increasing frequency of droughts in Alpine streams represents a recent and underexplored phenomenon. This study adopts a multidisciplinary approach to investigate the response of three Alpine rivers in Northwestern Italy to severe hydrological stress during an exceptionally dry year (2022). While climate change is often framed in terms of water quantity, its consequences on water quality especially when coupled with local pressures such as wastewater discharge remain poorly understood. In this study we focused on the impact of three wastewater treatment plants (WWTPs), analysing monthly variations in hydrological, chemical, microbiological, and ecological parameters along upstream (U) and downstream (D) river stretches. The study encompassed not only traditional metrics such as nutrient load, microbial contamination, and biodiversity indices (diatoms and macroinvertebrates), but also included a path analysis to quantify the interconnections among microbiological, chemical, and biological responses to flow reduction. Our results show that decreased flow significantly amplifies the impact of WWTP discharges. At very low flow conditions, downstream reaches exhibit biodiversity loss, increased presence of pollution-tolerant taxa, chemical degradation, and the spread of pathogenic microbial strains. These findings suggest a systemic collapse in both ecosystem integrity and potential sanitary safety. To synthesise the complex interplay of stressors, we calculated an index inspired by the One Health approach that integrates hydrological, ecological, chemical, and microbiological data. This index highlights how drought and anthropogenic pressures jointly undermine river health, reinforcing the deep interconnection between environmental degradation and human well-being. Given the projected intensification of drought events across Europe, our study can serve as a first building block and provide a useful starting point for future research aimed at improving our understanding of some of the largely overlooked consequences of these events.

Soil temperature and land use influence earthworms' richness across European soils

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Earthworms play a crucial role in soil ecosystems, contributing significantly to belowground biomass and mediating key soil biogeochemical processes. Due to their limited dispersal capacity and strong dependence on soil microclimatic conditions, they are particularly sensitive to changes in habitat suitability. In this study, we assessed the combined effects of soil temperature, pH, nutrient availability, and land use on annelid richness across 1,583 sites in Europe. Richness data were extracted from Phillips et al. (2021), a global database of local earthworm diversity. Generalized Linear Models were applied to investigate both large-scale environmental drivers and land-use-specific interactions. Our results showed that annelid richness increased with higher soil pH but declined with rising maximum temperatures of the warmest month, indicating potential vulnerability to future warming. Land use significantly influenced richness patterns. Woodlands appeared to buffer temperature effects, supporting higher richness under warming conditions, while in other land-use categories, increasing temperatures had a negative impact on richness. Additionally, nutrient imbalances (N:P ratio) negatively affected richness in pastures. These findings underscore the importance of integrating both abiotic factors and land management practices into conservation strategies for soil biodiversity under climate change scenarios.

Assessing the impact of climate change on thermal habitat suitability of the European clam *Ruditapes decussatus* in Sardinian Lagoons

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Climate change (CC), affecting the survivorship and behavior of bivalves, is progressively posing serious threats to aquaculture. The European clam *Ruditapes decussatus* (L., 1758) is among the most commercially important bivalve species in the aquaculture market. Rising temperatures caused by CC can induce physiological responses and, above certain thresholds, mass mortality events. In this study, we investigated the thermal tolerance of *R. decussatus* in the laboratory conditions, assessing the species' metabolic response (respiration rate, RR) to a wide range of temperatures (8-38 °C). Then, using these responses we obtained the best Thermal Performance Curve (TPC), by comparing 24 models. The best fitting Deutsch model was finally used to create seasonal Thermal Habitat Suitability (THS) maps under both current (2017-2022) and future (RCP 4.5 and RCP 8.5, 2050) temperature scenarios in a Sardinian coastal lagoon. RRs increased from 0.07±0.04 $mgO_2\ h^{-1}\ gWW^{-1}$ (at 8°C) to 1.55±0.40 $mgO_2\ h^{-1}\ gWW^{-1}$ (at 26°C), then started to drop at 30°C (to 0.54±0.33 $mgO_2\ h^{-1}\ gWW^{-1}$) and was nihil at 38°C (death of all specimens). We report here that *R. decussatus* shows an optimum thermal point (T_{opt}) at ca. 26.71 °C and a critical thermal maximum (CT_{max}) at 38 °C. An increase (up to 60%) in the extension of *R. decussatus* occurrence probability was observed in both RCP 4.5 and RCP 8.5 IPCC future temperature scenarios, possibly anticipating a better thermal environment for the performance of this species in otherwise less favorable seasons. On the other hand, a slightly worst environment would appear in summer (ca -1.5% of favorable thermal habitat). These findings highlight the urgent need for adaptive aquaculture strategies to optimize clam farming under future climate conditions. This work has been developed within the framework of the project e.INS www.einsardinia.eu (Next Generation EU- PNRR - M4 C2 I1.5 CUP F53C22000430001.

Soil microbial community response along afforestation dynamics differs between two mountain areas in Northern and Central Italy

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This study investigates the response of soil microbial community to spontaneous afforestation - a natural rewilding process that has been ongoing for decades across both national and European levels following land abandonment. The main objectives are to: i) characterize changes in topsoil physico-chemical properties and the associated microbial community response along the successional gradient, ii) assess causal relationships between soil variables and microbial diversity and composition. The research was conducted in two Italian sites: the Foreste Casentinesi National Park (CF) and Julian Prealps (JP). In both areas, five successional stages were identified based on historical orthophotos (1954-2020) and replicated across four chronosequences: meadow-pasture (G), early (E), early-mid (E-M), mid-late (M-L), and late (L) stages of afforestation. Topsoil samples (0–10 cm depth) were analysed for pH, bulk density (BD), organic carbon (OC) and total nitrogen (N). Soil microbial communities were characterized through environmental DNA extracted from fine soil fractions, followed by DNA metabarcoding using ITS and 16S rRNA gene markers for fungi and bacteria, respectively. The results reveal that, along the afforestation gradient, topsoil becomes increasingly acidic and less compact (lower BD), with a concurrent rise in organic matter content. However, these trends are modulated by site-specific variability. Notably, overall microbial diversity was lower at CF compared to JP, a pattern likely linked to more homogeneous environmental conditions and reduced above-ground diversity. Bacteria and fungi exhibited distinct responses to forest regrowth following meadow abandonment. Fungal communities - mainly composed of *Ascomycota* and *Basidiomycota* – peaked in diversity at intermediate successional stages. In contrast, bacterial communities, dominated by *Proteobacteria* and *Verrucomicrobiota*, showed greater site specificity, especially at lower taxonomic rank. Overall, the findings highlight the ecological relevance of nature-based solutions such as rewilding, not only in fostering microbial diversity but also in contributing to climate neutrality and biodiversity conservation at larger scales.

ASSESSING CYMODOCEA NODOSA SEEDLING DEVELOPMENT UNDER OCEAN ACIDIFICATION SCENARIO

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Progetto di ricerca finanziato dal premio “Luigi e Francesca Brusarosco” 2024 As a result of the anthropogenic emissions, ocean acidification (OA) has been consistently evidenced to have profound impacts on marine biota. The effects of high *p*CO2 levels on seagrasses have been a subject of global concern, although the evidence is not uniformly consistent. Furthermore, the responses exhibited by early life stages, specifically seedlings, remain to be fully understood. This study aimed at evaluating how projected Mediterranean Sea OA affect the survival and the morphological development of *Cymodocea nodosa* seedlings coming from two different thermal origins. Seeds originated from two warm and two cold Mediterranean sites were collected during spring 2025 and transplanted in Vulcano and Milos Islands, both characterised by a submarine hydrothermal shallow system. For each island, two different pH sites were selected for the transplanting field experiment: the control area (pH 8.14 – 8.15) and the low pH area (pH 7.45 – 7.6), representing the nowadays conditions and worst-case OA future scenario, respectively. For each site, 40 seeds from each origin were put for germination and seedling development (summer 2025). Results provide evidence on the adaptative, and acclimation responses of seedlings originated from different coasts and subjected to the future OA if an interactive effect of the OA x thermal origin was highlighted on their survival and morphology. Overall, this study evidenced that seagrass responses to OA may be not unidirectional and could depend upon in-situ characteristics. The need of further *in-situ* research, in combination with manipulative laboratory experiments that consider wider duration of exposure and range of pH conditions is needed to identify further acclimation responses of *C. nodosa* to an incoming acidified Mediterranean Sea, addressing eventual restoration management under a climate change scenario.

Temperature variations in the below-ground compartment of *Posidonia oceanica* meadows.

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Seagrasses represent highly productive coastal ecosystems, sustaining biodiversity and ecosystem services. In the Mediterranean, the physiology, abundance and distribution of the endemic *Posidonia oceanica* have been severely impacted by global warming. In this context, most research efforts have been devoted to the above-ground compartment, while little attention has been paid to the role of the below-ground compartment in regulating plant response to warming. Since Summer 2024, we have assessed how temperature fluctuations in the below-ground compartment track those in the water column, through the deployment of temperature loggers at the canopy level and at different depths within the *P. oceanica matte* (-30cm, -10cm, and surface) at four locations along the Italian coast. Samples of *P. oceanica* roots and sediment have been collected seasonally to investigate how temperature fluctuations are associated with changes in microbial communities of the rhizosphere. Preliminary findings suggest that the *P. oceanica matte* acts as a buffer, maintaining lower temperatures compared to those at the canopy level in summer and slowing sediment cooling during winter. Analyses of microbial communities associated with roots and sediments are currently in progress and will provide further insight into how fluctuations in the thermal profile are coupled with below-ground processes. Exploring how below-ground processes vary seasonally and regulate the response of *P. oceanica* to warming will provide key information for the conservation and restoration of *P. oceanica* under future climate scenarios.
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The effect of pH levels on the cellular metabolism of *Anemonia viridis* in natural habitat: a metabolomic approach

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Climate change is increasingly affecting marine ecosystems, and its impacts on coastal environments remain complex and difficult to disentangle. Natural CO_2 vents offer a valuable *in situ* model for investigating the ecological and physiological consequences of ocean acidification. The island of Vulcano, in the Aeolian archipelago, hosts submerged CO_2 emissions, particularly in Levante Bay, where pH ranges from 5.70 to 8.05. In this study, we investigated the effects of low pH on the metabolism of the snakelocks anemone, *Anemonia viridis*, a photosymbiotic species widely distributed in the Mediterranean sublittoral zone. Previous studies show that high pCO_2 can affect the microbial community and trophic metabolism of *A. viridis*. We applied a metabolomics approach to characterize variation in metabolite levels under different pH conditions. We designed an experiment involving four treatment groups. The first two included individuals naturally living at the control site (pH 8.05) and at the low pH site, respectively. The other two groups were part of a cross-transplanting setup, in which individuals from each site were transplanted to the opposite pH condition. With this design, we aimed not only to characterize the baseline metabolic profiles of individuals adapted to ambient or acidified conditions, but also to assess the metabolic plasticity of the species when exposed to environmental change. All individuals were maintained in experimental conditions for seven days, after which tentacle tissues were sampled and analyzed using proton Nuclear Magnetic Resonance (^{1}H-NMR)-based metabolomics. The 1D ^{1}H-NMR spectrum of polar extracts identified over 30 metabolites, with altered levels of organic osmolytes such as betaine, taurine, and glycine in individuals from the low pH site. A decrease in energetic molecules like pyruvate also suggested adaptive responses to acidified conditions. Our findings help clarify how natural pH variability may shape the physiology of coastal species under future ocean acidification.

Mediterranean coastal lagoons: plankton community responses to an experimental summer heatwave

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Coastal lagoons as transitional aquatic ecosystems are hotspots of biodiversity and highly productive, thus providing numerous ecosystem services. They are subjected to increasing anthropogenic pressures and the effects of climate change, notably in the Mediterranean region. Specifically, extreme events, such as heatwaves are predicted to be more intense and frequent in the Mediterranean, and to date their effects on planktonic food webs in transitional ecosystems have been poorly studied. In July 2024 we simulated a summer heatwave in laboratory to investigate its experimental effects on an entire plankton community collected from Cabras Lagoon, the largest shallow costal lagoon in Sardinia (Western Mediterranean). With the aim to distinguish direct warming effects from those indirect mediated by grazing, we exposed the natural community for 15 days to +5°C increased temperature compared to a control (environmental temperature) in presence and in absence of planktonic apical predators, mainly represented by rotifers and the ctenophore *Mnemiopsis leidyi* in Cabras Lagoon. Preliminary, we observed significant taxonomical shifts throughout the experiment: increased affirmation of rotifer resting stages under heatwave; among ciliates, Oligotrichia were replaced by Euplotia and Scuticoliatia under heatwave in absence of apical predators, and only by Euplotia under heatwave in presence of apical predators; among phytoplankton, Cyanophyceae and Bacillariophyceae increased under heatwave in absence of apical predators, while Chlorophyceae and picocyanobacteria decreased under heatwave in presence of apical predators. First observations also highlighted a strict negative correlation among abundances of ciliates Oligotrichia and heterotrophic nanoflagellates following the experimental manipulation, suggesting predator-prey dynamics. This study provides new insights on how heatwaves affect the size structure of a planktonic trophic web in Mediterranean coastal lagoons where fishing is one of the main economic activities.

Sedimentary organic matter characteristics along a natural pH gradient at Vulcano Island (Mediterranean Sea)

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In the worst future scenario, the uptake of anthropogenic CO_2 by seawater will reduce the ocean pH for up to 0.4 units by 2100. Nonetheless, the effects of ocean acidification (OA) on sediment biogeochemistry remain poorly understood. We investigated the effects of OA on sedimentary organic matter (OM) characteristics along a natural pH gradient at the Vulcano Island (Italy). Sediment samples were collected during summer 2024 in the Levante Bay at three stations characterized by natural (CpH = 8.1), moderately acidified (MpH = 7.9), and low (LpH = 7.7) pH values, resembling current, moderate-case and worst-case scenarios of OA, respectively. Sediments were analyzed to assess protein, carbohydrate, lipid, and phytopigment contents, and estimate OM ageing (in terms of the protein to carbohydrate ratio), nutritional quality (algal fraction of biopolymeric C), and OM turnover time (from extracellular enzymatic activities). MpH sediments showed higher protein contents, but lower lipid and carbohydrate loads compared to CpH and LpH. Sediments in MpH showed higher values of the protein to carbohydrate ratio, but the lowest values of the algal fraction of biopolymeric C, indicating a fresher OM origin but a nutritional quality lower than that in CpH and LpH. In LpH sediments C turnover time (20±1 d) was higher than in CpH (81 d) and MpH (35 d), suggesting that a stronger OA could accelerate sedimentary C cycling. Furthermore, OM biochemical composition differed significantly among the three pH conditions. Though these results are limited to the summer season, comparing these results with those obtained from other naturally acidified sites, suggest that OA can strongly influence the biochemical composition and degradation rates of sedimentary OM, but with variable and not consistent responses at different pH values. These preliminary results highlight the complex and non-linear effects of OA on sedimentary biogeochemistry.

Climate variability and long-term trends in Harmful Algal Blooms: insights from *Dinophysis* dynamics in the northwestern Adriatic Sea (1998–2023)

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Mussel farming is a key economic activity in the northwestern Adriatic Sea yet challenged from harmful algal blooms (HABs) caused by toxin-producing *Dinophysis* species. These mixotrophic dinoflagellates produce lipophilic toxins that accumulate in shellfish, leading to diarrhetic shellfish poisoning (DSP) and posing risks to human health. In this study, we analysed 26 years (1998–2023) of environmental and biological data from the Emilia-Romagna and Marche coastal regions to investigate long-term trends in *Dinophysis* and toxicity dynamics, and their relationships with environmental variables amid ongoing climate and ecosystem changes. Clear seasonal patterns were identified in *Dinophysis* species composition: *D. acuminata* and *D. sacculus* were predominant in spring and summer, followed by *D. caudata*, while *D. fortii* and *D. tripos* were more prevalent in autumn and winter. DSP events primarily occurred during colder months and were correlated with the presence of *D. caudata* (rs = 0.84), *D. fortii* (rs = 0.83), and *D. tripos* (rs = 0.66). Each species displayed distinct thermal preferences, highlighting temperature as a key ecological driver influencing bloom dynamics and toxicity patterns. We observed a significant increase in *Dinophysis* absence (+5.35% per year) and a concurrent decline in shellfish toxicity (-3.31% per year), alongside reductions in dissolved inorganic nitrogen (DIN), phosphate, total phosphorus, and chlorophyll-a concentrations, suggesting a shift in nutrient regimes and coastal productivity. Nonetheless, anomalous years such as 2015 and 2022, marked by prolonged toxicity under cooler conditions, illustrated how short-term climate variability can override longer-term trends. Our findings underlined the complex and evolving interplay between climate forcing, nutrient dynamics and HABs occurrence. As climate change continues to alter coastal environments, sustained monitoring and the development of robust ecological forecasting tools will be essential to track ecosystem responses over time, to support adaptive management strategies, and safeguard the sustainability of mussel aquaculture in the Adriatic Sea.

AI for Nature: The Nature 4.0 concept

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Nature 4.0 is a conceptual framework describing the integration of advanced digital technologies—such as artificial intelligence (AI), the Internet of Things (IoT), and robotics — into the monitoring, management, and restoration of natural ecosystems. It represents the next phase of conservation and environmental stewardship, enabled by cyber-physical systems. Nature 4.0 envisions a cybernetic ecology, where are tightly interwoven to enable real-time, adaptive, and intelligent environmental governance. The technological components of Nature 4.0 paradigm encompass Smart Sensors, AI and Machine Learning, Edge and Cloud Computing and Cyber-ecological Feedback Loops. In this regard, new opportunities for ecological community are arising to extend in space and time monitoring of ecosystem responses to climate changes and human disturbances. We will present some case studies of advanced monitoring systems for ecological applications.

Monitoring Biotic Stress in a Changing Climate: The Potential of IoT Technologies for Tree Management

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Climate change is intensifying the spread and severity of biotic stressors, altering the interactions between trees and pathogens, and increasing the vulnerability of many species across both urban and forest environments. In this scenario, it becomes crucial to assess how trees already affected by biotic agents respond physiologically not only to environmental conditions but also to treatments aimed at mitigating stress. IoT-based sensing technologies enable continuous, non-invasive monitoring of key parameters such as sap flow, radial growth, and microclimatic conditions. These high-resolution data allow the real-time analysis of physiological responses related to biotic stress and treatment effects, offering new insights into the combined impacts of climatic and pathogenic factors. This presentation will showcase several case studies where these technologies were applied in forest and urban settings to evaluate the effectiveness of post-infection treatments and to better understand tree responses under complex stress conditions.

Integrating 4D Refugia and Hotspot Analysis into Scenario-Based Climate-Smart Marine Spatial Planning

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Marine ecosystems are undergoing profound transformations due to climate change, challenging both biodiversity conservation and the sustainable use of marine resources. To ensure long-term effectiveness, marine spatial planning (MSP) must become 'climate-smart': it should preserve ecological functions and biodiversity under future conditions while ensuring the continued viability of the blue economy. Here, we identify climate refugia and climate hotspots across the Mediterranean Sea and assess the climate resilience of three alternative MSP zoning scenarios developed within the MSP4Biodiversity project of the National Biodiversity Future Centre. These scenarios ("SlowPace", "Nature@Work", "BlueDevelopment") propose different zoning of marine uses in Italian waters, reflecting distinct policy priorities. Using a 3D climate velocity based on temperature analogues across the entire water column (comparing the periods 2006–2030 and 2031–2055), we mapped areas of environmental stability (potential climate refugia) and zones of intense change (climate hotspots). We then evaluated the extent to which each zoning scenario aligns with stable areas and avoids high-velocity or no-analogue zones. Our results reveal high exposure to climate change across all three pilot areas—Northern Adriatic, Northern Tyrrhenian, and Strait of Sicily—with the Northern Adriatic showing the highest rate of change. None of the scenarios sufficiently safeguards areas of future stability or strategically places climate-sensitive uses (e.g., fisheries, aquaculture, tourism). However, the conservation-oriented "Nature@Work" scenario demonstrates the highest potential for supporting biodiversity resilience and long-term adaptation. This analysis provides a framework for integrating climate adaptation into MSP by highlighting spatial mismatches between future climatically stable areas and current or projected marine uses. Our findings underscore the urgency of future-proofing marine spatial plans to support both ecological integrity and socio-economic goals in a rapidly changing ocean.

Climate Change Drives Cryptic Elevational Shifts and Body Size Increases in a Riparian Bat

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Climate change is causing widespread shifts in species phenology, morphology, and distribution, with organisms moving to higher latitudes or altitudes as previously suitable areas become inhospitable. Bats are particularly vulnerable to warming due to their strong thermoregulatory constraints and temperature-dependent reproductive biology. Here, we present the results of a long-term study of *Myotis daubentonii*—a riparian bat species exhibiting altitudinal sexual segregation—along a river in Central Italy. Montane environments, with their compressed climatic gradients, are especially well-suited to detect such fine-scale responses. Historically, reproductive females were limited to downstream sections below 850–900 m a.s.l., where warmer conditions supported successful breeding. Our long-term data show that females have shifted their reproductive range upwards by 175 m, now regularly occupying elevations of up to approximately 1050 m a.s.l., in response to rising temperatures. We tested whether this shift represented a true expansion of the reproductive range rather than merely a foraging extension. Radio-tracking 14 reproductive females confirmed that maternity roosts have indeed been established at higher elevations. These roosts were consistently found in riparian forests, especially in rot cavities positioned high above the ground, within sparsely vegetated understories, with south-eastern exposures. Concurrently, we observed a generational increase in body size, likely driven by reduced thermoregulatory costs and improved energy allocation to offspring at higher, yet now warmer, altitudes. The observed shift, affecting only one sex and stage of life, exemplifies a subtle range expansion that might otherwise go unnoticed. Our findings emphasise the dual ecological response of *M. daubentonii* to climate change—both distributional and morphological—and underscore the vital role of riparian forests as ecological corridors that enable adaptive range shifts. Conservation strategies should prioritise protecting and restoring riparian habitats to bolster population resilience amid ongoing environmental change.

The Spread of IAS in the Mediterranean and the relation with Climate Change

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Ecosystems worldwide are rapidly changing. In the Mediterranean Sea, one of the world's fastest-warming marine regions, two major drivers are the spread of invasive alien species (IAS) and changing environmental conditions. Concurrently, warming conditions can facilitate IAS establishment. The focus of this study is to understand the dynamics between the description of invasions and research effort, and the relationship with climate change. Using the blue crab, *Callinectes sapidus* as a case study, this methodology provides a workflow for analyzing invasion descriptions of easily identifiable IAS. This investigation analyzed records along a naturally occurring north to south axis in the Adriatic Sea, the Ionian Sea and Central Mediterranean Sub-basins. A total of 336 research-grade observations of over 58 years were compiled from 106 peer-reviewed publications, including traditional scientific sampling to those incorporating local ecological knowledge (LEK) methodologies. Additionally, satellite-based sea surface temperature records were analyzed to track the spatio-temporal spread of *C. sapidus*. Segmented linear regression identified phases consistent with classic invasion theory. Generalized Least Squares modeling revealed exponential growth in records, doubling approximately every four years and at a faster rate than increases in research effort. LEK proved especially valuable in data-poor regions, filling gaps in formal monitoring. Sea surface temperature (SST) data revealed significant long-term warming, particularly in winter minima. These trends align with the observed overwinter survival and range expansion of *C. sapidus*. Episodic marine heatwaves and altered circulation patterns could contribute to enhanced larval dispersal and recruitment success. The results emphasize the need for early detection systems, coordinated monitoring, and adaptive management strategies. Integrating LEK, ecological data, and climate observations offers a scalable model for understanding the invasion dynamics of IAS under climate stress. As Mediterranean ecosystems grow increasingly vulnerable, evidence-based action is critical to mitigating the dual threats of warming seas and biological invasions.

Advanced IoT Sensors for In-Situ Validation of Satellite Data in Remote Forests: Nature4.0's Role in the RemoTrees Project

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Forests play a critical role in the global carbon cycle, acting as either carbon sinks or sources depending on natural and anthropogenic factors. Understanding these dynamics, particularly in remote, hard-to-reach forests, is essential for addressing climate change. The RemoTrees project aims to bridge the gap between satellite Earth Observations (EO) and in-situ data to improve the accuracy and reliability of carbon flux assessments in these ecosystems. RemoTrees focuses on the development and deployment of advanced IoT multi-sensor devices designed to monitor physiological and radiometric parameters of forests. These devices provide near-real-time, high-resolution data on variables such as under-canopy VIS-NIR data, soil moisture, and sap flow, with a particular focus on radiometric indicators vital for assessing forest health and carbon dynamics. By installing these sensors in remote forests, we can generate comprehensive ground-based datasets that are currently lacking, enabling more accurate validation and calibration of satellite-derived measurements. Our approach leverages EO data to model and predict the impacts of extreme climate events (e.g., storms, droughts, heatwaves, heavy precipitation) and human activities (e.g., logging, land-use changes, soil protection practices) on the carbon cycle. Integrating IoT sensor data with satellite observations enhances our ability to detect early signs of carbon losses or gains in biomass and soil, contributing to a more refined understanding of terrestrial carbon pools. The outcomes of RemoTrees will offer key insights into the role of remote forests in the carbon cycle and their response to environmental stressors. This will support more effective conservation and management strategies, ultimately aiding global climate mitigation efforts. Our presentation will showcase the technological innovations of RemoTrees, preliminary data from existing TT-Cyber installations (the baseline for RemoTrees devices), and implications for future EO-based carbon studies.

Local Ecological Knowledge as a tool for marine conservation: insights into species dynamics and climate perception across the Italian coastline

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Rising temperatures and recent marine heat waves in the Mediterranean Sea have significantly altered the composition and structure of marine communities, affecting species performance, distribution, and interaction dynamics. In this study, we explored the spatial distribution and conservation status of *Astroides calycularis*, a threatened and endemic structuring coral species in the Mediterranean, by collating and synthesizing Local Ecological Knowledge (LEK) from scuba divers along the Italian coasts. As climate change is facilitating the expansion of native thermophilic species such as the fireworm *Hermodice carunculata*, we also collected data on the distribution of this corallivorous polychaete and its potential interactions with *A. calycularis*. Results showed that divers were already familiar with both species and generally perceived the presence of the coral positively. The compiled data extended the known distribution range of both species, including new records and a high degree of spatial overlap along the Italian coastline. Additionally, numerous observations of necrotic *A. calycularis* colonies were reported. Lastly, divers' experiences over recent years reflected a clear perception of increasing sea temperatures, consistent with the occurrence of marine heatwaves in the region.

Climbing the gradient: diatom taxonomic and functional diversity patterns along elevational shifts in temporary ponds

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Temporary ponds (TPs) are ephemeral freshwater habitats which ecological importance was historically neglected. In an era of rapid and unpredictable climate change, understanding how these vulnerable ephemeral ecosystems respond to shifts in local and regional spatial factors can be crucial for anticipating global impacts. The aim of this research is to investigate whether the differences in the floristic composition of diatom communities at small and large scales are mainly driven by geographical, elevational or environmental factors (physicochemical factors). Taxonomic α diversity revealed no significant seasonal effects based on linear mixed models. Generalized Additive Models (GAMs) identified pH and electrical conductivity (EC) as significant predictors of species richness, while elevation emerged as the main driver of Shannon and Simpson diversity. Relative importance analysis confirmed EC as the most influential variable across indices. β diversity Mantel analyses showed a strong effect of elevation on community dissimilarity, with community similarity decreasing significantly with increasing elevational distance. Initial Compositional Similarities revealed that community similarity decreased steadily with elevational distance at a rate of approximately 0.00019 per meter, starting from an initial similarity of 41%, with a calculated Halving Distance of 1059 meters. Partial Mantel tests confirmed independent contributions of both elevation and environmental factors, while PERMANOVA analyses highlighted temperature, EC, and ORP as significant environmental drivers of community structure. Similarly, functional α and β diversity were mainly driven by the elevation gradient rather than seasonality, with the turnover component explaining most of the observed β diversity. Physical parameters (T, pH, ORP and TDS) exerted a more significant influence on functional α diversity, underscoring the resilience of functional β diversity, which was not influenced by physicochemical parameters. Our results highlighted the need for a greater focus on the analysis of predictive factors that may influence diatom communities, particularly in the global context of climate changes.

Toward reliable metrics of ecosystem resilience to droughts in the Mediterranean Basin biome

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The increasing frequency and intensity of droughts in the Mediterranean Basin poses the ecosystems of this biodiversity hotspot at risk, despite their adaptation to arid and semi-arid conditions. The concept of ecosystem resilience has been widely applied in framing the impacts of global changes on ecosystems, yet the transferability of the metrics used is rarely assessed. Moreover, estimating resilience to drought poses an additional challenge, being a multi-scalar hazard difficult to uniquely identify temporally. In this study, we aim to identify metrics suited to assess the impacts of drought on ecosystems in the Mediterranean Basin biome. We analyzed time series from 2001 to 2018 of drought and vegetation spectral indices across six sites, spread around the whole Basin and with different aridity and vegetation types. We used the Standardized Evapotranspiration-Precipitation Index (SPEI) at different aggregation time scales (3, 6, and 12 months), and four spectral indices — NDVI, EVI, NIRv and kNDVI — as proxies of vegetation functioning. We estimated the correlation between drought and vegetation indices to select the most relevant time scale for detecting droughts and their effect. Our findings show that aggregating SPEI over 12 months and using kNDVI for vegetation gives the most robust combination for detecting drought impacts. Eight vegetation response metrics were defined to represent various components of resilience. We analyzed them using an event-based approach, with droughts identified using four different SPEI thresholds. The distributions of response metrics were then compared with those from randomly occurring synthetic events to evaluate their reliability in capturing drought impact. Productivity loss and recovery emerged as the most consistent across sites and drought definition, supporting their relevance for large-scale assessments of drought resilience in Mediterranean ecosystems.

Limits under pressure: the case study of *Ellisolandia elongata* resilience during a rare prolonged low tide event

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In the Gulf of Naples, Italy, a rare prolonged low tide event lasting approximately eleven days, caused by a natural inverted barometer effect, determined extreme environmental conditions providing a singular opportunity to directly observe the long-term adaptive and recovery mechanisms of an *Ellisolandia elongata* population. This species, inhabiting the low rocky shore intertidal zone, represents a suitable model for studying how coralline algae respond to multiple environmental stressors. To investigate the resilience of the population, we examined structural and functional traits in submerged, exposed, and re-submerged thalli during and following the low tide event. Such approach allowed us to explore the intrinsic physiological plasticity and recovery potential of this species. The prolonged low tide caused bleaching in 74% of the exposed thalli and led to significant decreases in photosynthetic efficiency, PSII-D1 protein levels, and photosynthetic pigment concentration compared to submerged and re-submerged thalli. Despite these detrimental effects, the non-photochemical quenching remained stable, indicating the occurrence of an active photoprotection. Exposed thalli also showed reduced carbohydrate and decreased concentrations of antioxidant compound (polyphenols, flavonoids, tannins and overall antioxidant activity), indicating oxidative stress and mobilization of antioxidant defenses to mitigate cellular damage. Following the re-submersion, photosynthetic activity, pigment concentrations, and antioxidant levels recovered, demonstrating *E. elongata* capacity to preserve physiological integrity by down-regulating photosystem II efficiency and pigment synthesis during desiccation. Our findings shed light into the adaptive capacity and resilience of *E. elongata* to extreme climatic events, highlighting the role of antioxidant mechanisms in enabling recovery from multiple stressors. Understanding these physiological responses is pivotal for identifying vulnerability and resilience hotspots within intertidal ecosystems, informing climate-adaptation strategies for coastal conservation planning.

Assessing ecological communities' structure and dynamics in Mediterranean transitional water ecosystems through environmental DNA metabarcoding.

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Mediterranean transitional waters are vital ecosystems that provide essential services such as water filtration, carbon sequestration, and habitat support, while also acting as buffers against climate change impacts like sea-level rise and temperature fluctuations. However, these ecosystems face increasing threats from non-indigenous species (NIS), pollution, and human activities, emphasizing the need for effective conservation strategies. Environmental DNA (eDNA) metabarcoding is increasingly revolutionizing the way large-scale biodiversity monitoring is conducted, offering an innovative and non-invasive approach to assess ecological communities. This method relies on the analysis of genetic material, such as, DNA fragments shed by organisms into their surrounding environment, collected from environmental matrices such as water, soil, or sediment. Bypassing the need for direct observation or physical capture of organisms, eDNA enables the detection of a wide array of taxa, including cryptic, rare, or elusive species, with minimal disturbance to the ecosystem. Within this framework, we applied eDNA-based technologies to explore biodiversity patterns and community structure in transitional aquatic ecosystems of the Mediterranean region. In particular, the conducted studies implemented eDNA metabarcoding protocols focusing on two widely used genetic markers: the mitochondrial cytochrome c oxidase subunit I (COI) gene, typically employed for the identification of metazoans, and the V4 region of the 18S ribosomal RNA gene, a broad eukaryotic marker suitable for capturing the diversity of microeukaryotic communities like phytoplankton. The obtained results revealed distinct spatial patterns in both phytoplankton and macrozoobenthic communities, closely aligned with the environmental gradients of salinity and temperature characterising transitional waters, suggesting a strong environmental filtering effect on community assembly, where abiotic conditions and localised impacts can influence species occurrence and abundance. Overall, our research demonstrates the effectiveness of molecular approaches in ecological assessment, emphasizing the need for integrated conservation efforts that combine advanced technologies with traditional monitoring and community engagement to ensure the resilience of Mediterranean lagoon ecosystems in the context of ongoing environmental pressures.

L’ecotossicologia tra regolamentazione e nuove sfide per la sostenibilità ambientale

4

Multi-Tier Assessment of PVA-Based Liquid Dishwasher Pods on *Danio rerio* Embryos: the Hidden Impact of Additives

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Water-soluble polymers (WSPs) are widely employed in industrial, medical, and everyday applications. Despite their widespread use, the lack of specific regulation contributes to their uncontrolled release, especially into aquatic ecosystems, raising concerns about potential risks to organisms and human health. Among WSP-containing consumer products, dishwasher pods are particularly common. These single-dose pods typically contain powder and/or liquid detergent enclosed in a water-soluble film made of polyvinyl alcohol (PVA), one of the most widely used WSPs. This study aims to investigate the potential effects of different chemical components present in PVA-based liquid dishwasher pods on *Danio rerio* embryos. PVA was first separated from the additives by acetone extraction and chemically characterized using ^{1}H-NMR spectroscopy. Embryos were then exposed to the whole pod (excluding detergent) at the concentration of 0.1 mg/L, estimated for urban wastewater entering the Milan-Nosedo treatment plant, and to the corresponding concentrations of extracted PVA (0.07 mg/L) and additives (0.03 mg/L). A multi-tier approach was adopted to investigate the effects across molecular, cellular, physiological, and organism levels, including proteomics and metabolomics analyses, reactive oxygen species (ROS) levels, acetylcholinesterase (AChE) activity, as well as mitochondrial respiration and glycolysis. Additionally, heart rate was evaluated as a physiological endpoint, while behavioural parameters (*e.g.* distance moved, turn angle, and thigmotaxis) were used to assess swimming behaviour. At the cellular level, ROS were significantly ($p < 0.05$) decreased in embryos exposed to PVA and additives compared to controls, and a significant increase in AChE activity was observed in embryos exposed to additives and pods. Additives also caused a significant decrease in the heart rate at the physiological level. Although the analysis of some last endpoints is still ongoing, these results suggest that additives in commercial PVA-based products may be the primary drivers of toxicity, consistent with previous findings in the literature.

Early warning system beyond standard ecological assessment: Teratogenic risk in freshwaters

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Freshwater ecosystems are among the most vulnerable to anthropogenic stressors, with increasing concern over emerging contaminants that may affect aquatic organisms and compromise overall ecosystem health. Among these, substances with teratogenic potential represent an ecotoxicological concern that remains largely unregulated under the current Water Framework Directive (2000/60/EC), despite growing evidence of their biological impact. This study explores the use of biological tools to assess both the ecological status and teratogenic risk in eight riverine systems of Central Italy. Two complementary indicators were applied: the Intercalibration Common Metric Index (ICMi), derived from benthic diatom assemblages as a proxy for ecological quality, and the Teratogenic Risk Index (TRI), based on morpho-functional responses in *Hydra vulgaris*. Results revealed a wide spatial variability in both ecological status (ICMi ranging from poor to high) and TRI values. Several sites showed elevated teratogenic risk even in the absence of ecological degradation, with some classified as ecologically "good" presenting marked teratogenic effects and thus suggesting the presence of bioactive contaminants undetected by conventional monitoring. Diatom assemblages reflected natural and anthropogenic gradients, with motile and tolerant taxa dominating impacted sites, while low-profile species were more abundant under better environmental conditions. The lack of correlation between ecological quality and teratogenic risk highlights a critical gap in current assessment frameworks. These findings support the need to broaden environmental monitoring to include early warning bioindicators for pollutants currently outside regulatory control. Such an integrated approach can enhance the ability to detect significant ecotoxicological pressures and contribute to more effective strategies for ecosystem protection and regulatory innovation, within a One Health approach.

Flocculants and Microplastics: Efficiency, Sustainability, and Ecotoxicological Risk.

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The pervasive presence of plastics in the environment and their increasing release into natural ecosystems represent a significant concern for both human and environmental health. Wastewater Treatment Plants (WWTPs) are identified as a primary source for plastics to enter water courses. Although various studies have demonstrated the efficiency of certain coagulants/flocculants in removing plastics from wastewater in laboratory tests, their potential application in WWTPs remains under-explored, and numerous commercial polymer-based flocculants have not yet been tested. To address this gap, the aim of this study is the evaluation of the effectiveness of different commercial polymer-based flocculants, synthetic and natural, to decrease the plastic concentration in wastewater. To assess their effectiveness across different matrices and mixtures of plastics, wastewater samples will be collected from two distinct types of WWTPs (civil and industrial). The results will provide insight into the practical applications and potential environmental benefits of using natural flocculants instead of synthetic ones, which are currently the most used in treatment plants. This will contribute to the development of more effective strategies for plastic mitigation while also promoting more sustainable treatment processes. To achieve this goal, given that flocculation is one of the final depuration processes in wastewater treatment, it is imperative to also evaluate the effects that flocculants could have on aquatic ecosystems by using the freshwater crustacean *Daphnia magna.* Specifically, the investigation will span various levels of biological organization, from molecular to organismal. It will assess potential alterations in the proteome, as well as changes in behavior, reproduction, and feeding patterns. This comprehensive approach aims to provide a detailed understanding of how these treatments may influence aquatic organisms and ecosystem health.

One Health Insights into the Bioaccumulation and Neurotoxicity of PFAS

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Per- and polyfluoroalkyl substances (PFAS) are ultra-persistent anthropogenic chemicals whose strength of the C–F bond facilitates long-range atmospheric transport and trophic transfer. Applying a One Health framework, we bridged field surveys, mesocosm food-web simulations and structure–function analyses to characterize ecological and neurotoxic liabilities of both legacy and emerging PFAS congeners. Field sampling at a brackish wetland in southern Sweden detected PFOS and PFOA across four trophic levels (n = 158), with trophic magnification factors exceeding unity, confirming biomagnification in invertebrate food webs. Controlled mesocosm experiments replicating simplified terrestrial food chains corroborated these trends and revealed significant reproductive impairments in *Eisenia fetida*, including a 30 % reduction in cocoon output after 30 d (Welch's ANOVA, p

Trophic Magnification of Per- and Polyfluoroalkyl Substances in an AFFF-Contaminated Environment

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Per- and polyfluoroalkyl substances (PFAS) represent a class of persistent organic pollutants (POPs) characterized by strong carbon-fluorine (C-F) bonds, amphiphilic properties, and exceptional resistance to environmental degradation. These physicochemical attributes have led to extensive industrial and consumer applications, resulting in widespread environmental contamination. Consequently, PFAS compounds have been ubiquitously detected across various environmental compartments, raising substantial ecological and toxicological concerns. In this investigation, we quantified the distribution and trophic transfer of PFAS at a firefighting training site in Trelleborg, Sweden. The study encompassed 160 samples collected from abiotic matrices (water and soil) and biotic matrices including plant tissues (roots, leaves), arthropods, and annelids. Employing Stable Isotope Analysis (SIA), we accurately reconstructed the local trophic web, facilitating the quantification of PFAS concentrations and their trophic magnification potential. Twenty-two distinct PFAS were identified within the study area, and trophic magnification factors (TMFs) were calculated for each compound. The results revealed significant biomagnification across multiple trophic levels for both long-chain and short-chain PFAS, challenging the conventional assumption that biomagnification primarily pertains to long-chain PFAS compounds. Notably, short-chain PFAS exhibited pronounced biomagnification, particularly within the soil food web, highlighting their potentially greater ecological relevance compared to longer-chain compounds, such as perfluorohexane sulfonate (PFHxS), which showed limited biomagnification in this environmental compartment. These findings emphasize the importance of incorporating short-chain PFAS into environmental risk evaluations due to their notable potential for trophic transfer and accumulation. This robust dataset provides novel insights into PFAS distribution dynamics within trophic webs, particularly underscoring the critical role of soil food webs in mediating biomagnification processes. The demonstrated biomagnification across diverse PFAS structures necessitates expanded research efforts and revised regulatory strategies, specifically addressing the ecological implications associated with short-chain PFAS compounds

Ecotoxicological effects of Tire Road Wear Particles (TRWPs) collected from different asphalts

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Tire abrasion on the asphalt surface produces the so-called Tire Road Wear Particles (TRWPs), whose potential adverse effects on ecosystems are under consideration by the scientific community. Since the aquatic environment represents a reservoir of these contaminants, the aim of this project was to investigate the toxicity of TRWPs on *Danio rerio* (zebrafish) embryos. TRWPs were directly collected in the environment on different types of road surface, represented by rubberized (TRWP1), polymeric (TRWP2) and conventional (TRWP3) asphalts. Sampling was carried out using a vacuum system in different sections of the 73 Senese Aretina (SS73) State Road, which represents one of the few Italian routes with the contemporary typologies of the three abovementioned asphalts. The collected particles were sieved on a set of steel sieves (5, 4 and 1 mm) to remove the coarsest contaminants and characterized by Scanning Electron Microscopy (SEM) coupled with Energy Dispersive x-ray Spectroscopy (EDS). To confirm the presence of rubber particles in the samples, the hexamethoxymethylmelamine (HMMM), used in tire production as crosslinking agent, was quantified as TRWP marker. Subsequently, TRWP aqueous suspensions were prepared by 72 h stirring followed by 48 h settling. These suspensions were analyzed by Dynamic Light Scattering (DLS) to measure the eventual presence of particles in the aqueous medium. The organisms were exposed from 0 to 120 h post fertilization (hpf) to 10 and 100 µg/L of TRWP suspensions. To compare the effects between TRWP1 and TRWP3, based on the composition of the abrasive substrate, a wide battery of biomarkers of cellular stress, protein aggregation (amyloids), neuro-genotoxicity and alterations of heart rate and swimming behavior was applied. Moreover, the effect comparison between TRWP2 and TRWP3 were investigated through Omics techniques, such as gel free proteomics, metabolomics and transcriptomics (Next Generation Sequencing - NGS). The ecotoxicological analyses are ongoing.

Ecotoxicological evaluations of Lunar Regolith Simulants: new data for future challenges

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Setting up sustainable life support systems for long-term Lunar missions requires the implementation of In-Situ Resource Utilization (ISRU) techniques and the identification of possible substrates, such as Lunar regolith, for different uses and applications. However, the environmental and health compatibility of this substrate needs to be investigated. Literature toxicological data on Lunar regolith simulants (LRS) suggest health hazard if inhaled, however ecotoxicological aspects have not been investigated so far. For this purpose, in this study an ecotoxicological assessment of three commercially available LRS (such as LHS-1D, LHS-2 and LMS-1) with different particle size and composition was performed. The LRS substrates were tested alone and with the addition of a compost (30%), derived from organic fraction of a municipal solid waste for increasing their nutrient content. The ecotoxicological tests were performed on three model organisms belonging to different trophic levels and environmental compartments such as *Aliivibrio fischeri* (ISO 11348-3:2019), *Lepidium sativum* (APAT 2004) and *Daphnia magna* (ISO 6341:2013). The organisms were exposed to water extracts (UNI EN 12457-2:2004) of each substrate for evaluating their environmental compatibility. Moreover, the *Lepidium sativum* germination test was also performed exposing seeds to the solid matrices (APAT 2004). Preliminary results revealed a low acute toxicity of the LRS solid matrices and water extracts, which was generally lowered by the compost presence. Overall data will be discussed considering LRS mineral content and their potential interactions with compost. This study shows how the ecotoxicological approach can be applied a wide variety of "environmental scenarios", including extra-terrestrial ones and open new perspectives for a safe use of LRS in future long-term lunar missions, including their application as a substrate for plant growth.

Capitale naturale, servizi ecosistemici e contabilità ambientale

5

The role of ecosystem condition in urban ecosystem service models and assessments: a critical review

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Ecosystem condition refers to the quality of an ecosystem, both natural and anthropogenic, such as urban ecosystems. It is typically measured through abiotic and biotic variables, some serving as proxies for ecosystem processes or functions on which the supply of ecosystem services depends. While the linkage between ecosystem condition and ecosystem services is widely recognized, including by the UN Statistical Standard for Ecosystem Accounting (SEEA-EA), the relationship is complex, often non-linear or delayed, and varies by service. Generally, better condition is expected to enhance service supply, while overexploitation of services can lead to degradation of condition. This study critically reviews urban ecosystem service studies that incorporate ecosystem condition, examining how and to what extent it is integrated into assessment methods and models. For each service within each case study, we recorded key information, including: (1) assessment method; (2) condition variables and their classification (SEEA-EA, EBVs); (3) biodiversity level (for biotic variables); (4) spatial and temporal explicitness; (5) whether actual or potential service supply was assessed; and (6) consideration of sustainability. We reviewed 110 studies, with regulating services being the most frequently assessed category. Structural and compositional state variables were most commonly used, followed by chemical and physical variables, while functional variables were rare and largely limited to phenological traits. Only a minority of studies accounted for temporal dynamics or assessed actual service supply. Even fewer addressed sustainability aspects that could inform about overexploitation or unmet demand. Our findings show that, while ecosystem condition variables are increasingly considered in urban ecosystem service assessments, their integration remains partial. It is often limited to static, qualitative or semi-qualitative ecosystem service assessments and tends to overlook considerations related to the sustainability of service flows.

Carbon storage capacity of *Posidonia oceanica* matte: an assessment through the System of Environmental Economic Accounting – Ecosystem Accounting (SEEA-EA) framework

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Posidonia oceanica meadows are vital components of the marine carbon sink, playing a key role in carbon sequestration and storage and, therefore, in climate change mitigation. The species forms unique structures known as mattes, characterized by the complex intertwining of the sediment matrix, seagrass shoots, and rhizomes, creating a low-oxygen environment. Beyond stabilizing the seafloor, their primary ecological importance lies in the long-term accumulation of organic carbon at high densities. Nonetheless, the carbon storage potential of *P. oceanica* mattes remains insufficiently assessed. This study focuses on mapping the matte system and estimating the associated organic carbon stock of *P. oceanica* meadows in the Gulf of Sapri (Southern Italy). In particular, by applying the United Nations' "System of Environmental Economic Accounting – Ecosystem Accounting" (SEEA-EA) framework, we implemented an integrated assessment that addresses in both ecological and economic terms the important role that *P. oceanica* plays as a blue carbon ecosystem. Our results reveal an average C_{org} stock value of 201 ± 62 Mg ha^{-1} within the top meter of matte, representing a total estimated economic value of over €2.5 million in the study area. The results of this study can be considered in policy decisions for seagrass conservation and restoration and highlight the contribution that *P. oceanica* meadows can provide in supporting broader European climate objectives, such as reducing emissions and reaching climate neutrality by 2050. Finally, the study showcases how the SEEA-EA framework can be applied to marine ecosystems to quantify the benefits they provide to human well-being.

Eco-physical modelling of cultural capital: A conceptual framework

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Cultural heritage assets embedded in historical and archaeological landscapes play a fundamental role in shaping both the identity of a place (genius loci) and the social cohesion of the communities that inhabit it. Despite this, heritage sites are rarely interpreted as historical imprints of long-term human–environment interactions. Representing these past dynamics in a quantitative way remains a significant challenge, requiring a multidisciplinary and systems-based approach. This study proposes an integrative framework that combines eco-physics, archaeology, and ecology, positioning the research within the broader scope of historical ecology. The aim is to characterize historical anthropogenic biomes (i.e., anthromes) as complex systems whose structure and resilience are linked to environmental resource use and regeneration. Drawing from recent literature, we also argue for the inclusion of cultural heritage within the quantification of cultural capital and cultural ecosystem services (CES), thereby complementing the assessment of natural capital. The proposed approach enables the development of both monetary and non-monetary evaluations of cultural capital, expanding current experimental accounting frameworks. These evaluations are designed to be replicable and potentially integrable into ecosystem services accounting systems and Sustainable Development Goal (SDG)-oriented reporting tools. At this early stage, the research contributes a conceptual bridge between historical ecology and environmental physics, allowing for counterfactual analysis of resilience and resource dependence in pre-Anthropocene contexts. Ultimately, this framework supports the recognition of the ecosystemic value of cultural heritage, promoting its integration into both conservation policies and natural capital accounting, and fostering a more comprehensive understanding of sustainability in coupled human–natural systems.

Regulating Ecosystem Services: Spatial Modelling of PM_{10} and O_3 Removal by Alpine Forests in the Province of Trento, Italy

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Air pollution continues to represent a significant environmental and public health challenge throughout Europe, with the situation being particularly critical in Italy, where persistent exceedances of regulatory limits and widespread exposure to harmful pollutants raise serious concerns for both human well-being and the health of ecosystems. Particulate Matter (PM) and ground-level Ozone (O_3) are among the most harmful pollutants due to their broad spatial distribution and adverse health effects on humans and the environment. Their persistence is driven by complex atmospheric processes and regional emission sources that vary across different landscapes. In this study, we assess the capacity of alpine forest ecosystems in the Province of Trento (Northern Italy) to deliver Regulating Ecosystem Services (RES) through the removal of PM_{10} and O_3 from the atmosphere. While PM_{10} is removed via dry deposition on foliar surfaces, O_3 is mostly absorbed through stomatal uptake. The efficiency of pollutant removal is closely linked to species-specific traits and seasonal variations, which were accounted for by classifying forest vegetation into three functional groups based on their morphological and phenological characteristics. A spatially explicit, high-resolution modelling framework was used, combining land cover data, remote-sensing-derived Leaf Area Index (LAI), and spatial air pollution datasets. Seasonal removal efficiency (kg/ha) and total removal (Mg) were estimated using GIS-based analyses. The associated economic value of pollutant removal was quantified by using negative externalities value estimates from the European Environment Agency (EEA). The integrated biophysical and economic evaluation underscores the important role of forest ecosystems in mitigating air pollution. Results provide reference values useful for forest managers and policymakers to support evidence-based strategies for improving air quality while promoting functional biodiversity.

The impacts of Atlantic blue crab on provisioning services in the Sacca di Goro lagoon, Po River delta

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The introduction of non-native species can lead to biodiversity loss and disruption of ecological functions, with cascading impacts on ecosystem services, especially in intensively exploited socio-ecological systems. Among these species, the Atlantic blue crab (*Callinectes sapidus*) has gained widespread attention due to its recent invasion of the Northern Adriatic coast since 2023. This study aims to document the upstream expansion of the blue crab along the Po River and assess its impact on provisioning services in the Sacca di Goro lagoon, an internationally recognized brackish coastal system known for aquaculture. Field observations along the river were obtained through targeted sampling and reports from local anglers. Impacts on provisioning services (i.e. fishing and aquaculture) were quantified by comparing 2023–2024 data with previous years. Revenues from blue crab sales and associated disposal costs were also assessed to estimate the net economic impact. The results showed that male blue crabs migrated over 100 km upstream. This unprecedented dispersal capacity has not been observed in other invaded regions and is likely due to overcrowding in the Po Delta lagoons and the absence of predators of large sizes. Fishing impacts primarily involved grey mullets (*Liza ramada, Liza aurata*), the sand smelt (*Atherina boyeri*), the golden shrimps (*Penaeus* spp) and native crab (*Carcinus aestuarii*). Clam (*Ruditapes philippinarum*) aquaculture biomass dropped by 71.36% in 2024 compared to the 2013–2023 average, resulting in a monetary loss of 51.2 million €yr^{-1}. Net revenue from blue crab harvesting was positive in 2023 (+408,000 €yr^{-1}) but turned negative in 2024 (-714,000 €yr^{-1}) due to rising disposal costs and declining market value. To date, not only are the revenues from blue crab sales negligible, but they are also outweighed by the high costs of disposal. This case highlights how invasive species can profoundly alter ecosystem service flows, threatening both ecological balance and economic sustainability.

Integrating Ecosystem Accounting into Decision Making: The System of Environmental Economic Accounting-Ecosystem Accounting (SEEA-EA) Framework

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Healthy ecosystems and biodiversity underpin human well-being. However, increasing anthropogenic pressures are driving environmental degradation, depleting natural capital stocks and undermining the capacity of ecosystems to provide essential ecosystem services. As ecosystem degradation is now recognised as a multidimensional crisis (environmental, economic, and social), the demand for integrated frameworks has grown, aiming to reflect both our dependence on nature and the impacts of human activity. In this context, the United Nations launched in 2021 the System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA-EA), an integrated and comprehensive statistical framework for organising data about habitats and landscapes. The SEEA-EA offers a spatially explicit and integrative approach to organising biophysical data, assessing ecosystem services and assets in both physical and monetary terms, monitoring changes in ecosystem extent and condition, and linking ecological information with national economic accounts. Developed through a multidisciplinary process, the framework addresses key policy needs by making visible the role of ecosystems in supporting human systems while capturing the environmental consequences of economic activities. This study presents a methodological overview of the SEEA-EA framework, outlining its structure, components, and principles. Moreover, it highlights how the framework enables the mainstreaming of natural capital and ecosystem services into cross-sectoral decision-making and accounting practices. In addition to the potential of the SEEA-EA in supporting more coherent, transparent, and accountable policy frameworks that align economic development with ecological sustainability, this contribution also explores the main challenges associated with its implementation, including data limitations, uncertainties in valuation methods, spatial mismatches, and debates around the inclusion of non-market services and the risk of monetary reductionism. Through this analysis, the contribution aims to advance the understanding of the SEEA-EA framework as a tool for evidence-based environmental governance and to stimulate further reflection on its development and application for the conservation and sustainable management of ecosystems.

Global seagrass ecosystems blue carbon

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Seagrass meadows play a critical role in climate regulation through carbon sequestration, yet global patterns and drivers remain poorly quantified. Here we present a comprehensive global assessment of seagrass carbon accumulation rates (CARs) and their economic value. Using published field CAR measurements, we trained state-of-the-art machine learning models to map and project CARs across global seagrass habitats. We estimated a global mean CAR of 23.51 ± 11.76 g C m^{-2} yr^{-1}, corresponding to an oceanic carbon burial of 47.95 Tg C yr^{-1}. Subtropical and warm-temperate regions showed the highest accumulation rates, with distinct latitudinal peaks at 30-40° in both hemispheres. Our model identified sea surface height as the primary driver, with human pressures (shipping intensity, nitrogen inputs) and marine biodiversity also strongly influencing CARs. Model robustness varied geographically, with highest reliability in well-studied regions. National-scale analysis revealed marked inequality in blue carbon wealth distribution. Five countries (Australia, United States, Italy, France, Spain) account for 46.2% of global seagrass carbon sequestration, while the top 10% of nations control 67.3% of the total economic value, estimated at US$27.24 ± 0.51 billion annually. These findings provide essential baselines for blue carbon policy and highlight the uneven distribution of nature-based climate solutions across nations.

Sustainable recovery of Rare Earth Elements (REEs) and treatment of contaminated waters using *Galdieria daedala*: an integrated biotechnological system for natural capital regeneration.

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The increasing demand for rare earth elements (REEs), essential for modern technologies, is accompanied by significant environmental impacts caused by conventional mining activities, which compromise natural capital and the associated ecosystem services such as water quality and biodiversity. At the same time, the growing production of electronic waste (e-waste) represents a potential source of critical metals but also a widespread source of contamination, particularly through the dispersion of heavy metals in water bodies. This study proposes the use of the extremophilic microalga *Galdieria daedala* as a biotechnological filter for treating contaminated liquid matrices, especially effluents from e-waste recycling and acidic industrial processes. Thanks to its ability to survive in extreme conditions and selectively absorb metal ions, *Galdieria* enables the effective recovery of REEs while simultaneously reducing the pollutant load in waters, improving water quality and contributing to the protection of aquatic ecosystems. This integrated system acts as a regenerative biological filter, capable of removing heavy and toxic metals, mitigating negative environmental impacts and supporting the conservation of natural capital. Moreover, this approach can be incorporated into environmental assessment frameworks that also account for the ecological benefits it provides, such as water purification and pollution reduction in degraded environments. Therefore, the project represents a concrete example of biotechnology applied to the sustainable management of critical resources and ecosystem regeneration, supporting an ecological transition that combines innovation, conservation, and sustainable economic development.

Modelling the dynamics of multiple Ecosystem Services in the lagoon of Venice.

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Given the current global biodiversity crisis, understanding the dynamics and trends of ecosystem services (ESs) is crucial for the sustainable management of social-ecological systems. This is particularly relevant in highly fragile and anthropized systems such as the Venice Lagoon, especially considering the sensitivity of this area to the impacts of climate change. This work developed a modelling tool that represents the dynamics of twelve ESs in the Venice Lagoon by applying a social-ecological system framework and a systems thinking approach. The conceptual framework is translated into a zero-dimensional model where ESs emerge from the interactions among the state variables, described by a system of ordinary differential equations. The model's state variables describe the dynamics of habitats and fauna under the effects of climatic and socio-demographic forcings. A comprehensive set of data assessing the state of habitats, fauna, and ESs was considered to parameterise the model. Model results present long-term trends in simulated ESs and state variables, providing an overview of the feedback network within the lagoon socio-ecological system. Simulation results show a marked long-term decrease in lifecycle maintenance and fishing activities ESs, linked to the negative trends of intertidal habitats and fauna. A sensitivity test of the model to the internal parameters is presented to evaluate structural stability and identify possible leverage points. This test highlighted the relevance of the management of tourism and MOSE in shaping the future trajectory of the lagoon social-ecological system. Based on the comparison with historical data, we conclude that the model can simulate with a satisfactory degree of approximation the behaviour of the lagoon system, and we discuss potential further developments and applications.

Environmental accounting in marine habitat restoration: a case studies selection for future sustainability perspectives

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In the context of the NBFC (National Biodiversity Future Center), the MARES (Marine Ecosystem Restoration) project, financed through European Union funds, has developed standardized protocols for the restoration of a suite of degraded marine ecosystems under different socio-ecological settings. Ecosystem restoration is a key activity necessary to maintain natural capital and ensure the provisioning of ecosystem services at least at current levels. This is now regulated in Europe through the Nature Restoration Law, a key element of both the European Green Deal and the EU Biodiversity Strategy. However, artificially reconstructing the complexity of ecosystems created by nature may require the use of both renewable and non-renewable resources, as well as result in the generation of waste, which must be minimized from a sustainability perspective. Therefore, the development of protocols and guidelines must consider these aspects and integrate environmental accounting approaches to evaluate sustainability performance, with the aim of continuous improvement. For this reason, within the MARES project, the environmental sustainability of a selection of case studies has been assessed. The ecosystems considered include: *Posidonia oceanica* meadows, *Ericaria amentacea* macroalgal forests, *Ostrea edulis* reefs, and vermetid (*Dendropoma cristatum*) reefs. Sustainability was assessed by means of a system methodology known as emergy analysis which accounts for all the resources used in a process in a single unit of measure: solar emergy joule (seJ). This approach allows for the comparison of different inputs and phases within a single restoration process, as well as between different processes. Furthermore, sustainability indices were calculated to compare the various case studies. When possible, the value of the resources used was compared to the value of the restored natural capital. The results represent a practical tool to evaluate different restoration processes and to highlight the importance of conserving both natural and restored ecosystems.

Developing the ecosystem accounting for coastal wetlands: A Sardinian case study.

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The System of Environmental-Economic Accounting - Ecosystem Accounting (SEEA EA) is a globally recognised framework that integrates ecological and economic data to support informed decision-making and policy development for sustainable ecosystem management. By measuring and tracking changes in natural capital assets (ecosystems and species) and ecosystem services flows, SEEA EA provides essential information to balance environmental conservation and economic development. While most applications of ecosystem accounting have focused on terrestrial domains, its development in coastal-marine ecosystems remains limited. Moreover, while the SEEA EA is generally meant to be adopted at the national level, most ecosystem management decisions are made at the regional or local scale. Here, we apply the SEEA EA framework to a finer scale to investigate the supply of food provisioning ecosystem services in Sardinian coastal lagoons. Our results pinpoint that several difficulties remain in finding systematised data (e.g. structured and policy-relevant datasets). This, alongside a lack of data concerning key ecological aspects that could inform the condition tables, still hinder compilation of full accounts. Despite these limitations, we developed an initial informative set of accounts for the Sardinian lagoons, which includes variables that specifically assess the condition of these ecosystems, including variables directly influenced by external stressors and climate (e.g. water temperature, chlorophyll-a concentration, proportion of non-native species, species biomass, water exchange capacity). Our preliminary results are suggestive for a potentially fruitful applicability of the SEEA EA also at the regional/local scale. We therefore foster the use of SEEA EA to inform coastal lagoon management in contexts of climate change and increasing multiple stressor enhancement. This work contributes to the ongoing development of Ocean Accounts with particular attention to transitional waters.

A Mechanistic, Individual-Based Model to Simulate Urban Tree Growth and Ecosystem Service Dynamics

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Urban forests play a central role in supporting biodiversity and providing ecosystem services such as carbon storage, air purification and runoff mitigation. However, current models used in urban contexts are often static or oversimplified, limiting their ability to represent ecological dynamics and to inform long-term planning under changing environmental conditions. We present a dynamic, individual-based model for urban trees that simulates growth and ecosystem service provision over time. The model is explicitly species-specific and mechanistic, describing key physiological processes such as photosynthesis, phenology, and energy allocation to aboveground and belowground compartments. These processes are driven by exogenous variables including temperature, solar radiation, precipitation, and air pollution. The model operates at mixed temporal resolution (daily to hourly), allowing for the representation of both slow trends and rapid responses. Ecosystem services such as carbon sequestration, air filtration and heat mitigation are estimated as emergent outcomes of tree functioning. Model parameters are calibrated for four common and diverse species in Milan, using data from literature and open datasets. We tested the model on realistic planting scenarios, comparing historical trends with strategies optimized for species diversity. Results show how species composition and design choices affect long-term ES supply, offering insight for urban forest planning. The approach permits to account for the simulation of tree-to-tree interactions, such as competition for light and space, to capture feedbacks between individuals and improve spatial realism. This model provides a process-based framework to evaluate ecological functioning and offers practical support for decision-making in urban green infrastructure design.

Conservazione e gestione di specie e habitat minacciati

6

A topological perspective on the spatiotemporal evolution of meta-communities – insights from Algerian charophytes

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The study of the spatiotemporal evolution of ecological systems is steadily gaining prominence in conservation biology, especially for meta-populations and meta-communities, where entangled spatial and temporal dynamics jointly determine their persistence and evolution. In this context, topological approaches and the theory of homology group persistence can be effectively adopted to track temporal changes, at local to global scales, in the spatial structure of ecological systems and to derive references for their evolutionary trajectories. Here, we demonstrate how temporal changes in meta-community topology can shed light on the dynamics of endangered species. Specifically, our approach leverages over data-driven derivation of topological features through the unraveled voting algorithm and on zigzag persistence for the analysis of their temporal changes, using seasonal data of charophyte communities (one of the most threatened groups of macroalgae worldwide) from 21 Algerian ponds. Results reveal steady seasonal oscillations in connectivity and centrality, with regular annual cycles of formation and destruction of transient topological features and robust structures forming a backbone persisting throughout the time. On the one hand, findings provide crucial insights into the spatial evolution of the Algerian charophyte meta-community, defining references to evaluate the effects of local to global pressures and fostering informed prioritization of conservation efforts. On the other hand, the approach goes beyond the dynamics of topological structures embedded in metric spaces, allowing the understanding of the spatiotemporal evolution of every kind of ecological system.

Paving the way for conservation of fragile ecosystems: drivers of diversity and abundance of pollinators on small Italian islands

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Biodiversity loss and habitat degradation pose critical challenges in the Mediterranean Basin, a recognized hotspot hosting unique species and ecosystems. Small islands, due to their physical isolation and fragile ecosystems, are particularly vulnerable to anthropogenic pressures, and many remain still underexplored in terms of biodiversity and ecosystem function. To fill the knowledge gap regarding the conservation of island terrestrial biota, in this study we investigated pollinator communities, key providers of ecosystem services, across five small Italian islands differing in size, land use and degree of isolation, by integrating morphological and molecular approaches. We analyzed the effects of land use, management as indicated by floral diversity, island area, and distance from the mainland on pollinator abundance and diversity. While pollinator richness was negatively influenced by island isolation, it was not significantly affected by island size, consistent with the small-island effect. In contrast, flowering plant diversity emerged as the most crucial variable driving pollinator presence and diversity, underlying the importance of how land is actually managed. Our findings highlight how sustainable land use and conservation of natural resources on islands can help maintain pollinator diversity even in anthropized and vulnerable areas. Furthermore, the genetic analyses revealed localized haplotypes and cases of population structuring, emphasizing the role of isolation in shaping unique evolutionary lineages relevant to conservation. This study offers valuable baseline data for conservation planning and landscape restoration. It highlights the need for tailored, targeted actions to mitigate biodiversity loss and integrate ecological priorities into land management and urban planning.

Studying habitat trees and biodiversity: from research to conservation implications

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Trees are essential to urban biodiversity, providing key ecosystem services and enhancing the resilience of urban environments. However, urban trees often have short life spans, and urban forests frequently lack age diversity—particularly mature and senescent habitat trees, which are scarce or entirely absent. These older trees support the highest levels of biodiversity, yet they are frequently removed, posing a significant threat to biodiversity conservation, ecosystem service provision, and ultimately, ecosystem resilience. Our research project, *"Habitat Trees: Home for Biodiversity"*, investigated the biological communities supported by habitat trees. The aim was to better understand tree-associated biodiversity and to develop practical strategies for tree management and conservation. We assessed biodiversity across various taxonomic groups—including microorganisms, invertebrates, vertebrates, lichens, and mosses—while also considering vertical stratification, tree-related microhabitats (TreMs), seasonal variation, tree species, and other structural characteristics. Our findings show that habitat trees can host thousands of species from multiple taxonomic and functional groups, including rare and protected species. Many of these organisms are vertically stratified and associated with specific structures such as TreMs, which are often removed in urban contexts, leading to significant biodiversity loss. This knowledge is critical for implementing biodiversity-conscious tree management, as interventions like pruning or branch removal can have substantial ecological impacts. Our findings are being integrated into urban forestry practices by developoing standardized approach for identifying and mapping habitat trees and for creating ecological networks that acknowledge their conservation value.

Modelling the ecological drivers of European groundwater copepods' distributions to guide biodiversity conservation in subterranean aquatic environments

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Anthropogenic global change is reshaping spatial patterns in biodiversity and the ecosystem services it underpins. In this context, ecological modelling techniques are being widely implemented to investigate the distribution of species and the composition of biotic communities across multiple surface ecosystems, anticipating biodiversity shifts and contributing to design effective conservation measures. On the other hand, this approach is still poorly applied to subterranean biotas due to persisting knowledge gaps, including widespread Linnean and Wallacean shortfalls. Among subterranean environments, groundwater hosts a diverse array of invertebrates, with thousands of species described so far, mostly crustaceans. These organisms play pivotal roles in groundwater-dependent ecosystems, including nutrient recycling and water purification. Nonetheless, they are still poorly considered in international conservation agendas. Many groundwater crustacean species possess traits such as restricted distribution, slow metabolism, low reproduction rate and limited environmental niche breadth, which make them especially vulnerable to environmental stressors. We took advantage of the first expert-validated occurrence dataset encompassing all the known species and subspecies of European groundwater-dwelling copepods (Crustacea: Copepoda) to model, at the continent scale and fine spatial resolution (~ 1 km^2), the potential distribution of target groundwater copepod species showing different thermal niche breadths and biogeographic histories. We found that a mix of hydrogeological, climatic and soil-related variables explained most of the observed occurrence patterns and provided the fitted Species Distribution Models (SDMs) with a high predictive performance. The models were then projected across Europe under current conditions and various CMIP6-based global change scenarios to estimate potential range shifts and changes in coverage of suitable regions by European protected areas. This approach enabled us to assess the likely impacts of global change on groundwater species with varying degree of thermal plasticity. Moreover, the framework serves as a replicable template for leveraging SDMs in prioritizing conservation actions for groundwater communities.

The recovery capacity of the critically endangered bamboo coral, *Isidella elongata*, in the Otranto Strait highlights the need for conservation measures

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The bamboo coral *Isidella elongata* is a Mediterranean near-endemic octocoral able to form unique marine animal forests on muddy bottoms between ca. 120 and 1600 m depth. This deep-sea coral ecosystem plays a fundamental ecological role, providing shelter and representing nursery, feeding and spawning area for several species. Until fifty years ago, *I. elongata* was the most common coral of the Mediterranean bathyal zone, where it overlaps with important stocks of fishing resources including the shrimps *Aristeus antennatus* and *Aristaeomorpha foliacea*. With the relentless development of trawl fishing technologies in the last century, *I. elongata* forests almost completely disappeared. The species has been classified as critically endangered, and the General Fisheries Commission for the Mediterranean recognised bamboo coral forests as Vulnerable Marine Ecosystems. Despite the need to take action to ensure the conservation of *I. elongata* forests, crucial information regarding life-history traits such as age, growth rate, and life span is still limited. Following the incidental catch of 751 *I. elongata* in South-Adriatic Sea during experimental trawl fishing surveys from 2012 to 2023, and after a Remotely Operated Vehicle survey, this study provides new life-history traits of this emblematic deep-sea species. Population size structure by means of imaging and species growth model through thin sections and radiocarbon analysis were performed. The species' lifespan in the study area was predicted to be from 57.5 to 59 years. The species showed an exponential growth with significant difference between two groups of age data (48.8 years). Ageing and population insights of *I. elongata* is critical in determining the species' long-term population dynamics and recovery capacity from an ecosystem-based fishery management perspective, particularly in an area where a Fishery Restricted Area has been just implemented.

Promoting Barn Swallow Conservation for Sustainable Fly Control and Livestock Welfare in Dairy Farms

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In recent decades, insectivorous birds associated with agricultural ecosystems have declined globally by up to 60%. This alarming trend is driven by pesticide use, climate and land-use changes, and shifts in farming practices. Additionally, human-animal conflicts reduce suitable nesting sites, further worsening their decline. Yet, these birds offer essential ecosystem services—most notably, natural pest control—helping farmers reduce pest populations and save on pesticide costs. Therefore, evaluating the ecosystem services that insectivorous birds provide in farmed landscapes, and promoting their conservation, represent a win-win strategy that both support Nature-Based Solutions, enhancing farming sustainability, and tackle one of the most urgent conservation challenges. This study evaluates the role of the Barn Swallow (*Hirundo rustica*), a rapidly declining species, in controlling filth flies and its potential benefits for dairy cow welfare. From April to July 2024, we monitored fly activity and Barn Swallow presence in 23 cattle sheds in Parco Adda Sud, Northern Italy. At the same time, cow stress levels were measured through ear and tail movements—indicators of fly-related disturbance. Our findings show that Barn Swallows significantly reduce fly activity and cow stress, offering effective, natural pest control. The presence of the Barn Swallow can thus lead to economic benefits for farmers by reducing pesticide use for fly control and potentially improving milk quantity and/or quality by lowering the level of stress due to flies experienced by cows. These results can be a valuable tool for the conservation of swallows and for better management of human-animal relationships in agroecosystems. Future research should quantify the economic value of this service and assess any risks of pathogen transmission from swallows to livestock. Such insights could inform policy changes—particularly regarding current regulations that ban swallows from barns—further advancing farm sustainability and biodiversity conservation.

Impact of microsporidia on Pacifastacus leniusculus: a study of Astathelohania contejeani infection

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The microsporidian parasite Astathelohania contejeani is the causative agent of porcelain disease, a chronic infection affecting populations of the endangered European crayfish Austropotamobius pallipes complex and the vulnerable noble crayfish Astacus astacus across Europe. The disease is characterized by progressive tissue degeneration and whitening of the abdominal muscles, ultimately leading to the death of infected individuals. Porcelain disease has been implicated in significant crayfish population declines and past mass mortality events, posing a serious threat to the conservation of native crayfish species. The aim of the present study is to assess the horizontal transmission of this parasite from A. pallipes to Pacifastacus leniusculus and to evaluate the development of the disease in this invasive crayfish. A total of 60 P. leniusculus were collected and divided into two groups: a treatment group consisting of 20 females and 20 males, and a control group consisting of 10 females and 10 males. All crayfish were housed individually in separate tanks, each equipped with a shelter and an aerator. Animals were fed weekly and standard housing conditions were maintained throughout the study. The infection process consisted of feeding the treatment group three times with fresh muscle tissue derived from A. pallipes heavily infected by A. contejeani. Infection status was periodically monitored using non-invasive sampling techniques in combination with molecular biology analyses. A low infection rate was observed, which did not align with findings from previous studies. The first infected individual was detected three months after the beginning of the experiment and the final infected crayfish was recorded after five months. Interestingly, no additional infections were detected by the end of the nine-month monitoring period. Keywords: Pacifastacus leniusculus, experiment of infection, microsporidian Acknowledgement: This study was supported by EU LIFE Programme: LIFE-CLAW, Crayfish Lineages Conservation in North- western Apennine (LIFE18 NAT/IT/000806).

Assessing the macrobenthic community of lotic ecosystems for the conservation of the native crayfish *Austropotamobius pallipes* in north-western Italy.

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The ongoing decline of the native crayfish (*Austropotamobius pallipes*) populations, coupled with its endangered status, has prompted the implementation of conservation programmes. Although reintroduction and long-term population monitoring were suggested as a crucial part of management strategies, only a few studies were conducted. The purpose of this study was to identify suitable sites for the reintroduction of juvenile crayfish (spawned in the breeding centres of the EU-funded Life CLAW project) through the analysis and comparison of macrobenthic communities in sites with and without native crayfish. Macrobenthic community and physicochemical variables were sampled at 30 sites – 16 inhabited by the native crayfish and 14 uninhabited but potentially suitable due to their genetic lineage and crayfish plague-free status. In general, no statistically significant differences in water chemistry, physical parameters and macrobenthic community composition were observed between sites with and without native crayfish. The study indicated a high percentage of Trichoptera and Ephemeroptera abundances at sites both with and without crayfish. Moreover, the similarity coefficients obtained by using the Jaccard Index were remarkable high, indicating a strong degree of similarity among all the sites. Acknowledgement This study was supported by the European Funds through the Financial Instrument for the Environment, LIFE Nature and Biodiversity (LIFE18 NAT/IT/000806).

Comparing morphological- and DNA-based biomonitoring for evaluating biodiversity and ecological status in river ecosystems using macroinvertebrates

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Benthic macroinvertebrates are widely used as bioindicators to assess the ecological status of freshwater ecosystems. Current biomonitoring programmes based on macroinvertebrates rely on morphological identification at genus or family level. However, this approach can be time-consuming and requires a high level of expertise, especially if identification is performed directly in the field. Moreover, the taxonomy of these organisms is constantly evolving and this can lead to uncertainties and mis-determinations. DNA metabarcoding is a genetic technique that provides faunistic lists from composite samples and holds the promise to replace morphological identification for biomonitoring purposes in the near future. Comparing the performance of both these methods is thus key to evaluate their strengths and weaknesses, in order to inform future biomonitoring programmes. We compared morphological and DNA metabarcoding identification on 17 streams belonging to 4 different hydroecoregions in NW Italy. Macroinvertebrates were collected with a proportional multihabitat method and organisms were identified in the field according to the Italian national legislation. On the same samples, DNA metabarcoding was performed to obtain macroinvertebrate community composition, using the BF2/BR2 primer set targeting a 421-bp fragment of the Cytochrome c oxidase I. STAR_ICMi index and its sub-metrics were then calculated from the results of both methods. Morphological identification detected more families than metabarcoding and the STAR_ICMi indices correlated just moderately between the two methods. However, metabarcoding provided species-level identification for most organisms, including alien species in multiple taxonomic groups. Although metabarcoding provides novel perspectives, reveals hidden biodiversity, and enhances ecological understanding, it cannot yet fully replace traditional biomonitoring methods, as it misses some invertebrate taxa detected through morphological identification. Our study shows the importance of maximising the amount of available information in a global climate change scenario, with the perspective of preserving fragile river ecosystems from invasive species and biodiversity loss.

First assessment of the ecological status of transitional water in Emilia-Romagna Po River basin, based on fish fauna biological quality element

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Transitional aquatic ecosystems are characterized by much greater levels of environmental variability and ecological productivity than are typically found in marine ecosystems. Fish fauna present in transitional ecosystems must and are able to cope with the high variability and instability of the abiotic environment in order to utilize the abundant trophic resources available in these ecosystems, representing an essential component of the biodiversity of transitional aquatic ecosystems. For this reason, Directive 2000/60/EC declares that fish fauna also contributes dominantly to the definition of the ecological status of transitional waters in the Biological Quality Elements. This paper describes the results related to the ecological status assessment study of the transitional waters of the Po Delta E-R for an evaluation by analysis of the biological quality element "Fish Fauna" and application of the HFBI index. The study was carried out in 5 lagoon-estuaries, for two seasons (spring-autumn 2024), using a beach seine "for juvenile fish," as per ISPRA protocol, in order to standardize catch data in terms of sampled area units. All individuals sampled were identified to the species level and classified into ecological and trophic categories. Abundance and biomass values by species, were expressed as density values (individuals/100 m2 and grams/100 m2) for the sampling area. For the analysis of lagoon biological quality, the HFBI multimetric index was used (Catalano et al. 2017; Franzoi et al. 2019). The six metrics required to calculate the Habitat Fish Bio Indicator (HFBI; Catalano et al., 2017) were calculated from fish stock density and biomass data, The HFBI scores, calculated on an annual basis by averaging spring-autumn values, were used to assess the ecological status of lagoon-estuaries A total of 35 species of nectonic fauna were identified, of which 4 belong to the order Decapoda. The most represented functional group belongs to the lagoon residents, 90% of individuals in spring and 42% in autumn, followed in quantitative abundance by the marine migrants 6.7% in spring and 17.6% in autumn. The results of the application HFBI index in the transitional waters of the Po Delta E-R, show that out of 16 stations, 4 stations achieve "good" ecological status, 5 'sufficient' status and 7 "poor" status. Assessing the annual average values of the HFBI index, only one lagoon reaches the "good" ecological status, 3 lagoons the 'sufficient' status and one results in the "poor" status. The application of the HFBI index shows that the ecosystems of the Po Delta tradition are in an average state of "sufficient" quality, with only a few areas at good and poor status, no environment has recorded values at "excellent" or "bad". This first application showed that the HFBI index can be an effective tool for the assessment of the ecological status of transitional waters, capable of assessing and identifying the main anthropogenic threats and pressures that insist on these ecosystems and become a basic element for the management and conservation of these environments.

CONSERVATION STATUS OF THE ITALIAN MARINE BIODIVERSITY UNDER THE EU HABITATS DIRECTIVE (92/43/EEC): UPDATES AND METHODOLOGICAL CHALLENGES

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To assess the effectiveness of the Habitats Directive (92/43/EEC), a cornerstone of biodiversity conservation in Europe, EU Member States are required to submit a national report every six years. This contributes to a comprehensive European evaluation of the conservation status of habitats and species of community interest. In Italy, the fifth national report (covering the 2019-2024 period) was concluded in July 2025 by the Italian Institute for Environmental Protection and Research (ISPRA). This study presents the key findings of the conservations status assessments for 8 marine habitats and 27 marine species included in the report. To understand the dynamics over time, the current status, based on parameters such as distribution, abundance, threats, and implemented conservation measures, was compared with the status reported from the previous evaluation. Results indicate that 37% of habitats and 63% of species are currently in a favourable conservation status; 25% of habitats and 10% of species show an inadequate conservation status, 10% of species are in bad condition, whilst for the remaining cases conservation status is still unknown. Notably, three habitats and three species showed a declined conservation status compared to the previous period. Additionally, the methodological approach adopted in the evaluation was critically analysed to identify both its strengths and limitations. Some improvements were noted in terms of data availability and resolution. However, much of the assessment still relied on expert judgment, primarily provided by members of the Italian Society of Marine Biology (SIBM), rather than standardized monitoring protocols applied consistently across Italian marine waters. Furthermore, disparities in data availability among habitats and species, as well as regional inconsistencies, were observed. This evaluation highlights critical areas for improvement in future assessments, and it supports the identification of degraded habitats, which is particularly relevant to reach the goals set by the EU Nature Restoration Law.

Evaluating the impact of a beach wrack (*Posidonia oceanica*) management approach on coastal dune habitats

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Wrack made of marine macrophytes accumulated along many Mediterranean beaches plays relevant ecological roles in coastal environments such as providing habitats and nutrients to a variety of organisms and protecting coastline from erosion. Wrack deposits are also considered as reference habitats subjected to mandatory conservation and protection within the Barcelona Convention. Nevertheless, they are deemed as a nuisance by beachgoers and often moved from beaches to adjacent embryo dunes, an important coastal habitat included in the European Directive. But the possible impact of such practice on the development of plants involved in dune formation processes and stability has not been examined. Here, field experiments were used to test the effects of placing *Posidonia oceanica* wrack layers of different thickness (2, 4 and 8 cm) and composition (wrack without or with sand) on the toe of embryonic dunes on the survival of already established seedlings and on the recruitment success and growth of new seedlings. *Thinopyrum junceum*, *Euphorbia paralias*, and *Cakile maritima* were used as model species. The placement of the thickest wrack layer reduced drastically (up to 70%) the survival of established seedlings, regardless of the species and wrack composition. Wrack also decreased seed recruitment success more than 50%. The thickest wrack layer reduced the growth of newly emerged seedlings of *T. junceum* (aboveground organ height) and *E. paralias* (aboveground biomass) while favoured that of *C. maritima* ones (total biomass). These findings suggest that placing beach-collected wrack at the base of dunes can hinder their colonization by plants, thus questioning about the ecological sustainability of this practice. Coastal managers should be aware that repeatedly moving wrack from the coastline to dunes could ultimately undermine the resilience of these habitats.

Moth and vegetation diversity in Mediterranean coastal dunes: insights from a Central Adriatic eLTER site in Italy

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Coastal dunes represent ecologically rich yet fragile environments, demanding improved indicators for effective biodiversity assessment. While moths are increasingly acknowledged as bioindicators, their distribution and diversity within dune ecosystems are still insufficiently explored. This study investigates the taxonomic and functional diversity of moths belonging to the superfamily Noctuoidea on changing abiotic factors such as dune zonation and biotic components like plant communities, within a well-conserved dune system on the Adriatic coast of Central Italy. Research was conducted at a European Long-Term Ecosystem Research (eLTER) site using UV LEDs light traps to sample moths biweekly over the course of a year across replicated plots in both zones of zonation: the shifting dunes subject to strong environmental stressors and the fixed dunes less exposed to abiotic perturbations. Simultaneously, plant surveys were performed in spring using 4 $\times$ 4 m plots under a stratified random sampling framework based on dune zonation. We analyzed species richness, abundance distributions, and functional traits for both moths and plants across different dune environments. Furthermore, we assessed the degree of congruence in species composition and abundance variations between the zones. The moth assemblage included 98 species (78 Noctuidae, 18 Erebidae, 1 Nolidae, and 1 Notodontidae). Our results showed that the noctuoid assemblages exhibit distinct patterns of species richness and abundance across seasons. High beta diversity and the occurrence of species confined to specific dune zones point to the significance of both abiotic and biotic filters in structuring moth communities on the coastal-inland mosaic. Trait-based and diversity analyses revealed strong ecological associations between moth and plant communities, indicating structural and functional alignment across dune zones. Our findings highlight the importance of preserving the integrity of dune zonation to maintain functional and taxonomic biodiversity of noctuoid moths and their role as reliable indicators of ecological conditions in dune ecosystems.

Update on the status of *Pinna nobilis* populations in the Venice Lagoon: spatial patterns of mortality, environmental drivers and age-dependent survival

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The Mediterranean fan mussel *Pinna nobilis* (L. 1758) has undergone since 2016 severe Mass Mortality Events (MMEs), leading to a drastic decline of the species throughout its entire range. The distribution and structure of *Pinna nobilis* remnant populations in the Venice Lagoon, one of the largest Mediterranean coastal transitional ecosystems, have been investigated through multiple approaches across different spatial and temporal scales. Since 2020, the population in a study area near Ottagono Alberoni island (central Lagoon) has been monitored monthly, the frequence shifting to seasonal in 2024, when a second site characterized by a higher density of alive specimens, near Valgrande channel, was also included in the monitoring. Overall, the status of 556 individuals was assessed over time. The study areas were examined for the presence of main pathogens involved and for the physiological response of selected *Pinna nobilis* individuals. Temperature, salinity and dissolved oxygen were measured in continuous in the two areas. Hypoxic events recorded at the Ottagono Alberoni study area may help explain the differences observed in mortality rates between the two sites. Additionally, mortality is positively related to age, with younger individuals showing a relatively higher survival rate. Moreover, an extensive sampling campaign was carried out in 2024 at 40 sampling stations over the whole lagoon in collaboration with Regione Veneto, in the framework of Interreg IT-SI POSEIDONE. Density, size structure and dead/alive status were determined for 2646 recorded individuals, and the overall status of the species in the lagoon was assessed. Despite the observed MMEs, the Venice Lagoon may still host one of the largest extant population of *Pinna nobilis*. Present results will also be discussed in relation to research perspectives, management policies and conservation strategies for the species.

Ecologia del suolo: dalla conoscenza alla gestione sostenibile

7

Can microbial-based biopolymers and algal and cyanobacterial biomass improve soil properties?

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Restoring degraded soils and improving soil quality in agroecosystems are key objectives of the United Nations 2030 Agenda for Sustainable Development. To improve soil quality, modern agriculture mostly relies on inorganic soil fertilizers, which undoubtedly improve crop yields and some soil characteristics, but adversely affect the environment. Consequently, there is a growing demand for eco-friendly alternatives. Biopolymers derived from bacteria and biomass of cyanobacteria and marine algae could be suitable soil improvers. However, bibliographic research using the entire Scopus database revealed that only a few but promising studies focused on biopolymers/biomasses as improvers of degraded soils. The present study aimed to evaluate the effects of biopolymer/biomass addition on soil quality, assessed through several microbial and chemical properties. As part of the PRIN PNRR 2022M7S2J *SeaForSoil* Project, a pot experiment was conducted by adding a biopolymer or biomass to the soil (10 g/kg). The experimental design included 5 treatments: exopolysaccharide (EPS) from the thermophilic *Geobacillus thermodenitrificans* B3-72; biosurfactant (BS) from the thermophilic *Bacillus* sp. s7s-3ng; biomasses from the seaweed *Ulva ohnoi* (BM); the cyanobacterium *Leptolyngbya* sp. (BC); a control soil, without any additive. After 60 days of exposure to the biopolymer/biomass in a thermostatic chamber (25 ± 3°C), the following properties were determined: fungal biomass, potential soil respiration, nitrogen mineralization, nitrification, water holding capacity, pH, cation exchange capacity, and ammonium and nitrate contents. Without causing any negative effects on the soil, the addition of each biopolymer/biomass improved most of the considered parameters, with the best results observed in soil treated with EPS or BM. The data suggest that the biopolymer/biomass could be suitable for the restoration of degraded soils. However, further studies are needed to further investigate the effect of the biopolymer/biomass in different soil types and in-field conditions.

Assessing the impact of agroecological practice combinations on ecosystem services: a meta-analysis from European agriculture

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Agroecology offers a comprehensive framework for guiding sustainable agricultural transitions, integrating ecological science, local knowledge, and socio-political dimensions. By promoting diversified, ecologically grounded practices, agroecology aims to enhance ecosystem services (ES) while increasing system resilience and reducing environmental impacts. This study applies agroecology both as a theoretical lens and as an analytical basis to evaluate how land management practices influence ES provision in European agroecosystems. A meta-analysis was conducted following the PRISMA protocol, resulting in a dataset of over 130 peer-reviewed experimental studies. Quantitative comparisons between conventional and agroecological systems were extracted and analyzed in R, focusing on seven ES: yield, carbon storage, soil health, water regulation, nutrient cycling, pest and disease regulation, and biodiversity. Attention was given to the performance of combinations of agroecological practices, not only on individual interventions. Preliminary results show that some practice combinations consistently deliver positive outcomes. For example, no-till combined with organic fertilization (NT + ORG FERT) improved soil regulation (i.e. 10%) and nutrient cycling (i.e. 43%), with over 80% of comparisons showing positive effects. Agroforestry (AFS) led to substantial gains in carbon storage (i.e. 44%) and biodiversity, although its effects on yield were mixed. BIOCH + ORG FERT showed strong improvements in water regulation (i.e. 48%) and nutrient cycling (i.e. 66%). Yield responses were variable: slightly negative under organic-only systems (i.e. ORG FERT, –13%), while more stable outcomes were observed in some combined systems, such as BIOCH + ORG FERT. Pest and disease regulation showed mixed results, with some positive effects in diversified organic systems, but high variability remains due to limited and heterogeneous data. While many combinations of agroecological practices showed promising results, several studies also reported neutral or negative outcomes, particularly for yield and soil health and partly due to outliers or limited observations. These trade-offs highlight the importance of context and implementation. Nevertheless, the emerging trends suggest that bundled agroecological strategies can enhance multifunctionality. As the meta-analysis evolves with additional data, this work aims to strengthen the empirical basis for supporting agroecological transitions and informing policies focused on ecosystem service provision in European agriculture.

Effectiveness of green compost in enhancing soil quality in an agricultural soil co-contaminated by antibiotics and copper

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Intensive agricultural practices have led to progressive soil degradation, in terms of organic matter exacerbated by the co-occurrence of heavy metals and pharmaceutical residues. This study aimed to evaluate the effectiveness of a green compost (GC), derived from vegetal waste, in improving the quality of an agricultural soil with low organic carbon and reduced microbial activity. A microcosm experiment was conducted using lettuce (*Lactuca sativa*) seedlings grown in the treated soil. A contaminant mixture consisting of three antibiotics: sulfamethoxazole, ciprofloxacin, and chlortetracycline (7 mg kg^{-1} each) and copper (as copper phosphate, 30 mg kg^{-1}) was added to simulate worst case scenario of co-contamination. Control treatments included soil with and without compost and/or contaminants. Soil microbial communities were assessed in terms of structure (microbial abundance and diversity, NGS) and activity (dehydrogenase, phosphatase, and β-glucosidase activities). A Soil Quality Index (SQI), integrating both biotic and abiotic indicators (e.g., pH, temperature, contaminant and organic carbon presence), was applied to provide a holistic view of soil health. Application of GC improved the SQI, enhancing soil physical and chemical properties, such as increasing pH and reducing compaction, which in turn supported microbial activity and plant growth. Antibiotic resistance genes (ARGs) were promoted in antibiotics and copper presence with the highest values in the bulk soil. Interestingly, GC promoted not only the highest plant biomass, but also the lowest ARG values. Moreover, the soil microbial community showed shifts in some populations under compost and lettuce treatments. Although the contaminant mixture inhibited lettuce development, the presence of compost partially mitigated these adverse effects. These findings highlight the potential of a vegetal waste compost as a sustainable strategy for the ecological restoration of degraded and co-contaminated agricultural soils. The use of green compost not only promotes microbial functionality and plant productivity but also contributes to soil resilience in contaminated environments.

A sustainable strategy for the recovery of soils degraded by mining activity

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Recovering degraded soils is crucial to ensure food supply and security, preserve biodiversity, sequester carbon (C) to counter climate change, and regulate water and nutrient cycles. Mining is one of the worrying anthropogenic activities responsible for soil degradation because it is a major source of trace elements in the soil. An effective strategy to restore degraded soils may be the use of organic improvers. The aim of this study was to evaluate the effects of two organic improvers, hydrochar and compost, both deriving from urban pruning residues, on soil physical, chemical and biological properties. Compared to compost, which is a traditional organic improver, the hydrochar, obtained from hydrothermal carbonization, has recently been receiving much interest as a new potential soil improver. A pot experiment was carried out using soil collected from a contaminated site (the disused Mónica mine, Madrid, Spain). The experimental design included three treatments: soil + hydrochar (SH), soil + compost (SC), untreated soil (S) and two exposure times (t0 and t60 days). Preliminary results showed that both soil improvers, applied at the same dose (92.4 g kg^{-1}), significantly increased soil water retention, total organic carbon content and its available fractions (extractable C and mineralizable C), microbial biomass and enzyme activities (dehydrogenase, hydrolase and urease activities), with a marked effect only after 60 days. On the contrary, no effect of treatments was recorded on soil potential respiration. No univocal differences were found between the effects of the two improvers. Data suggest that both soil improvers can enhance soil health, also activating microbiological processes that are fundamental to soil resilience to disturbance. This work confirms the hypothesis that both organic materials derived by treatment of urban pruning residues could represent an effective and sustainable strategy for soil restoration, contributing to the regeneration of ecosystem services.

Linking Behavioural Bioassays and Soil Biodiversity as an Integrated Strategy for Environmental Quality Assessment

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Soil health is a key priority for assessing environmental safety and achieving the European Union's climate and biodiversity targets. Changes in edaphic diversity are the first indicators of soil health, but require long-term monitoring. Therefore, integrated approaches with minimal ecological and economic impact are essential. This study explores the potential of behavioural bioassays, specifically avoidance and disaggregation responses, as rapid indicators of soil habitat degradation, following the principle of limited habitat functions. Given the metrics of biodiversity loss and behavioural responses analysis are not aligned, a multi-approach comparative study was conducted to link multispecies behavioural responses with in situ measures of soil biodiversity. Behavioural tests using model organisms were employed to detect signs of habitat depopulation or fragmentation. These data were then compared with structural and functional diversity metrics of soil invertebrate and microbial communities, summarised using standard ecological indices. The results showed consistent metrics between model organisms' responses and levels of invertebrate diversity. Specifically, soils that altered population behaviour also showed a reduction in edaphic invertebrate structural and functional diversity. However, these changes did not emerge from microbial analysis, suggesting that metrics linking ecological responses of model organisms to changes in microbial diversity are yet to be investigated. This study suggests that behavioural bioassays, in combination with invertebrate diversity assessments, offer a valuable, early-warning tool for identifying soils at risk. Such integrative methodologies could support more targeted and efficient soil monitoring and restoration efforts, contributing to broader environmental protection and sustainability goals.

Soil organic carbon pool as affected by wildfires in a Southern Italy coastal pinewood

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Soil is an important component of natural capital that provides many ecosystem services, such as habitat supply for a myriad of species, nutrient cycling regulation, and climate regulation through organic carbon sequestration. The soil organic carbon pool can be affected by anthropogenic disturbances, such as wildfires, which occur annually in large areas of Southern European countries. This study aims to assess the effect of wildfires on soil organic carbon (C) in a coastal pine forest in Southern Italy included in the Special Area of Conservation (SAC) of the Natura 2000 Network (IT9130006 - Pinewoods of the Ionian Arch), as part of the PRIN 2022 FLER_MeCoFor Project. Wildfires that occurred in the study area were mapped using Landsat imagery in the Google Earth Engine platform. Fire effects were assessed in relation to the time since the last fire (4-42 years) through synchronic sampling carried out in 2024 at seven sites, each of which included burned plots and unburned control plots. In each plot, the weight and organic C content of the organic layer (O-layer, including both litter and fermentation layer) as well as organic C content and bulk density of the underlying mineral sandy soil (S layers, 0-5 cm, 5-10 cm) were measured. In the most recently burned plots (in 2020, 2017 and 2012), fires caused a significant reduction in the weight of the O-layer and in the organic C content of the O-layer and S-layers, compared to controls. The differences between burned and control plots were less marked at sites affected by older fires (in 1994, 1992, 1986 and 1982). The data suggest that full recovery of the organic C pool after fire requires several years. Therefore, strategies need to be adopted to reduce the frequency and intensity of fires in areas prone to recurrent fires.

Collembola Communities as Indicators of Post-Fire Succession in Mediterranean Soils: Ecological and Management Implications

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Mediterranean ecosystems experience frequent fires that significantly affect soil biodiversity and functioning. Soil Collembola plays fundamental roles in the decomposition process and in microbial regulation. Moreover, they are early colonizers of disturbed environments, such as burnt areas. The present research aimed: *i)* to analyse the recovery trajectories and the functional trait shifts inside the Collembola community in burnt soils of a Mediterranean region *ii)* to highlight probable differences due to different plant covers such as shrubs and trees. To achieve the aims, soil samples were collected every 6 months starting from 3 to 6 years since fire occurrence at 12 plots in burnt (6 plots dominated by trees and 6 plots dominated by shrubs) and 12 plots unburnt (6 plots dominated by trees and 6 plots dominated by shrubs) areas. Collembola were extracted by the soil cores and identified at species level. Then the community was described by density, richness, diversity, and by functional traits such as body length, presence of eyes, presence of furcula, pigmentation and reproduction type. Results showed that while taxonomic indices (density, richness, diversity) did not significantly change in burnt and unburnt areas both under trees and shrubs, both species composition and functional traits showed difference between burnt and unburnt communities. In particular, in the short time (3 years after fire), fire significantly decreased the abundance of Collembola species with larger body size, pigmentation, and mobility, but these species showed an increase already after 4 years after fire, especially under trees. Overall, Collembola species and functional trait assemblage revealed increasing divergence between burnt and unburnt communities over time, suggesting that fire leads to long-term shifts in community assembly. These findings emphasize the need to integrate functional metrics into soil biodiversity monitoring for effective post-fire ecosystem assessment.

Ruolo dell’Ecologia in conservazione, restauro e pianificazione

8

Protecting Connections: A Network-Based Assessment of Marine Protected Areas in the Central Mediterranean Sea

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Maintaining or restoring connectivity among protected areas is widely recognised as a strategy to improve ecosystems resilience and populations viability. The recent emphasis of international policies on increasing protected surface worldwide offers a unique opportunity to embed connectivity into the spatial planning of new sites, thereby maximising the effectiveness of conservation investments. In the context of the marine conservation project "Reconnect", using the dusky grouper *Epinephelus marginatus* as a model species, we assessed connectivity patterns in the central Mediterranean Sea, with particular focus on Sicilian coasts. We used Lagrangian simulations with an individual-based bio-physical model to simulate larval dispersal throughout the region with the aim of (1) identifying priority areas for protection, *i.e.* connectivity hotspots; (2) evaluating to what extent the existing network of marine protected areas (MPAs) is well connected; and (3) assessing how the designation of candidate MPAs ("*aree marine di reperimento*" as defined by the Italian legislation) would contribute to improve network connectivity. The overall performance of the protection network as well as the role of each node within it were quantified by global (*i.e.* efficiency) and local (*i.e.* degree and strength) network metrics. Finally, we integrated the connectivity analysis with spatial data on fish abundance and suitable habitats for dusky grouper into a spatially explicit metapopulation model, enabling scenario-based evaluation of different fishery restriction policies and their effects on population persistence. We believe that such an approach can offer useful insights into spatial conservation planning and site prioritisation, at a time when national authorities are required to make crucial management decisions that will impact long-term ecosystem health.

Spatial network dynamics and emergent properties in shallow rocky reef ecosystems

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Ecological systems are complex: interactions between organisms and their environment combine in ways that are difficult to represent or predict. Emergent properties, which are not apparent from the analysis of individual components, may arise from the intricate interplay of those components across different spatial and temporal scales. In the context of the PRIN 2020 project "MARECO", we investigate emergent behaviors in a tri-trophic marine ecosystem conceptualized as a spatial network. The analysis builds on a spatially-implicit model representing the local-scale dynamics of a shallow rocky reef ecosystem in the Tyrrhenian and Ligurian Seas. The spatially-implicit model can reproduce the shift from a healthy ecosystem state, characterized by extensive erect macroalgal cover and high fish biomass, to a degraded state (barren) deprived of erect macroalgae, with high sea urchin abundance and low fish biomass, in response to stressors such as overfishing or climate change. To explore how these processes scale up to the regional scale, we extended the spatially-implicit model to incorporate connectivity through larval dispersal across the spatial domain. This transforms the model into a spatially-explicit metacommunity model, enabling investigation of the system as a network of interconnected patches. While final results are still in development, we expect this approach to uncover how connectivity influences the system's response to environmental and anthropogenic stressors. In particular, we anticipate identifying emergent properties that are not observable in isolated small-scale systems. Preliminary insights suggest that network structure critically affects the system's response to stress: heterogeneous and modular networks may respond more gradually and adaptively to stress, while highly connected networks may resist change until reaching a tipping point, beyond which they collapse. Understanding these dynamics is crucial from a conservation and management perspective, as it may inform strategies to prevent irreversible regime shifts and the consequent loss of vital ecosystem functions and services.

Expanding the role for plant historical collections in habitat conservation, restoration and planning

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We are currently implementing a set of plant biodiversity modelling analyses to support habitat restoration, conservation, and ecological planning. To achieve this, a crucial challenge is to ensure that the resulting ecosystems are adequately functioning and able to provide the necessary ecological services. We integrate existing data and approaches in workflows and analyses that include: • The compilation of a comprehensive list of plant species for the area of interest based on modern and historical literature; • The automated extraction of plant trait information from herbaria specimens and taxonomic descriptions using machine learning tools and expert-curated databases; • Estimation of the species expected to be present through species distribution modelling; • Estimation of the expected level of functional diversity needed for the ecosystem to thrive. The ultimate goal is to provide a set of complementary metrics, all calculated on the same area, geographic resolution, and species, leading to a multifaceted understanding of biodiversity change. Such an understanding is extremely useful for assessing the efficacy of protection and restoration efforts. This approach, which is still under development, is currently informing reforestation projects in several locations across Africa. Once fully established, it has the potential to play a significant role in our efforts to meet the Convention on Biological Diversity's target to conserve and protect 30% of land by 2030.

Proforestation as a driver of avian vocal activity in a Mediterranean forest: insights from passive acoustic monitoring

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Proforestation is increasingly recognized as an effective strategy for enhancing biodiversity, particularly through the promotion of structural complexity and habitat heterogeneity. In this study, we investigated the effects of forest management abandonment on bird communities in a Mediterranean forest in Croatia. We compared three forest stands representing stages of proforestation: one actively managed, one abandoned for over 30 years, and one abandoned for more than 60 years. Forest structure was also surveyed in each stand to assess habitat complexity and support interpretation of bird community patterns. Bird data were collected using bioacoustic audio recorders (AudioMoths), which recorded 30-second audio samples every 10 minutes throughout the day from April to June 2025. Recordings were analysed with BirdNET, an automated bird sound recognition tool. Detections were filtered by applying a confidence threshold (>0.3) and excluding: (i) species detected fewer than 20 times across all sites; (ii) species ecologically incompatible with the study area (e.g., aquatic, alpine, or wintering species); and (iii) overflying species unlikely to use forest habitats, such as buzzards, and swifts. High-confidence detections were subsequently reviewed by an expert to minimise false positives. Results revealed a significant positive effect of long-term abandonment on avian vocal activity, used as a proxy for bird abundance. In contrast, species richness did not differ among the stands. These findings suggest that while species composition remains relatively stable, differences in structural complexity - particularly in long-abandoned stands - can influence bird abundance patterns, with higher vocal activity associated with more complex habitats. These findings support the role of proforestation in enhancing bird abundance in Mediterranean forests, even when species richness remains unchanged. Furthermore, the use of passive acoustic monitoring, when paired with rigorous filtering and expert validation protocols, represents an effective and scalable approach for assessing biodiversity responses to forest management practices.

Use of a soil health index as tool to evaluate the effect of a new improver to restore degraded soil

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Soils provide important ecosystem services, including climate and nutrient cycling regulation, and food supply, which can be compromised by their degradation. According to the European Commission's Joint Research Centre (JRC), above 60 % of European soils are in an unhealthy state, which mainly consists of the loss of soil organic carbon (SOC) and biodiversity. Consequentially, is crucial to explore innovative strategies to improve soil health and productivity. However, laboratory assays can be essential for testing soil restoration strategies and excluding any adverse effects before field application. This study explored the effectiveness of hydrochar, a possible soil improver derived from thermochemical conversion of organic residues, in enhancing health of agricultural degraded soils. In a pot experiment, five soil treatments were compared: hydrochar derived from sewage sludge or from thistle (*Cynara cardunculus* L.) residues applied at two doses (34 and 68 g kg^{-1}), and a control without hydrochar. After three exposure times (18, 92, 146 days), 19 key indicators of soil health were assayed: microbial biomass (C_{mic}), total microbial activity (soil respiration), specific activities related to nutrient cycling (respiration responses to 11 substrates), bacterial genetic richness, pH, total organic carbon content (C_{org}), and its extractable and mineralizable fractions, cation exchange capacity. A weighted soil health index (SHI_w) was developed by selecting a minimum data set (MDS) of indicators using multivariate analysis. Results showed that hydrochar application did not cause adverse effects on soil microbial community, playing a crucial role in nutrient cycling, but generally improved microbial activities, soil pH and C_{org}. SHI_w obtained from a MDS of five indicators (C_{mic}, respiration, respiration response to L-asparagine, pH, C_{org}) confirmed a significant improvement in soil health across all hydrochar treatments, and exposure times. Further researches are needed to confirm long-term persistence of hydrochars' beneficial effects and to assess its applicability in field conditions.

Designing Climate-Resilient Plant Communities through Trait-Based Multi-Objective Optimisation

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The increasing frequency of drought events under climate change poses significant challenges for the selection of plant communities in ecological restoration. This study introduces a trait-based, multi-objective optimisation framework that identifies plant community compositions balancing physiological adaptation to drought with functional trait diversity. This approach integrates climate-derived ecological targets and trait-based community assembly principles. Climatic constraints are incorporated by defining targets for the community-weighted mean of P50, a physiological trait indicative of xylem vulnerability to embolism, using site-specific drought intensity derived from the Standardised Precipitation Evapotranspiration Index (SPEI). Functional diversity was quantified using Rao's quadratic entropy to capture trait dissimilarity across communities. The optimisation procedure, implemented via the Non-dominated Sorting Genetic Algorithm II (NSGA-II), generates a set of Pareto-optimal solutions that represent trade-offs between aligning the community-weighted mean P50 with the climatic target and maximising functional diversity. The model was applied to a Mediterranean forest (Palo Laziale, Italy) under two drought scenarios: Near Normal and Extra Dry. Results show: I) increasing aridity reduces the solution space; II) in more arid conditions, species with moderate drought tolerance and distinct functional profiles are favoured; III) despite the stronger climatic filtering, drier conditions tend to promote communities with more balanced and diversified species contributions, suggesting a shift from single-species dominance; IV) kernel density estimation and convergence analyses across 500 replicated runs confirmed the stability and recurrence of optimal configurations, particularly under extreme climatic stress. This framework offers a flexible and reproducible tool to support ecological restoration planning under climate change. By explicitly modelling ecological trade-offs and incorporating climate-responsive trait targets, it enables the identification of multiple alternative plant assemblages that are both resilient and ecologically plausible.

Enhancing *Posidonia oceanica* restoration with nursery-grown seedlings: a seed-based approach exploiting early life history traits

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Seagrasses are habitat-forming organisms providing key ecosystem services in coastal marine environments, including carbon sequestration, habitat provision, and water clarification. Anthropic pressures on coastal areas are major drivers of global seagrass regression. In the Mediterranean Sea, *Posidonia oceanica* meadows have experienced a documented decline over the past century. Therefore, restoration and conservation initiatives are increasing, exploring several techniques. Among these, seed-based restoration has emerged as an effective and sustainable approach, as the use of sexual propagules provides ecological genetic, and evolutionary advantages to the restored populations. Furthermore, the ability to propagate plants in controlled cultivation systems can significantly increase the yield of the biological material collected in the field, reducing potential negative impacts to donor beds. Here we evaluate the feasibility of a novel *P. oceanica* transplantation techniques that makes use of nursery propagated plants from seeds and takes advantage of specific adaptive traits of *P. oceanica* juveniles, namely adhesive root hairs, to achieve fast and secure anchorage to specially designed supports. These supports act as stabilizers during seagrass early life stages. *P. oceanica* beach-cast seeds were collected along the northwestern coast of Sicily and grown in two mesocosms located in Genoa (Liguria) and Mazara del Vallo (Sicily), using rocky supports designed to maximize adhesion rate and strength. Half of the seedlings were cultivated for six and the other half for eleven months in order to test two transplanting periods: winter and spring. After six months of ex situ cultivation under controlled conditions, seedling survival reached 75% and approximately 95% of the plants spontaneously attached to the rocky supports, as observed also after eleven months. Plantlets, together with their supports, were transplanted at the selected restoration site on dead matte. After four months, in situ early survival reached 96.8% during the winter season. The experiment is still ongoing.

Reinforcing urban biodiversity: flower strips and unmown meadows as tools for small scale habitat enhancement

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Pollinators are facing dramatic declines worldwide, largely due to land-use change and urban expansion. However, urban areas can increasingly act as important refuges where targeted habitat restoration and enhancement counteract habitat loss, providing essential foraging and nesting resources. In this context, urban green spaces represent a practical opportunity to sustain pollinator populations and the vital ecosystem services they deliver. In this contribution, we show a novel framework for the conservation and enhancement of biodiversity at several trophic levels in cities, where coordinated actions are necessary, including the adoption of effective tools for habitat enhancement and restoration targeting adequate trophic and nesting resources. Then, the contribution focuses on insects as a group involved in ecosystem functioning: among the main strategies, sowing flower strips is a frequent small-scale habitat enhancement together with ecosystem restoration by maintaining unmown urban meadows. This study assesses the effectiveness of these practices, comparing mown and unmown meadows, the benefits of flower strips, and the coexistence of flower strips adjacent to unmown meadows. Fieldwork was conducted in the urban parks of the Milan metropolitan area during the years 2024 and 2025, where pollinators were monitored using standardised methods, and plant–pollinator interactions were analysed to evaluate their impact on biodiversity. The results show that unmown meadows host a greater number of individuals and support higher species diversity than frequently mown lawns. Flower strips also prove effective in attracting more pollinators in terms of both abundance and diversity. Moreover, the study highlights that combining flower strips with adjacent unmown meadows can further enhance pollinator presence. The findings aim to inform urban biodiversity conservation strategies, offering practical recommendations for city planners and policymakers to develop pollinator-friendly urban green spaces.

From zygote to forest in the restoration of *Cystoseira crinitophylla*: too slow to recover?

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Marine forests formed by *Cystoseira sensu lato* are key components of coastal ecosystems, enhancing biodiversity and delivering ecosystem services. However, these structurally complex habitats have undergone extensive decline, prompting a growing number of restoration initiatives. While restoration success is mainly attributed to site selection and local stressor mitigation, our study highlights the equally crucial - yet underestimated - role of species-specific biological and reproductive traits. Within the EU-LIFE "REEForest" project, *Cystoseira crinitophylla* was targeted for restoration in the Cilento Marine Protected Area (Southern Tyrrhenian Sea). Results reveal several traits that constrain the restoration potential of this species. *C. crinitophylla* does not exhibit a single, well-defined reproductive window with synchronous maturation of numerous receptacles. Instead, fertility occurs intermittently, with only few fertile receptacles maturing at a time, particularly in early spring. This discontinuous reproductive pattern makes it challenging to collect large amounts of fertile material. It also produces few viable zygotes with high early-stage mortality, limiting natural dispersal and recruitment. Its known range is restricted to only two regions of the Mediterranean (Cilento Coast and Aegean Sea), underscoring its vulnerability and conservation priority. Compared to other *Cystoseira* species, growth is extremely slow (~2 cm/year) and its monopodial thallus architecture leads to self-thinning over time due to intraspecific competition. Moreover, the species prefers highly hydrodynamic environments and is particularly sensitive to sedimentation, which further hampers restoration efforts. Early developmental stages are slow-growing and require prolonged laboratory cultivation, increasing the risk of microbial and epiphytic outbreaks and adding logistical and economic challenges for large-scale interventions. The time needed for transplanted thalli to reach reproductive maturity, enabling self-sustaining populations, far exceeds the typical 3–5-year timeframe of most restoration projects. These findings highlight the need to incorporate species-specific growth and reproductive traits into restoration planning, since overlooked biological constraints can undermine long-term restoration success.

Connectivity network analysis to inform marine spatial planning: insights from the Central Mediterranean

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Understanding patterns shaping marine species connectivity is essential for effective management of marine resources and the development of conservation strategies. Yet, incorporating connectivity into marine spatial planning remains challenging due to the complex dynamics linking species' dispersal and environmental variability. For instance, detailed information on spawning grounds is often lacking, complicating the identification of connectivity pathways. Further, the effects of climate change on the structure and strength of marine connectivity are still not fully understood. In this study, we reconstructed and analysed the larval connectivity of European hake (Merluccius merluccius), a commercially important species in the Mediterranean Sea, focusing on the Adriatic and western Ionian basins. We employed a Lagrangian particle-tracking approach combined with network analysis to assess spatial and temporal connectivity patterns across different timeframes and climate scenarios, specifically under Representative Concentration Pathways RCP4.5 and RCP8.5. Community detection methods were used to identify potential sub-populations, revealing biologically meaningful management units. Our results show that, despite the increase in seawater temperatures under moderate and extreme scenarios, connectivity metrics and the spatial structure of communities remain broadly consistent, supporting their application as stable indicators for conservation planning. However, climate-induced shifts in biological and physical parameters, such as increased larval transport speeds and a shortened dispersal period—likely driven by temperature-dependent metabolic responses—may lead to more polarised and vulnerable sub-population structures in future conditions. Finally, we classified network nodes based on their connectivity roles, reflecting their structural importance within and between communities. These findings, together with the persistence of community boundaries across scenarios, offer a robust foundation for spatially explicit management aimed at enhancing population resilience under both current and projected climate scenarios.

Insights for future seagrass restoration: the effects of canopy density and thermal conditions on *Posidonia oceanica* seedlings

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Seagrass meadows have been declining due to climate change and anthropogenic activities and, therefore, their restoration has been significantly increased worldwide. In *Posidonia oceanica,* endemic to the Mediterranean Sea, the use of seedlings in restoration actions have been lately encouraged, also due to the increase of sexual restoration of this plant associated to the increase of temperature. However, to successfully use seedlings in restoration, understanding the factors that affect their growth has become pivotal. This study aimed at evaluating the development of *P. oceanica* seedlings during the early life stages at i) different thermal environments by cross-transplantation between the eastern and western coast of Sardinia (Italy) and at ii) several *P. oceanica* canopy densities. Plant morphology (total number of leaves, total leaf length, maximum root length, number of roots, and tot necrosis length) and leaf fiber content were considered to evaluate seedling performance.Overall, results about survivorship and acclimation of seedlings after the cross-transplantation suggest that the different average thermal conditions of donor and receiving sites do not affect seedling development during the first months, considering that seedlings from the same origin developed consistently in both sites, highlighting a good acclimation. Furthermore, seedlings germinated in dead matte (0 % canopy density) developed longer roots than seedlings germinated in higher canopy density, likely due to the need of anchoring in an environment where there is no meadow to protect the seedlings from hydrodynamics. Seedling mortality was higher at high canopy density rather than low density or dead matte: even though *P. oceanica* meadows have an important nursery role, the conditions created within the meadow seem not to favor the seedling development, likely due to the low irradiance. Results of this study provide insights for future *P. oceanica* restoration actions using seeds and seedlings.

Ecologia del Paesaggio ed analisi spaziale degli ecosistemi

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Optimizing fungicide deployment in a connected crop landscape while balancing epidemic control and environmental sustainability

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Bioaggressors cause significant losses in crop production and the efficacy of control methods, primarily based on chemical compounds, comes with considerable environmental and health costs. Plant protection practices implemented locally overlook the mobility of bioaggressors, which can spread between fields, connecting different crop populations. As a consequence, the yield in a given field depends also on the management of connected fields. In this study, the efficiency of different fungicide deployment strategies across a national-scale agriculture landscape is assessed, balancing the conflicting objectives of maximizing crop production and reducing fungicide use. A climate-driven metapopulation model describing the dynamics of the peach (*Prunus persica*)-brown rot (caused by *Monilinia* spp.) pathosystem in continental France is used. Fungicide deployment strategies are based on indices or algorithms, considering network topology, epidemic risk, territory, and stochastic sampling, which prioritize sites to be treated first. Finally, the objective of maximizing crop revenue is investigated, assuming that untreated fruit can be marketed at higher prices. The optimal strategy depends on the treatment allocation threshold: if up 20 % of the area is treated, epidemic risk provides the most effective prioritization. If more than 40 % of the area can be treated, a combination of random sampling and risk-based prioritization proves optimal. When only considering monetary revenues, we find that the higher the consumer's willingness to pay for untreated fruit, the larger the proportion of untreated sites becomes. Fungicide use could be avoided if untreated fruit were sold at 2.9 times the price of treated fruit.

Evaluation of drought-induced water stress on holm oak (*Quercus ilex* L.) and wild olive trees (*Olea europaea* L. var. *sylvestris* Brot.) in Mediterranean forests by remote sensing: a case study from the Sardinia region, Italy

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Forests account for a significant portion of the global net primary productivity and provide essential ecosystem services, including carbon sequestration, biodiversity conservation and regulation of the hydrological cycle. In recent decades, the increasing frequency and intensity of drought conditions has threatened forest health in many parts of the world, negatively affecting physiological processes and increasing the risk of tree mortality. Therefore, it is crucial to better understand the response of forest species to drought conditions in the field and extend it to larger spatial scales, thanks to the current advances in remote sensing monitoring techniques. The main objective of this study is to assess the sensitivity of holm oak (*Quercus ilex* L.) and wild olive (*Olea europaea* L. var. *sylvestris* Brot.) trees to drought-induced water stress at four sites in the south of the Sardinia region, Italy. These two species were selected because of their abundant presence in the Sardinia region and their known different behaviour under water stress conditions. Sites will be monitored every two weeks from the end of May to the beginning of September by measuring relative water content (RWC) as a proxy of actual water stress, and calculation of vegetation indices derived from satellite remote sensing. Expected results will show the differences in the response to water stress of the two species across the four sites, based on the trends in RWC values and remotely acquired vegetation indices. Furthermore, the relationship between RWC values and vegetation indices will enable the interpretation of remotely sensed data on the impact of water stress across larger spatial scales, considering the diversity of species and vegetation types present in different forested areas. This approach would allow an accurate identification of forest areas to be prioritised against the risk of water stress and tree mortality due to drought conditions.

The resource-based habitat concept: from butterflies to all life forms

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Habitat is a fundamental concept for understanding and conserving nature, yet it remains one of the most confusing terms in ecology. Traditionally, it refers to discrete, uniform environmental units–a notion familiar to both scientists and the general public. Since the early 1990s, interest in the habitat concept has grown, particularly with the emergence of the resource-based habitat (RBH) concept, first described for butterflies by R.L.H. Dennis in 1996. Dennis's work on the RBH concept was later recognized with the British Ecological Society Book Award in 2012, highlighting its significance and impact on ecological thinking. An RBH is defined as the geolocated set of resources and conditions sufficient to support a population or cohort of a species. It includes all the essential resources and conditions that an individual uses or experiences throughout its life. This approach reveals that many species occupy multiple traditional habitats, challenging our understanding of their environmental preferences, distribution and abundance. A core principle of the RBH is that each individual has a unique RBH, reflecting its specific needs and behaviours. Thus, to determine a species' RBH, scientists must analyse variation across a representative sample of individuals. Understanding a species' RBH across a region–or throughout its range–requires sampling at multiple sites to capture variation in resource use and environmental tolerance. The RBH concept is not intended to replace the traditional concept, which remains valuable–especially in relatively uniform landscapes and for community-level conservation. Although originally developed for butterflies, the RBH concept is applicable to all organisms, including humans. The application of the RBH concept to all life forms may provide novel insights into our understanding of species biology and community characteristics. Ultimately, the RBH concept highlights the importance of sampling and analysing variation, offering a more detailed and flexible framework for understanding species' ecological relationships.

Spatio-temporal patterns of pine canopy mortality in response to hotter-drought events: the role of landscape ecohydrology

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Promoting climatic resilience in production systems is key to ensuring their sustainability in the face of ongoing climate change. Forest plantations have proven vulnerable to compound events of drought and heatwaves, although vulnerability varies depending on the ecohydrological characteristics of the landscape. We present case studies in which satellite imagery and Earth observation products were used to identify landscape units that reduce pine plantation mortality at local and regional scales. We focused on an unexpected, regionally distributed tree mortality event that occurred in commercial *Pinus* species in the most important forestry region of Argentina during the 2021–2022 warm season. This hotter-drought event followed three consecutive years of drought. Using Sentinel-2 imagery, we estimated canopy mortality between November 2021 (first field mortality observations) and October 2022 in *Pinus* spp. plantations established across the Mesopotamian region in the N.E. of the country. Our analysis revealed that spatio-temporal heterogeneity in canopy mortality was strongly associated with landscape features related to ecohydrology. Mortality was higher, earlier, and progressed faster in shallow soils with likely limited and short-lasting water availability. In contrast, mortality was near zero in depressed, waterlogged units. Intermediate levels were observed in areas with shallow water tables, where trees developed shallow root systems. These results suggest that landscapes allowing for deeper root development and/or longer-lasting soil water availability may be more suitable for drought-resilient pine plantations. Additionally, this approach helped identify areas with low crop production potential and/or high importance for biodiversity conservation, offering valuable insights for sustainable land-use planning at landscape and regional levels under climate change.

Analysis of the relationships between NDVI, LST, and land use: comparison between urban and forest areas

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Urban expansion and the increase of impervious surfaces (Parvar and Salmanmahinyal, 2024; Zhou et al., 2025) have affected contiguous forest landscapes (Guo et al., 2025). Cities are the most compromised, and urban temperatures have been characterized by a strong increase (Hwang et al., 2025; Fetene, 2025). Afforestation and reforestation in urban green areas are crucial strategies in urban settings (Fahrudin et al., 2024). In this context, this study aims to compare an urban area in southern Italy with the forested area near a natural park. The analysis involves data collected from 2006 to 2022 using Google Earth Engine in both contexts, focusing on 1) the change of NDVI (Normalized Difference Vegetation Index) and LST (Land Surface Temperature) from 2006 to 2022, and 2) to identify the correlation between NDVI and LST in 2022. The results of the spectral indices indicate a functional vulnerability, both in their capacity to provide supporting (primary productivity) and regulating (temperature regulation) ecosystem services. In particular, NDVI decreases over time in both contexts. The trend is more pronounced in the urban area, with NDVI values dropping below 0.3, corresponding to significantly higher land temperatures, more than in the forest area. In the forest area, NDVI and LST show a strong correlation. In the urban area, where the green areas represent only 0.62%, NDVI values are below the vegetation functionality threshold (0.5), while LST reaches 45°C in summer. The creation of a buffer zone of green areas around the city and the establishment of a network with the natural park can help balance land take with land cover capable of providing supporting ecosystem services. At the same time, increasing green areas can mitigate climate change on a local scale by improving local temperature regulation.

Identify priority areas for protection and restoration action by assessing spatiotemporal changes in forest connectivity in Sicily (1990–2018)

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In Sicily, a Mediterranean island characterized by high biodiversity and increasing anthropogenic pressure, forest connectivity is a key indicator for assessing ecosystem health and guiding effective conservation and management strategies. This study aims to identify degraded areas, areas in need of protection, and potential zones for reforestation efforts, by investigating changes in forest connectivity between 1990 and 2018,. We assessed spatial and quantitative changes in forest connectivity at the regional level, by using Corine Land Cover data and connectivity models based on circuit theory (Circuitscape). A statistical analysis was performed to compare 1990 and 2018 scenarios. The results revealed a decline in forest connectivity in several key areas, primarily due to infrastructure expansion and land-use changes. However, some regions remained resilient or showed improvements, often overlapping with areas protected under the Natura 2000 network. Forest connectivity is particularly relevant in the Sicilian context, given its ecological significance and the island ecosystems vulnerability to fragmentation. Incorporating connectivity metrics into spatial planning may provide a practical approach for identifying vulnerable zones and prioritizing restoration actions. This is especially timely considering the objectives of Italy's National Forest Strategy and the targets set by the EU Nature Restoration Law, which emphasize restoring ecological connectivity as a central pillar for achieving resilient and functioning forest landscapes.

Urbanization reshapes spider diversity: current impacts and future gains from green space expansion

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Urbanization strongly impacts biodiversity and related ecosystem services, making its proper evaluation essential, with a specific focus on taxonomic groups providing fundamental ecosystem services. Among these, spiders are renowned regulators of trophic chains and sensitive bioindicators. We assessed the response of foliage-dwelling spiders to urbanization in Turin (Italy), by sampling their communities in urban green areas along an urbanization gradient and in a natural park (control area) a few kilometers from the city. We built the urbanization gradient by calculating and comparing six landscape fragmentation metrics (effective mesh size, landscape division, splitting index, coherence, splitting density, net product) plus building density within 1000 m buffers around each sampling point. Among these, building density was the best-performing proxy, as it was strongly correlated with all other fragmentation metrics and most effectively explained the observed patterns in species diversity. Species richness, abundance, and functional diversity declined along the urbanization gradient, with the lowest values observed in the city. This trend, largely driven by the loss of specialized foraging guilds (e.g., pollinator-feeders), mirrors previous findings on ground-dwelling spiders. Species turnover explained most of the variation among urban green sites, reflecting stochastic dynamics, while urban communities appeared as subsets of semi-natural ones, indicating environmental filtering favoring urban-adapted species. We also assessed current taxonomic and functional diversity responses and projected biodiversity trends under future scenarios aligned with the EU restoration law, which calls for a 3% increase in urban green areas by 2040 and 5% by 2050. As all diversity metrics were strongly correlated, we synthesized them into a single biodiversity index. Simulations suggest that even modest increases in green space can significantly enhance urban biodiversity. Overall, our results highlight how urbanization reshapes spider communities, favoring generalists and selected traits.

Assessing Drivers of Dieback in Mediterranean Evergreen Forests using Remote Sensing

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Extreme climatic events, such as heatwaves and prolonged droughts, significantly contribute to forest degradation by increasing tree mortality and dieback. This phenomenon results in the loss of tree organs, thereby reducing ecosystem resilience. Although climate-driven dieback has been extensively studied in deciduous trees, relatively few studies have monitored this phenomenon in evergreen forests. This study aims to investigate dieback affecting Mediterranean evergreen forests, using the Gargano promontory (Apulia, Italy) as a case study, where significant dieback was recorded in the summer of 2024. Specifically, we focus on forests dominated by *Quercus ilex* and *Pinus halepensis*, aiming to identify key environmental variables (geomorphological, hydrological, and climatic) that explain differential dieback patterns, and to assess the ecosystem's capacity for recovery through remote sensing techniques. We analysed spectral indices representing eco-physiological attributes, such as leaf chlorophyll content, productivity, and canopy biomass, during stress (April–August) and potential recovery (September–March) periods in dieback-affected areas. Our analysis utilised monthly Landsat 8 imagery to calculate a suite of spectral indices serving as proxies for these eco-physiological parameters. Using linear regression models, we identified dieback-affected areas by detecting significant negative trends in these indices between the stress and recovery periods. Subsequently, we applied a Random Forest model to correlate observed dieback trends with environmental predictors. Our preliminary findings indicate two key outcomes: firstly, dieback intensity varies significantly across the landscape; secondly, there is a strong relationship between geomorphological variables and the patterns, severity, and recovery potential of these forests. This research underscores the potential of satellite imagery as a powerful tool for monitoring eco-physiological stress in Mediterranean evergreen forests, highlighting their vulnerability to climate-driven dieback events.

Reconciling climate change resilience and biodiversity objectives in a Mediterranean beech forest landscape: alternative management simulation modelling and trade-off assessment

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The European beech (*Fagus sylvatica* L.) plays a crucial role in European forests, supporting high levels of biodiversity and delivering key ecosystem services. However, beech forests are increasingly vulnerable to the impacts of climate change, particularly at the southern edge of their distribution (i.e. the Mediterranean region), where climate change threatens their structure and functions. In this context, the evaluation of forest management strategies becomes essential to promote biodiversity conservation and enhance ecosystem resilience. Simulation models represent powerful tools to assess the long-term effects of alternative management scenarios under changing climatic conditions. We used the LANDIS-II forest landscape model to evaluate the impacts of forest management strategies (even-aged vs. uneven-aged vs. no-intervention) on forest biodiversity (using tree species diversity as a proxy) and carbon pools, under two climate change scenarios (SSP 126 and SSP 370). The studied beech forest is located in the Gargano National Park (southern Italy) and consists of the Natura 2000 Habitat 9210*. Landscape structure (composition and configuration) analyses were performed at the scale of both individual management units and the whole management area to capture local dynamics as well as broader spatial patterns relevant to conservation planning and adaptive forest management objectives. Our results show that uneven-aged management determines fine landscape textures in terms of the spatial distribution of above ground wood biomass (standing stock) at both spatial scales, while even-aged management determines fine and coarse landscape textures at the management area scale and management unit scale respectively. Regarding biodiversity, tree species diversity declines under both no-intervention and even-aged scenarios but shows a positive trend under uneven-aged management. In contrast, carbon stocks increase more significantly under even-aged management, highlighting a trade-off between biodiversity conservation and carbon sequestration.

Sustainable management of UNESCO landscapes

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Abstract Through an integrated approach between tangible and intangible heritage, UNESCO landscapes should be managed to guarantee the maintenance of its socio-ecological values for future generations. The research aims at (1) analyzing the landscape dynamics from 1954 to 2023 of a study area including the Cerveteri UNESCO site, by comparing the UNESCO core and UNESCO buffer area with a landscape context which is characterized by high ecological and natural value (2) verifying the effects of the international recognition of the UNESCO site, in terms of landscape multifunctional stability, (3) building-up possible scenarios by identifying sustainable policies aimed at achieving a high level of socio-ecological connectivity between UNESCO area and its landscape context; (4) at last, an assessment of natural capital in monetary terms was carried out to quantify the benefits of goods and services provided by this multifunctional landscape. The land-cover analysis of the study area and the identification and quantification of the areas characterized by socio-ecological stability have been carried out using QGIS software. The study area has shown a total land-cover change from 1954 to 2023 of 23.2%, while the UNESCO site has faced a higher land-cover change of 30.9%. The landscape change was stronger before the site nomination year (2004) in the UNESCO World Heritage List. Throughout the time range (1954-2023), the whole study area shows a change trend toward loss of natural capital: natural grasslands have been converted into croplands, tree cover mainly in croplands and built-up, so that built-up class has increased. Therefore, the loss of natural capital results in a decrease in ecosystem services provided. In addition, landscape metrics show higher fragmentation in the landscape UNESCO site than in the landscape context. Finally, some sustainable policies have been identified to foster the management and valorization of this multifunctional landscape.

Underwater photogrammetry in low visibility environments for ecological characterization and biomonitoring: preliminary findings

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Photogrammetry has become an increasingly popular tool for the characterization and mapping of underwater habitats in the last decade. Compared to other methodologies, it is cost-effective, non-destructive and allows for repeatable high-resolution measurements. Ecological and morphological information regarding epibentic underwater communities can be extracted from high-resolution Digital Elevation Models (DEMs), orthoimages and 3D models created from photographs. This study aims at assessing the potential of underwater photogrammetry in low visibility environments, with three main objectives: 1) to analyze the structure of epibenthic assemblages, 2) to perform a general characterization of the whole benthic habitat, and 3) to carry out an evaluation of environmental quality within the framework of bioindication and biomonitoring techniques. The investigations were carried out on various coastal environments of the Northern Adriatic, with particular focus on bio-geogenic outcrops scattered throughout the Northern Adriatic seabed, locally known as "tegnùe" or "trezze". Photogrammetric surveys were carried out between 2022 and 2025. The main study areas were located in *Tegnùe di Porto Falconera* SAC, near Caorle (Venice) with depth ranging from 6 to 10 m. Specific protocols were developed to apply the method to low-visibility conditions. A purpose-designed multi-camera rig was used to widen the overall image footprint over the seabed. High-resolution models (0.5 mm/pix) of large areas (5000 m^2) were built with the collected data, representative of the different facies of the outcrops. In order to test approaches and tools for the ecological analyses of the dataset, a few representative sub-areas were selected. Distribution, abundance and diversity of conspicuous epibenthic organisms were assessed through semi-automatic segmentation and classification pipelines. Preliminary evaluations of the ecosystem status based on biotic indices were attempted. Overall, this methodology can efficiently assess changes within communities and habitats over time even in limited visibility conditions, representing a valid and cost-effective monitoring tool.

The fragility of Special Areas of Conservation in the Broad Area Site "Murge"

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Specific level of ecological sensitivity and human pressures can affect the fragility of an area, intended as the opposite of ecological resilience. Therefore, the aims of this research are: (1) the analysis, mapping and classification of the special area of conservation (SAC) in terms of ecological sensitivity and human pressures; and (2) the assessment and classification of the SACs in terms of ecological fragility. The study area is part of an Italian survey, and it includes 18 SACs. Among the nine priority habitats present in the SACs, the habitat 6220* is the largest (5,935.37 ha), followed by the habitat 2270* (1,917.01 ha). The SAC n. 12 has shown the highest ecological sensitivity for its high number of animal and plant species. SAC n. 2 is the only characterized by a very high human pressure, mainly due to habitat fragmentation. In the case of SACs n. 5 and n. 6, the high pressure is attributable in the first case to urbanization, while in the second case to agriculture. SAC n. 2 has resulted the most fragile, because of its high ecological sensitivity and high habitat fragmentation. As habitat connectivity is one of the main concepts used to address the link between landscape pattern and function, we carried out an additional approach not only to analyze habitat connectivity, but also to assess the effect of temperature through LST analysis and biomass productivity through NDVI analysis. The present research proposes an innovative approach to implement the mere perspective based only on the reduction of habitat size with a comprehensive vision of SACs' fragility by combining ecological sensitivity and human pressures. In this perspective, it can support the application of the Nature Restoration Law, aiming at promoting EU Biodiversity Strategy and Natura 2000 Network by restoring degraded habitats.

Spatio-Temporal Landscape Transformation in the Monti Prenestini (Rome): Insights from Remote Sensing and Landscape Ecology

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This study examines the landscape transformations in the Monti Prenestini area of Lazio, Italy, from 1990 to 2023. It analyses changes in land cover dynamics and spatial structure using a landscape ecology approach. The study area covers approximately 229 km^2 and is ecologically significant due to its diverse habitats, which include forests, shrublands, grasslands, and agricultural lands. In recent decades, anthropogenic pressures such as urban expansion and agricultural abandonment have altered the landscape's composition and configuration, affecting biodiversity and ecosystem services. Land cover data were obtained from the Copernicus CORINE Land Cover datasets covering the years 1990 to 2018. For the year 2023, land cover was reconstructed using the Random Forest machine learning algorithm, which was applied to Sentinel-2 satellite imagery, topographic data, and ground truth points. All land cover maps were reclassified into seven thematic classes to ensure consistency and comparability. Spatial metrics were calculated using FRAGSTATS 4.2 to quantify fragmentation, connectivity, and landscape heterogeneity at both class and landscape levels. The results reveal a progressive transformation of land cover types, with significant forest expansion and the disappearance of natural grasslands by 2018. Between 2018 and 2023, notable increases in the Largest Patch Index and reductions in diversity metrics (e.g., Modified Simpson's Diversity Index) were observed, suggesting increasing dominance of fewer land cover types. Artificial surfaces and permanent crops have shown a marked spatial expansion in recent years, while agricultural mosaics and transitional shrublands experienced reductions in area and connectivity. Overall, the study highlights how land cover change patterns in the Monti Prenestini reflect broader socio-environmental trends, such as land abandonment and urbanisation. The integrated use of remote sensing, landscape metrics, and machine learning provides a robust framework for monitoring ecological resilience and informing sustainable landscape management strategies.

The quest for conservation allies in Mediterranean islands and beyond

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Increasing conservation targets to protect biodiversity and safeguard sustainability is seen as one-way for humankind. The Half earth concept proposed by E.O. Wilson led to a debate over whether and how this can be achieved given increasing societal needs and pressure for land. The new European Biodiversity Strategy (EBS) for 2030 calls among other things for binding targets to restore degraded ecosystems setting an ambitious target of 30 % of the EU's land areas under legal protection with 10 % of EU land under strictly Protected Areas. A concept which is gaining ground globally as a potential ally in this effort is 'other effective area-based conservation measures' (OECMs). The aim of the paper is to demonstrate how biodiversity conservation can be achieved on a Mediterranean island, beyond existing Protected Areas, by 'giving nature half' on the terrestrial realm. We assess the role of conservation 'allies' in Cyprus, by identifying potential OECM areas on the island, according to four IUCN criteria. Specifically, we assessed High Nature Value Farmlands (HNVfs), commons, archaeological sites, wildlife conservation areas, roadless areas, and mapped their spatial relationship with the Natura 2000 network. We devised a Conceptual Framework for evaluating and classifying potential OECMs on the island based on their legal protection status and the potential for persistence over time. Potential OECMs areas, which may act complementary to the N2K, extend to c. 50 % of the island. The spatial properties/arrangement of any OECM are probably as important as the criteria proposed by the IUCN. Our analysis suggests that the "allies" with the larger geographical extent and smaller overlap with N2K are HNVFs and temporary wildlife conservation areas. What we propose herein can serve as a model for rethinking and redesigning nature conservation in Mediterranean islands and beyond.

Ecologia ed educazione alla sostenibilità

10

Ecological and Social Preferences for the Management of Forest Bathing Sites in Italy

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Over the past decade, forest bathing (or *Shinrin-yoku*), a practice originating in Japan in 1982 to improve people's psycho-physical well-being, has gained increasing popularity across various regions of Italy; alongside this diffusion, national scientific interest in its physical and psychological benefits has grown. However, a knowledge gap persists in the literature regarding the ecological characteristics of suitable sites. Limited international studies have shown that both site-specific features (e.g., accessibility, slope, terrain characteristics) and forest stand variables (e.g., species composition, age, structural diversity, presence of deadwood and underbrush) play a crucial role in delivering beneficial effects. Ideal environments include mature broadleaf forests (e.g., high-forest beech stands) or mixed forests over 60–70 years old, with irregular structure and diverse vertical and horizontal stratification. Based on these considerations, this study applied Q-methodology to explore stakeholder perceptions and preferences concerning environmental and functional requirements of forest bathing sites. A total of 34 Italian stakeholders—including forest bathers, academic experts, forest managers, and medical professionals—were involved to identify their perspectives and priorities related to ecological, economic, and social aspects of the practice in Italy. The analysis revealed four main viewpoints: (1) a medically and scientifically focused view emphasizing psycho-physical health; (2) a perspective valuing managed forest environment; (3) a nature-centered vision emphasizing ecological integrity; and (4) a socio-economic outlook highlighting the practice's broader benefits. Despite differences, a shared emphasis emerged on the importance of site accessibility, proximity to existing trails, and the tangible physical benefits. Moreover, user preferences sometimes diverged from scientific recommendations, reinforcing the need to integrate perceptual and experiential dimensions into site planning. In particular, less-managed forest environments—often favored by users—can offer an opportunity to promote and enhance other ecosystem services, such as biodiversity conservation and the maintenance of structural complexity in forest stands.

The Evolution of Love. An educational framework to understand the history of Life.

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The history of Life on Earth offers a captivating narrative, particularly well-suited for middle school students as they begin to develop formal operational thinking, according to Jean Piaget's theory of genetic epistemology. Reproduction, in particular, presents an opportunity for integrated learning with sexual education within the school curriculum. Here, I propose a learning pathway titled "The Evolution of Love," designed for middle schoolers, which uses ancient Greek terms – eros, storgé, and biophilia – to illustrate the evolution of this concept. Survival and reproduction form the two fundamental pillars of evolution. Reproduction itself results from a series of adaptations that address the challenge of passing genes to the next generation. This challenge is universal across all living species and can be understood as *eros*, (ρως) a form of love directed towards reproduction. Approximately 200 million years ago, the emergence of homeothermic animals, capable of stabilizing their internal environment through temperature regulation, enabled more effective parental care and the evolution of *storgé* (στοργή). Finally, within the genus *Homo*, around 2 million years ago, the internal environment of the brain stabilized with the increasing impermeability of the choroid plexuses, giving rise to a new form of love: *biophilia* (βιοφιλία). Biophilia broadens the care inherent in storgé to encompass other unrelated conspecifics and even members of different species.

Citizen Science in action: tracking species of (European) Union concern through the "AilantItaly" project

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In recent years, Citizen Science (CS) has become increasingly important for monitoring biodiversity and its pressures and threats, such as invasive alien species. In the European, some of the invasive alien species with the greatest impact on biodiversity are listed under the Regulation (EU) No. 1143/2014, which requires all Member States to conduct management actions, including continuous monitoring. This monitoring is essential to identify new invasion foci (early warning) for potential eradication, as well as heavily invaded areas, where management and containment measures must be implemented. This study aims to implement a national-scale CS initiative (AilantItaly) to enhance knowledge on the ecology, distribution, and spread of the invasive species *Ailanthus altissima* (Mill.) Swingle in Italy.

Through active public engagement and collaboration among 15 research institutions and organizations, the project, launched within the framework of the TESO working group (Tavolo ESOtiche – UniMiB and UniMoRe) under the National Biodiversity Future Center (NBFC), seeks to collect large-scale occurrence data to support early detection, detailed mapping and modelling, and the development of targeted management strategies. Data are collected and shared through a dedicated project, AilantItaly, launched on March 15th, 2025, on the iNaturalist platform (https://www.inaturalist.org/projects/ailantitaly), a global biodiversity data repository. The initiative promotes active and structured monitoring in urban, natural, and semi-natural environments. By comparing *Ailanthus altissima* records on iNaturalist before and after the launch of AilantItaly, we explored and provided evidence of: (i) the effectiveness of CS in enhancing spatial and ecological knowledge of the target species at a national scale in Italy, and (ii) the identification of geographic areas with higher susceptibility to invasion, based on citizen-contributed data. Combining scientific rigour with participation, the project fosters dialogue between academia and society, showcasing how CS contributes to addressing invasive species challenges.

Engaging citizens on the management of acquatic invasive alien species: the 'GuardIAnS of the biodiversity' OpenLab

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Within the Horizon Europe project 'GuardIAS' (Guarding European waters from Ivasive Alien Species), a citizen science project was designed to achieve a deep level of citizens engagement (stimulating behavioural changes and desire to take action), with activities related to IAS management. Target species of the activity, structured as an 'OpenLab' in the field, is the swamp crayfish *Procambarus clarkii*, while target group of participants includes citizens of any age, recruited through local associations. After filling in a pre-event questionnaire that explores their perceptions on IAS, citizens are exposed to a short info-session on the biodiversity of the study area and impacts of aquatic IAS, specifically *P. clarkii*, using an online brochure that is also distributed to participants before the event. Subsequently, participants are instructed and encouraged to use crayfish trapping systems, and to collect and record biometric data, under the guidance of scientists. These data will be part of the Lombardy regional IAS database. During the activity, discussions are stimulated about the challenges of IAS management, dealing with topics such as: pros and cons of capture strategies; compliance with the EU IAS Regulation; bioethics issues. In this ways, participants can provide ideas that can eventually contribute to improve management strategies. After the activity, citizens receive an email with a short report on the biological results of the fieldwork, along with the link of a post-activity questionnaire to fill in. The latter is functional to assess the impact of the OpenLab in terms of knowledge improvement and levels of engagement, as well as to collect further recommendations. So far, activities have been carried out in three natural and semi-natural oxbow lakes in southwestern Lombardy, and almost 50 citizens have been involved: nearly 75% of them have shown increased awareness and concern on biodiversity loss due to IAS after the activity.

Habitat tree: home for biodiversity. Outreach and environmental education opportunities

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Habitat Tree: Home for Biodiversity is a research project aimed at studying the specific biodiversity associated with mature and old-growth trees. Trees were studied in various areas, from urban parks to protected areas of high natural value (the Abruzzo, Lazio, and Molise National Park, Sasso Simone Natural Park). Beyond the scientific results (i.e., a tree in the center of Milan can host up to 250 different species in its dendromicrohabitats – excluding bacteria –) and the management implications (identification and proposal of new techniques to safeguard mature trees in urban environments, where they are often considered a problem rather than an opportunity), this research has developed several environmental education programs. First, between September and November 2024, an exhibition was organized at the Natural History Museum of Milan, illustrating the concept of tree habitat. This exhibition received approximately 20,000 visitors per month and generated several collateral events (training and outreach courses). The exhibition enabled the creation of a large-scale reconstruction of a habitat tree, which now serves as a traveling installation available to museums and events. Ten theses in the Primary Education Sciences program were then supervised, where prospective teachers analyzed how tree representations vary in children's books and textbooks, and developed practical activities with children in the schools where they were completing their internships to teach the concept of tree habitat. A story-telling show has been created with the collaboration of the Master Science communication of Insubria University. Finally, a final result was the development of a program to translocate a relict population of *Cerambix cerdo*, a species listed in Annex II of the Habitats Directive, based on the feedback from citizens who had learned about the Habitat Tree project.

Social perception and biodiversity conservation in productive forests: comparison between Italy and Germany

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In recent years, social acceptance of biodiversity conservation in forests has become increasingly important at the international level, both within the scientific community and among policy makers. In the literature, some studies have investigated citizens' preferences towards biodiversity conservation in protected areas, while there is a knowledge gap regarding the social acceptance of biodiversity conservation measures in productive forests (for timber and/or bioenergy production). The creation of a network of senescence islands or deadwood islands – areas of 2-3 ha aimed at promoting the formation of deadwood and microhabitat trees – within productive forests represents an efficient measure for the conservation of saproxylic biodiversity. The present study investigated– through the administration of a semi-structured questionnaire to a sample of citizens–the social preferences and perceptions towards the biodiversity conservation through the creation of a network of senescence islands in two case studies: Cansiglio Orientale forest in Italy and Sailershausen university forest in Germany. The questionnaire–divided into three thematic sections–has investigated the first thematic section the socio-demographic characteristics of the respondents, in the second section the opinions on the importance of the main ecosystem services provided by the forests, and in the third section the aesthetic-visual preferences towards different forest management scenarios representing through images (from the production forests without deadwood to the deadwood islands characterized by an high amount of deadwood volume). The results showed that German respondents assign a higher visual-aesthetic value to images of the Sailershausen university forest characterized by a high presence of deadwood (typical of senescence islands), while Italian respondents assign a clear preference to images of productive forests without lying deadwood and standing dead trees. This result is confirmed by the importance assigned by German respondents to the conservation of fauna and flora as the main ecosystem service provided by forests compared to Italian respondents who were more oriented towards regulating services such as climate change mitigation and natural hazards protection.

Tobacco smoke in the water: the *Daphnia magna* lesson

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In the first chapter of the third SItE notebook," Quaderno di Ecologia", the topic of the harmfulness of cigarettes to the environment is introduced. Cigarette filters and smoking products are known to be a serious environmental problem because they are toxic and dangerous. The environmental hazard is generated by the presence of residues of toxic substances such as polycyclic aromatic hydrocarbons, heavy metals, pesticides and nicotine in tobacco, which are retained by the discarded filter with the cigarette butt. Following rainfall events, these substances may be leached from the butts and contaminate soils and/or surface water bodies. Ecotoxicological studies have revealed that chemicals released from butts are highly toxic to aquatic organisms including nicotine and ethylphenol. Inspired by the publication, *Daphnia magna* specimens, reared at the University of Milano Bicocca, were delivered to Prof. Moccaldi's institution and they were reared by her first-class students in dechlorinated tap water in common jars, with 20 individuals per vessel, and they were fed with a spirulina and yeast solution every two days. The experiment comprised the exposure of test organisms to water extracts of cigarette butts that had been collected in the square in front of the school building. The volume of water employed in each experiment was a minimum of 2 mL per organism, in accordance with the established guidelines. Students have recorded each step of the activity, and they have read up on the toxicity of butts on the SItE notebook. The activity has been very useful because it has allowed students to understand how butts can be dangerous, but also to study science and maths topics in a more effective way. Students' approach to nature, their expectations and impressions have been collected through validated tests.

Parte III

Poster

Reti trofiche ed ecologia di comunità

1

Seasonal isotopic niche structure of dominant pelagic and benthic species in Kongsfjorden, Svalbard Islands

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Arctic marine ecosystems are biodiversity hotspots essential for commercial exploitation and ecosystem management. These typically nutrient-limited environments, experience seasonal fluctuations in resource availability driven by variation in light, sea-ice cover, and terrestrial runoff. Climate change alters temperature and precipitation patterns, resulting in increased terrestrial inputs and reduced sea-ice extent, which effect on timing and quantity of resource inputs into marine food webs. However, the impact of these changes on resource partitioning among species, and their implication for species coexistence and productivity, remain understood. As an initial step toward addressing this gap, this study investigates how seasonal variations in terrestrial inputs and phytoplankton influence isotopic niche structure and niche partitioning of dominant zooplanktonic and benthic species in Kongsfjorden, Svalbard Islands. Sampling was conducted in early summer, when resource levels are low, and late summer, during peak resource availability. Individual stable isotope analysis was used to characterise species' isotopic niches and overlap. Results reveal significant niche partitioning of both within and between zooplanktonic and benthic species. Benthic species maintained stable carbon isotopic signature throughout the summer, reflecting benthic and sympagic inputs. Conversely, zooplanktonic species shifted to more negative carbon isotopic values in late summer, reflecting increased assimilation of phytoplankton-derived carbon, while a mix of pelagic and sympagic sources appeared to support early summer diets. As predicted by optimal foraging theory under resource-abundant conditions, pelagic species reduced isotopic niches breadths and greater overlap in late summer. Our findings suggest a limited direct contribution of terrestrial runoff to marine consumers in both time periods. This study presents the first seasonal, individual-level isotopic profiles of key species in Kongsfjorden, providing valuable insights into how climate-driven shifts in resource inputs may influence niche partitioning of species. These dynamics have important implications for nutrient transfer within the Arctic food web and the ecosystem services it sustains.

Exploring phytoplankton community dynamics through eDNA metabarcoding across size-fractionated assemblages in a coastal marine ecosystem

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Marine autotrophic communities play a fundamental role in marine ecosystems, acting as primary producers and supporting entire food web. Understanding their structure, diversity, and distribution across different size fractions is essential for evaluating ecosystem functioning. In this study, we applied eDNA metabarcoding to investigate the taxonomic composition of plankton assemblages in coastal seawater samples, filtered through different size fractions: 100-50 µm, 50–10 µm, and 10–3 µm potentially corresponding to the size traits of phytoplankton. This approach enabled the characterization of micro- and nano-phytoplankton, including rare and or unculturable taxa. Seawater samples were collected from a temperate coastal site in the northwestern Adriatic Sea. Total genomic DNA was extracted from each size fraction and amplified using primers targeting the 18S V4 region of rRNA gene, followed by high-throughput sequencing. Preliminary results revealed distinct community profiles across the three size fractions, highlighting the ecological partitioning of taxa by cell size trait. At phylum level, the 100-50 µm fraction was dominated by large Alveolata (70%), including Dinoflagellata and Ciliophora subphyla, and by Stramenopiles (30%), mainly including the Bacillariophyta class of Mediophyceae, which consists of centric diatoms. In the 50–10 µm fraction, a slight shift was observed, with Stramenopiles (53%) more abundant than Alveolata (45%). The 10–3 µm fraction showed an enrichment in Stramenopiles (57%) and a reduction in Alveolata (27%). Additionally, Chlorophyta appeared in this fraction (15%), with small-sized families as Pycnococcaceae, Pyramimonadaceae, Chlorodendraceae. The size-structured distribution of these taxa reflected not only taxonomic diversity, but also functional and trophic differentiation, with important implications for coastal ecosystem functionality. The autotrophic-mixotrophic component was dominant in the smaller fractions, while the bigger one was dominated by the heterotrophic taxa. Thus, the eDNA metabarcoding with size-fractionated sampling can enhance the resolution of marine plankton community dynamics and enable a more detailed assessment of trophic structure and ecosystem functioning.

The burden of formalin: metabarcoding analysis on mesozooplankton samples preserved in buffered formalin from the Gulf of Trieste

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Long-term ecological research and monitoring reveal how ecosystems change across decades by tracking spatial and temporal patterns. They offer snapshots on shifting communities and biodiversity loss driven by anthropogenic and climate-related stressors, thereby supporting biodiversity conservation and resource management. In the case of zooplankton, several historical collections around the world span multiple decades. Researchers often preserved samples in buffered formalin after morphological analysis. While formalin remains one of the most commonly used fixatives for maintaining structural integrity, it complicates genetic analysis due to DNA degradation and cross-links between nucleic acids and proteins. Integrating a molecular approach alongside traditional morphological analysis remains a crucial challenge, especially for understanding potential shifts in mesozooplankton communities under rapid climate change. This study aims to establish a protocol capable of performing metabarcoding analyses on mesozooplankton samples preserved in buffered formalin for seven years. In 2017, we collected samples monthly at the "MAMBO Station" in the Gulf of Trieste using vertical nets. The samples were then taxonomically identified and preserved in formalin. We pretreated the samples with an alkaline buffer, followed by thermal shock and extracted DNA using the E.Z.N.A.® Mollusc DNA kit (Omega Bio-Tek). Three primer sets targeting 18S and COI markers were successfully amplified. We processed raw reads in QIIME2 (2024.5) and clustered sequences with VSEARCH using abundance-based greedy clustering at a 94% similarity threshold. Taxonomic assignment was performed against reference databases (MetaZooGene for COI and SILVA for 18S). Our results demonstrate that meaningful community composition data can be recovered from archived formalin-preserved zooplankton samples, supporting their use in retrospective ecological studies, including those associated with climate change. The optimized workflow provides a valuable tool for integrating molecular and historical data to assess long-term changes in zooplankton communities.

The Fate of Biodegradable Plastics in Freshwater: Preliminary Insights from a Lake Maggiore incubation study

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The increasing use of biodegradable plastics, derived from both fossil and renewable resources, raises questions about their actual degradation and ecological interactions in aquatic environments. While these materials are designed to be more environmentally friendly, their persistence and the biological communities they host under natural conditions remain poorly understood. In this study, we investigated the long-term behavior of biodegradable plastic films incubated for over a year in the surface waters and sediments of Lake Maggiore (Northern Italy). We focused on changes in the physical and chemical properties of the materials, as well as the structure of microbial and diatom communities colonizing their surfaces. Preliminary results suggest measurable degradation of the films over time, evidenced by alterations in spectral and thermal properties, changes in shape and weight, and visible fragmentation. Differences were observed between materials derived from renewable versus fossil sources, with some showing greater structural changes than others. These findings highlight the complex interactions between biodegradable plastics and freshwater ecosystems, emphasizing the need to evaluate their performance and ecological footprint under realistic environmental conditions. Further analyses are ongoing to characterize the biofilm communities in greater detail and quantify degradation rates.

Relationship between Zooplankton Abundance and Oceanographic Conditions in the Waters Around Sardinia

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A zooplankton survey was carried out in the waters around Sardinia in September 2019 during oceanographic cruise IDMAR 2019. The samples here analyzed were caught in 57 stations, both near-shore in shallow water and in the continental slope above higher bottom depth. The sampling tool used was a 200 µm mesh size Bongo 40 Net. The Zooplankton community was investigated from the point of view of numerical abundance and taxa composition. Subsequently, these data were related to oceanographic conditions and orographic conformation. In the southwest, we have a wide continental shelf, while, along the East and South-East coasts, the continental shelf is narrower and at times almost absent. Along the East and South-East coasts, the continental shelf is narrower. According to the CTD data at 5 m depth, the eastern, northern, and southern salinity was higher with respect sardinian western coast, which in turn resulted also characterized by colder and more oxygenated waters. Considering total zooplankton, coastal stations resulted in abundance almost one order of magnitude higher than slope ones (357.05-6309 ind./m^3 and 97.25-514.31 ind./m^3, respectively), with the exception of the eastern coastal station 66 (29.9 ind./m^3). With regard to single taxa, copepods resulted in almost every station greater than 71.18%, except in the SW coastal station 4 (copepods: 56.56%; gastropods larvae: 27,17%). Cladocerans have been in most cases less than 10%, except for stations 85 (17.97%), 83 (13.98%), and 58-59 (~13%), probably because of nutritional enrichment due to coastal ponds proximity. Appendicularians was the third zooplankton taxa for numerical abundance of the whole cruise, followed by aforementioned gastropods larvae. Other groups accounted for less than 1% (pteropods, decapods larvae, euphausiids larvae, chaetognaths, cnidarians, ostracods, polychaetes) or less than 0.1% (thaliaceans, siphonophores, amphipods, euphausiids, mysids, teleosts larvae).

A dedicated web service for animal biomass estimation from length-weight relationships at the order level

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Body size is a fundamental functional trait that integrates various morphological and physiological characteristics, which respond differently to environmental pressures. When expressed as body mass, body size provides insights into energy flows, scaling up from individual to ecosystem levels using the integrative theoretical approach of the Metabolic Theory of Ecology (MTE; Brown et al., 2004). According to MTE, individual body mass is a convenient proxy of individual energetics, space use foraging behaviour, population density and energy use, ecosystem processes and services. On the other hand, assessing individual body mass is problematic for many groups of organisms, being the individuals either too small or too large for practical measurements or the whole methodological process too time consuming and expensive. Length-weight relationships offer a convenient means of estimating individual body mass from simple measurements of individual length. To this aim, we have assembled an extensive length per weight database, continuously growing with increasing international collaborations, of 7500 animal species, mainly covering invertebrate and fish species. At higher taxonomical level we have collected length per weight relationships of 133 animal orders, corresponding to more than the 15% of the animal orders. Here, we present an e-service developed by LifeWatch Italy to allow researchers to estimate individual body mass of the taxa pertaining to the already available orders from the respective length per weight relationships. The database's weight-length relationships are set to be expanded through an intensifying international collaboration, with the aim of implementing the service at more specific taxonomic levels. The proposed model efficiently obtains biomass data useful for functional community analyses, ecological assessments, and environmental monitoring. This approach helps to bridge the gap in the provision of high-resolution, quantitative data by providing a pragmatic, transferable tool for ecological studies in both terrestrial and aquatic ecosystems.

Effetti del disturbo sui sistemi ecologici

2

Responses of Alpine bird communities to Storm Vaia and Bark Beetle outbreaks in the Central Alps

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Alpine forest ecosystems have increasingly experienced extreme disturbances due to climate-related events. In October 2018, Storm Vaia struck the Italian Alps, followed by widespread outbreaks of the bark beetle *Ips typographus*. These events impacted forest structure, offering the opportunity to study post-disturbance bird community dynamics. We investigated species richness, diversity, and turnover in bird assemblages in an 8 x 2 km area in the upper Valtellina valley (Central Alps), using 51 standardised point counts. The study area is elongated mainly south-north, with open areas in the south and closed forest in the north. The altitudinal gradient ranges from the anthropised valley floor (1164 m above sea level) to the east to coniferous woods (1839 m a.s.l) to the west. Point counts were performed between 5:00 and 10:00 am, recording for 10 min all individuals heard or seen within 100 m. Environmental predictors included land cover proportions (from classified raster data) within 100 m of point counts, altitude, latitude, longitude, and the extent of forest damage (bark beetle and tree felling). For each point count, we computed biodiversity indices from the maximum observed abundances. Results showed 55 bird species, with richness ranging from 6 to 18 per point count. Species richness and Shannon diversity were positively associated with built-up areas. Shannon diversity was also positively associated with tree cover and negatively with latitude. A distance-based redundancy analysis model on Bray-Curtis distances explained 28.4% of community variation, with tree cover, built-up areas, altitude, and latitude as the most important predictors. A variation partitioning analysis showed that land cover variables explained 24.6% of community variability, 8.6% was explained by the spatial variation in land cover, and only 2.7% by spatial variation in bird communities. Turnover was the dominant beta-diversity component (β_{SIM} = 0.63). These findings suggest that moderate disturbance, like the presence of open areas in the south and around built-up areas at lower elevation, can support diverse avian communities by promoting habitat heterogeneity. Community variation was primarily driven by species replacement along these gradients. Post-disturbance management should therefore aim to preserve structural complexity to maintain bird diversity.

Otolith morphology and growth variations in *Citharus linguatula* populations subjected to different fishing pressure: a comparison between Sicilian and Sardinian populations.

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Both growth estimation and otoliths analysis represent a valuable source of information that can be used to reconstruct life-history traits of species, to investigate its trophic interactions, and delineate its stock structure. In this study, we focused on analysing the growth pattern and otolith's shape of the spotted flounder *Citharus linguatula* (Linnaeus, 1758) with the aim of preliminary assessing the possible presence of biological and morphological variations between two population of specimens caught in a bottom trawling-banned area (Gulf of Patti, Sicily, law n.25, art.9 of the Sicilian Region, emitted in the 7th August 1990) and a highly fishing impacted area (GFCM Geographic Sub Area 11, Sardinia). A total of 517 right sagittal otoliths (290 collected in Sicily and 227 in Sardinia) was analysed. From the results of a multi-model growth analysis emerged that the Sicilian population seems to benefit the absence of bottom trawling, being capable to reach age up to 6 years, while in the whole Sardinian area no specimen above 3 years have been caught. In support of these initial findings, the shape analysis further highlighted some differences in the otoliths' contour between the antirostrum and postantirostrum and in the postrostrum region, as confirmed by the ANOVA test and the Canonical Analysis of Principal Coordinates (CAP). Both the distinct age structure found between the areas and the variations in otolith's shape underline how deeply the presence of human-related stress could impact the life history traits of demersal species. In conclusion, this study highlights the potential of growth estimation and otolith shape analysis as a cost-effective preliminary method for stock status evaluation. The resulting data are crucial for implementing sustainable fisheries management strategies, thereby addressing important ecological challenges.

Seasonal dynamics of herbaceous and microbial communities in Mediterranean urban green spaces – the role of management strategies

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The management of green areas in urban ecosystems can affect their capability to support ecosystem functions and services in ways and extents still unsatisfactorily elucidated. The present research, funded by the National Recovery and Resilience Plan (NRRP), Project code CN_00000033, CUP, H43C22000530001 Project title "National Biodiversity Future Center—NBFC", aims to shed light on the effects of management on the seasonal dynamics of the structural and functional diversity of herbaceous communities and on the activity of soil microbial communities in Mediterranean urban ecosystems. To this end, the study adopted a comparative approach between two areas differing in mowing, irrigation and fertilization. The diversity of herbaceous communities, in terms of species richness, evenness and composition, was studied by means of phytosociological surveys, with taxa identified at the species level and functional traits obtained from literature. The metabolic activity of edaphic microbial communities was evaluated through the analysis of enzyme activities (hydrolase, β-glucosidase, phenol-oxidase) as proxy for specific steps of the carbon cycle. Results highlighted that anthropogenic management pervasively affects the structure and functionality of urban ecosystems and their temporal dynamics. Management strategies reduce the structural and functional diversity of herbaceous communities via the process of biotic homogenization, fostering the dominance of generalist species with specific functional traits. Whereas management practices directly affect plant communities, the effects on microbial communities appear to be mediated by the changes in vegetation, with the promotion and inhibition of different enzyme activities through the alteration of organic matter inputs to the soil. Understanding how anthropogenic constraints in urban ecosystems affect biological communities may contribute to the planning of sustainable management approaches able to preserve biodiversity and to improve the stability of urban green spaces.

A biomarker-based field study assessing environmental pressure in honeybees across different land use types

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Bees are responsible for the pollination of approximately 70% of the planet's plant species and play a vital role in maintaining the structure and functioning of ecosystems. Due to their foraging behavior and constant exposure to environmental conditions, bees can reflect local environmental quality. Pollutants may bioaccumulate in their tissues and in hive products, potentially affecting both insect health and the safety of bee-derived substances consumed by humans. In this study, honeybees (*Apis mellifera*, Linnaeus 1758) were sampled from three sites selected based on different land use types: a rural site, an industrial zone and an urban environment. Oxidative stress biomarkers were assessed in various tissues to assess bee health status. Specifically, the activities of superoxide dismutase (SOD), catalase (CAT), glutathione peroxidases (GPx's), glutathione reductase (GR) and cholinesterase (ChE) were evaluated on the abdomen-thorax sections of the specimens, while acetylcholinesterase (AChE) activity was measured in the heads. Variations in biomarkers levels were observed across sites, indicating differing oxidative stress responses likely linked to environmental pressures. Whereas microplastics (MPs) were not detected in bee tissues from the three apiaries, sorbitan monostearate, a surfactant used in agro-industrial products, was incidentally detected in samples from one apiary. While the compound was not the primary focus of the study, its presence warrants further in-depth investigation. These preliminary findings highlight both the physiological responses of bees to environmental exposure and the potential for such contaminants to accumulate in bee tissues. These responses may also provide indirect insights into the quality and safety of bee products such as honey, beeswax, and propolis, which are widely valued for their nutritional and pharmacological properties.

Impact of fire on soil total N content and organic C stock in beech and pine forests of central Italy

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This study is part of the BIOSFeR3a project, that aims to explore the relationship between specific and functional biodiversity at various levels: from landscape to plants, to microorganisms, with a particular focus on the functions relevant to the biogeochemical cycles that most contribute to climate change, i.e. the carbon cycle and the nitrogen cycle. The ultimate goal of the BIOSFeR^{3}a project is to investigate the mechanisms linking specific and functional diversity, connected to the resilience, resistance and recovery capacity (R3) of ecosystems, in 12 large area sites subjected to fire disturbance or fragmentation. In this context, this study analyzed the effects of fire disturbance on soil total N content and organic C stock and on POM (Particulate Organic Matter) and MAOM (Mineral-Associated Organic Matter) fractions, at different depths along soil profile (0-5, 5-10, 10-20 cm). The study was carried out in different forests of the Maiella National Park in central Italy: two beech forests (*Fagus sylvatica* L.), in which fire occurred in 2023, and three pine forests (*Pinus nigra* J.F. Arnold), in which fires occurred once (2023) or twice (2017 and 2023). In each forest an unburned undisturbed soil was also selected as control. Results showed, in beech forests, a reduction in total N content and organic C stock and in the POM and MAOM fractions, in burned soils compared to the control soils, which was more marked in the deeper soil layer (10-20 cm). In pine forests, the reduction in these parameters in burned sites was even more marked, showing a deep impact of fire on soil organic C stock in these forests. Project "BIOdiversita' Specifica e Funzionale per la Resistenza, Resilienza e Recupero ai disturbi ed al cambiamento climatico [BIOSFeR^{3}a]", funded by Italian Ministry of University and Research, "National Biodiversity Future Center - NBFC PROJECT", CUPB83C22002930006

Exploring decadal changes in macrobenthic assemblages of shallowest soft bottoms impacted by clam fishery in the northern Gargano (Southern Adriatic Sea)

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This study explores the decadal changes in soft-bottom macrobenthic assemblages in two southern Adriatic areas, Lesina and Varano, respectively characterized by high and occasional impact of fishing dredging, targeting *Chamelea gallina*. The biological data analysed were obtained from monitoring surveys conducted in the winters of 2013 and 2022 in 45 sampling stations to assess the status of the *C. gallina* stock and associated assemblage. Standardized abundance data (N/100m^2) of collected benthic species were analyzed using Shannon's and Pielou's diversity indices, and testing differences through the non-parametric Kruskal-Wallis test. A multivariate analysis was performed on fourth-root transformed data for 53 species using a Bray-Curtis similarity matrix. Permutational analysis of variance (PERMANOVA) and principal coordinate analysis (PCoA) were performed to explore the structure of macrobenthic assemblages according to two fixed factors (Year and Area, both with 2 levels). Significant decreases in median values of both diversity indices were observed in Varano in 2022 compared to 2013 (p

Impact of Ocean Acidification on brown algae *Dictyota dichotoma*: limitation or Potential Benefit?

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The Mediterranean Sea is undergoing increasing acidification, with surface ocean acidity having risen by approximately 26% since pre-industrial times. Due to its semi-enclosed nature, the Mediterranean basin may experience intensified impacts, particularly on autotrophic organisms such as macroalgae in rocky shore habitats. Natural CO_2 vents of Ischia Island (Italy) provide a unique natural laboratory for studying the long-term effects of ocean acidification (OA) on marine ecosystems and exploring potential resilience mechanisms. This study investigates the physiological responses of the brown macroalga *Dictyota dichotoma* along the acidification gradient at the Ischia vents. Sampling area included three extremely low pH replicated sites (6.25), three intermediate pH sites (7.14), and three control sites (8.13), supplemented by an external control 300m away from the acidified area, to avoid the influence of pH gradient. Apart from pH, all sites shared the same depth, exposure, and substrate characteristics. Macroalgal community composition was assessed with visual estimate of substrate coverage followed by measurements of photosynthetic efficiency. Furthermore, thalli were analysed for functional traits, pigment composition and antioxidant response. Results revealed *D. dichotoma* as a dominant species under highly acidified conditions. *D. dichotoma* maintains consistent photosynthetic efficiency under low pH, while reinforcing its structural tissue, likely suggesting a strategy that aim at withstanding chronic stress. Moreover, data showed a significant upregulation of antioxidant and phenolic defences in acidified environments, highlighting a noticeable ecological plasticity. The high antioxidant pool in acidified sites has a pivotal role in enabling *D. dichotoma* to mitigate oxidative damage and persist in altered seascapes. Overall, these findings highlight the ecological plasticity of *D. dichotoma* and its adaptive capacity under OA scenarios, positioning it as a potential model for further applied research into marine resilience in high-CO_2 environments.

Oxidative stress responses in freshwater mussels: a window into spring watercourse health

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Freshwater ecosystems are increasingly impacted by chemical stressors, with microplastic (MP) pollution emerging as a significant threat to aquatic life. Bivalves, such as mussels, are widely used in biomonitoring programs to assess ecological pressure from MPs. This study investigates the impact of MP accumulation on oxidative stress biomarkers in freshwater mussels (*Unio elongatulus*) from Sacchetti Ditch, a lowland spring watercourse in Northwestern Italy. Over one-year period, levels of several oxidative stress biomarkers were measured, including superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), glutathione reductase (GR), glutathione S-transferase (GST), glyoxalases I (GI) and glyoxalase II (GII), lactate dehydrogenase (LDH), and metallothioneins (MTs) in both the gills and digestive gland of mussels, which were sampled every two months. These biomarkers were correlated with MP bioaccumulation in the same mussels. MPs were detected in all sampled mussels, with filament sizes ranging from 110-155 µm being the most common, and white, black, blue, and red being the predominant colors. Polypropylene, polyethylene, polyethylene terephthalate, and polyamide were the dominant polymers MP concentrations remained low but stable throughout the year, with slightly higher levels observed during warmer months. The study revealed that GII and LDH in the digestive gland, as well as GST in the gills, were most affected by the MP load, indicating oxidative stress. Correlations revealed a negative relationship between MP levels and GST in the gills and LDH in the digestive gland, while a positive correlation was found with GII in the latter tissue. The response of other biomarkers, such as SOD, CAT, GPx, GR, GI, and MTs, suggests that additional environmental contaminants or ecological changes may also play a role. These findings underscore the ongoing ecological pressure on mussels in lowland spring watercourses, particularly those impacted by human activities like Sacchetti Ditch.

Glitters: ecotoxicity of sparkling microplastics on aquatic invertebrates

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Microplastics (MPs) are emerging contaminants characterized by high hydrophobicity and specific surface area, which facilitate the adsorption of pollutants. Among MPs, glitter is commonly found in cosmetics, handicrafts, and special coatings. Glitters come in various shapes and sizes and are primarily composed of polyethylene terephthalate (PET) or polyvinyl chloride (PVC). They typically have a metal coating (e.g., Al, Ti, Fe, or Bi) which is responsible for their high reflectivity; these metals can be released during the degradation process. In the present study, a market survey and a questionnaire were conducted targeting both young and mature populations to analyze glitter usage habits and the level of awareness regarding its environmental effects. The survey identifies the most common types of glitter available on the market and those most likely to be released into the environment. Among the various commercial glitters, a type made of PET, hexagonal in shape and silver in color, was selected and characterized using a stereomicroscope and a microscope based on the Fourier-transform infrared spectroscopy (μFTIR). To assess the environmental impact of the selected glitter, ecotoxicity experiments were conducted using the model species *Procambarus clarkii* from Lake Trasimeno. After acclimating in lake water for 30 days, the crayfish were exposed to different concentrations of glitter over four weeks. The study investigates the accumulation of glitter in the gastrointestinal tract of crayfish and examines the dynamics of metal release from glitter into the experimental waters. Glitter particles ranging from 0 to 4800 items per gastrointestinal tract were observed. Untreated and preconditioned glitter samples showed different elemental (metals and metalloids) concentrations, indicating that conditioning can alter the chemical profile through leaching or enrichment processes. The findings contribute to a better understanding of the potential toxicological effects of these MPs on exposed aquatic organisms.

Diet Composition of Salmonids from two Alpine Lakes: Preliminary Insights from Stomach Content Analysis

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Alpine lakes are ecologically sensitive and relatively pristine ecosystems where fish introductions or changes in predator populations can have significant cascading effects on native biota. In this study, we investigate the diet composition of salmonids in three glacial lakes of the Friuli Venezia Giulia region in northeastern Italy: Fusine Inferiore (928 m a.s.l.), Fusine Superiore (929 m a.s.l.), and Raibl (959 m a.s.l., also known as Lago del Predil). These oligotrophic lakes, of glacial origin and located near the border with Slovenia, host populations of alpine char *Salvelinus umbla*. Its status in the region remains uncertain, whether native or introduced, making it crucial to assess its ecological role and potential impact on lake food webs. We analyzed stomach contents from multiple individuals across different size classes to explore possible ontogenetic dietary shifts and spatial variation in feeding behavior. Prey items were identified to the lowest feasible taxonomic level, including both aquatic and terrestrial invertebrates. Preliminary results and multivariate analysis reveal marked differences in diet composition among lakes, likely influenced by variation in habitat structure and local prey availability. Chironomid larvae, trichopterans, and other benthic macroinvertebrates dominated the diet, with some variation linked to fish size. These early findings highlight the trophic plasticity of *S. umbla* and the importance of understanding its feeding ecology for assessing the potential effects on native macrobenthic communities and terrestrial insects. Continued investigation will support conservation and management strategies in these fragile alpine systems.

Plastic entrapment by riparian vegetation across ecological gradients in European rivers: first insights from the Biodiversa+ RIPARIANET Project

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Plastic litter accumulating in riverine riparian habitats is a threat of global concern. Macrolitter items, being highly visible (items > 0.5 cm) and impactful pollutants, pose significant threats to biodiversity and ecosystem functioning. Although research recently started to address plastic entrapment, large-scale studies and predictive models aiming at reducing biases and uncertainties in understanding plastic accumulation are still scarce. Given those gaps, this study investigates plastic entrapment by riparian vegetation at different ecological scales and gradients across European rivers. We focused on six river basins across Europe, covering the boreal (Sweden), continental (Germany), alpine (Trento, Italy), Mediterranean (Rome, Italy), and Atlantic (Northern Spain, Northern Portugal) climatic regions as part of the European project Biodiversa+ RIPARIANET. By surveying six European basins, we aim to unveil riverine macrolitter accumulation in riparian areas across biogeographic regions. We found that riparian vegetation acts as a sink for macrolitter, with the highest trapping value recorded in the Tiber River catchment (Italy) and the lowest in the Sävar River basin (Sweden). Among river basins, we highlighted a latitudinal gradient for plastic entrapment by vegetation, which increased from North to South. Among macrolitter items, we found that plastics was the most abundant litter type, followed by textile items. Additionally, we observed most macroplastics near the downstream zone of rivers rather than the upperstream zone. Urbanization, land use, river discharge, river sinuosity, and vegetation structure are crucial predictors of macroplastic accumulation. Our findings shed light on how macroplastics accumulate in European riparian zones, emphasizing their ecological and societal implications and potentially supporting environmental managers in addressing macrolitter removal from the environment. Monitoring macroplastic accumulation is essential to understand the interactions between pollutants and ecosystems, enabling the development of effective conservation strategies. Given the potential impacts on biodiversity and ecosystem resilience, specific monitoring and clean-up activities should be prioritized to protect riparian ecosystems under future conditions.

Physiological and Growth Responses of *Helianthus annuus* to Heat and Water Stress: Can Nature-based Solutions Help?

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This study investigates how abiotic stresses—specifically heat and water stress—affect dwarf sunflower (*Helianthus annuus*) physiology, growth, and productivity. Key physiological parameters assessed include photosynthetic activity, stomatal conductance, and chlorophyll fluorescence. The study also evaluates whether two Nature-based Solutions (NbS), pollination services and enhanced soil fertility via clover intercropping, can mitigate the effects of these stresses. The experiment was conducted in a controlled greenhouse using 64 plants distributed across eight plots. Temperature stress was applied using heating sleeves (up to 40 °C) and plastic tents to simulate warming, while water stress was imposed by maintaining soil moisture at 40% of water-holding capacity. The factorial design combined two abiotic stress factors (temperature, water) with two NbS interventions, resulting in 16 treatment combinations (n=4 plants per treatment). Clover was intercropped 25 days post-planting to enhance soil fertility, and manual cross-pollination was performed during flowering. Preliminary results show that the warming treatment alone led to a greater than 30% increase in plant height compared to the controls, while water stress and combined stress resulted in a 30–40% reduction in growth. Elevated temperature led to increased stomatal conductance, indicating greater stomatal opening, but this response was observed only when water was sufficiently available. These results highlight distinct physiological responses to abiotic stress, with evidence of potential thermal acclimation. Ongoing analysis will determine the extent to which NbS buffer against stress impacts, offering insights for sustainable crop management under climate change.

An island under siege: origin, fate and impacts of non-indigenous aquatic fauna in coastal wetlands of a large Mediterranean island (Sardinia, Tyrrhenian Sea)

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Coastal wetlands are hotspots for biological invasions, yet comprehensive assessments of non-indigenous species (NIS) across Mediterranean islands remain scarce. Here, we present the first systematic list and analysis of aquatic NIS in 31 coastal wetlands across Sardinia, Italy. We identified 34 aquatic NIS spanning multiple taxonomic groups, with Mollusca, Chordata, and Annelida accounting for 82% of the total records. We reveal a sharp rise in introductions since the 1970s, with most species introduced via aquaculture, shipping, or recreational pathways. Reported NIS are mostly of Indo-Pacific and North Atlantic origin, with estuaries and hydraulically interconnected wetlands hosting the greatest NIS diversity. The most frequent impact mechanisms of NIS include chemical, physical, or structural alteration of ecosystems (35%), followed by predation (26%) and competition (12%). Impacts severity varies a lot from major to minor, though several species lacked sufficient impact data. Spatial analyses revealed that Santa Gilla Lagoon and the Flumendosa River wetlands harbored the highest NIS richness. The blue crab *Callinectes sapidus*, the fish *Gambusia holbrooki*, and the polychaetae *Ficopomatus enigmaticus* were the most widespread, reflecting their high ecological adaptability. Using a novel Invasiveness Risk Score (IRS), integrating species mobility and establishment success, we ranked wetlands by their cumulative invasion risk. Santa Gilla and the Flumendosa river wetlands emerged as the highest-risk sites. While this study provides a baseline for invasion risk assessment, limitations include its regional scope, potential underreporting due to uneven research effort, and data gaps regarding species-specific ecological impacts. This work has been developed within the framework of the project e.INS www.einsardinia.eu (Next Generation EU- PNRR - M4 C2 I1.5 CUP F53C22000430001.

Coastal pollution in the northwestern Adriatic coasts: exploring the accumulation and impacts of beach litter

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The accumulation of macro litter along coastal beaches and dune systems poses a growing ecological threat. It harms biodiversity, endangers human health, and causes significant economic losses. In the Mediterranean basin, the increasing amount of waste washing ashore has become a major challenge, with waste management emerging as a critical environmental issue. This study analyses the accumulation patterns of coastal litter in the northwestern Adriatic and investigates its sources and composition to support targeted waste management actions. Litter was sampled at two Sites of Community Importance (SCI's): SCI-IT5310006 "Fiorenzuola di Focara" and SCI-IT5310007 "Litorale Baia del Re" as well as at an unprotected beach, "Spiaggia Libera Sottomonte". Using the standardized OSPAR protocol, data on litter abundance and composition were collected across 112 plots (2×2 m) distributed among the three sampling sites per season. Vegetation cover was also recorded to explore potential interactions between litter presence and dune plant communities. Preliminary results, based on Generalized Linear Models (GLMs), revealed significantly higher litter abundance within SCI sites, probably due to limited mechanical cleaning activities to avoid disturbing sensitive habitats such as protected dunes, compared to unprotected beaches where waste is regularly removed to allow activities for recreational purposes. Of the total debris recorded, 62.87% was plastic and 33.81% polystyrene, with approximately 40% likely associated with fishing activities originating from polystyrene boxes and plastic fishing nets. The high percentage of this type of litter is linked to its buoyancy and wind-driven transport over long distances. A strong positive correlation was found between plastic debris and proximity to urban areas ($z = 26.85$, $p < 0.001$), with fishing-related debris also significantly associated ($z = 16.34$, $p < 0.05$). This widespread pollution is driven by excessive plastic production and stronger enforcement and wider implementation of regulations to protect Mediterranean coastal ecosystems are required.

Trawling disturbance in soft-sediment ecosystems: tracing carbon sequestration

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Sandy and muddy seabed ecosystems are key components of marine carbon cycling, contributing to climate regulation through carbon storage and nutrient flux modulation. However, anthropogenic activities such as bottom trawling disturb sediments, potentially resuspending and oxidizing buried carbon, and compromising long-term carbon sequestration capacity. This project investigates the impact of bottom trawling on carbon stocks in soft-sediment ecosystems, focusing on sedimentary and biogeochemical alterations and the responses of benthic communities, particularly Marine Animal Forests (MAFs)—complex habitats formed by habitat-forming suspension feeders. Their structural complexity makes them both key components in carbon sequestration processes and especially vulnerable to physical disturbance from trawling, making their inclusion critical to understanding ecosystem-scale impacts. Sediment and water samples will be collected before and after experimental trawling in three Sicilian coastal areas with different fishing pressures: the Gulf of Castellammare, the Gulf of Catania, and the area of Capo Passero. Analyses on sediments and water samples will assess carbon fluxes following trawling, quantify resuspended carbon, and investigate its fate. Controlled laboratory experiments will simulate sediment resuspension to evaluate impacts on the physiology, feeding efficiency, and health of key MAF species. By coupling ecosystem-level fluxes with organism-level mechanisms, the project will: (i) estimate recovery half-times and carbon-return-on-closure metrics; (ii) identify threshold trawling intensities beyond which MAF-mediated sequestration collapses; (iii) mint a 'carbon coin', quantifying the tons of carbon fixed or lost and translating them into present-day market value to expose the hidden economic cost of trawl-induced leakage and (iv) generate actionable benchmarks for climate-smart fisheries management. This framework finally connects seabed disturbance, biological engineering and carbon-climate-economy feedback into a single, policy-ready toolbox for one of the planet's most intensively trawled seas.

Airborne plastic invasion: what lichens tell us about our polluted skies

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Atmospheric deposition, including airborne microplastics (MPs), poses a growing threat to both natural and urban ecosystems, potentially disrupting ecological balance. Among the organisms affected, lichens are particularly vulnerable, yet their capacity to serve as bioindicators of environmental pollution remains underexplored. This study investigates the bioaccumulation of airborne microplastics in epiphytic lichens across a gradient of anthropogenic pressure. Lichens from the genera *Cladonia* and *Xanthoria* were collected at three sites in central Italy: a natural area in Altipiani di Arcinazzo, a protected site within the Castelporziano Presidential Estate, and an urban area in the center of Rome. In total, 90 samples were analyzed to assess both external and internal microplastic entrapment. Samples were digested using hydrogen peroxide and screened for MPs. Recovery rates were calculated to validate the method. A total of 253 microplastic particles were identified, with 97% being fibers and 3% fragments. A clear gradient in microplastic accumulation was observed, increasing from the natural site (n = 58) to the urban site (n = 116). Fiber length was positively correlated with abundance, and the longest fibers were found in the urban site. Additionally, this study reports the first evidence of airborne mesoplastics entrapped in lichens. No significant differences in microplastic retention were found between the two lichen genera. Our findings demonstrate that epiphytic lichens are effective passive biomonitors of airborne microplastic deposition. Their ability to trap both micro- and mesoplastics highlights their potential role in monitoring and possibly mitigating microplastic pollution, especially in sensitive or protected environments. Given their widespread distribution and sensitivity to atmospheric pollutants, lichens offer a valuable tool for environmental surveillance. Their use is strongly encouraged, especially in light of the emerging risks that airborne microplastics pose to both ecosystems and human health.

Coppicing disturbance and belowground biodiversity: evidence of long-term microbial community stability.

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Forest ecosystems are increasingly exposed to anthropogenic pressures, with forest management practices, such as coppicing, acting as controlled disturbances that can affect soil microbial communities and alter soil processes. Soil microorganisms are sensitive indicators of ecosystem health, and understanding how they respond to management practices helps to ensure the stability of forest ecosystems. This study investigates the long-term effects (15–20 years post-intervention) of coppicing on the soil microbial community in two forest systems, beech and turkey oak, in the Matese National Park (Southern Apennines, Italy). Functional diversity of microbial community was assessed through enzymatic activity and Biolog® EcoPlates, while structural diversity was evaluated through 16S rRNA and 18S rRNA gene sequencing. Several resilience indices were applied to compare microbial profiles between coppiced and high forest systems. The co-occurrence interactions between soil microbial taxa were also reconstructed by Microbial network analysis. For both functional and structural data, Sousa and Kaufman indices showed a mean value > 1 in both beech and turkey oak systems, highlighting a high resilience of the microbial community to coppice disturbance. Moreover, the separation of coppice and high forest clusters obtained through hierarchical cluster analysis, based on a visual inspection of the dendrograms related to enzymatic activities and DNA data, was not statistically significant for both systems. This indicates that the structural and functional profiles in control and disturbed soils were largely comparable. This study demonstrates that coppicing, with the frequency of cutting applied in these forests, does not compromise the stability of soil microbial communities. The findings highlight the potential compatibility of traditional forest management practices with the conservation of belowground biodiversity and ecosystem functioning, offering valuable insights for the development of sustainable forest management interventations.

Harnessing Plant Growth-Promoting Bacteria as Nature-Based Solutions to mitigate anthropogenic disturbances and boost plant productivity in urban farming

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Anthropogenic disturbances, such as urbanization and soil degradation, significantly alter the structure and function of ecological systems, particularly in Mediterranean regions. Technosols, urban soils derived from organic and mineral waste, are increasingly used for urban greening, yet their limited nutrient availability constrains plant productivity. This study examines how Plant Growth-Promoting Bacteria (PGPB) can mitigate the negative effects of environmental disturbances on lettuce growth in both sterilized and non-sterilized Technosols. By comparing sterile and non-sterile conditions, we assessed the impact of three bacterial administration treatments: a Technosol-derived consortium (P3), a halotolerant species *Bacillus amyloliquefaciens* (R18), and their combination (P4). In the absence of native microbiota – sterilized Technosol - P3 significantly improved of 25% leaf development, of 23% water status, and of 3% photosynthetic efficiency, compared to R18, indicating a strong plant-microbe-soil synergy. However, under non-sterile conditions, competition with indigenous microorganisms reduced the beneficial effects of resulting in increased oxidative stress in plants. Notably, P3 maintained higher specific leaf area with minimal root infection, while R18 delayed leaf senescence and improved physiological resilience. These results highlight the importance of understanding soil microbial dynamics when developing sustainable Nature-Based Solutions to counteract anthropogenic disturbances. Our findings highlight the potential of tailored microbial consortia to restore ecological functions in disturbed urban soils, contributing to more resilient urban farming systems. Ermenegilda Vitale and Christian Lorenz contributed equally to the research

Ecosistemi e cambiamento climatico

3

Effects of simulated marine heat waves on sediment biogeochemistry of a Baltic coastal lagoon

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Coastal lagoons can be considered ”sentinel systems” for detecting climate change impacts. Indeed, extreme events like marine heat waves (MHWs) can severely impact coastal lagoons at all levels of the ecological organization. In coastal lagoons the benthic compartment plays a crucial role in ecosystem functioning and is a good indicator of ongoing changes. Despite this, MHWs effects on sediment biogeochemistry of coastal lagoons are poorly known. We investigated the effects of MHWs of different magnitudes (+2°C and +6°C) on benthic processes of a brackish, semi-enclosed coastal lagoon facing the Baltic Sea. Intact cores of either sandy or muddy sediment from the Curonian lagoon (Lithuania) were exposed to 5-day lasting heatwaves in benthocosms. During the experiment, we measured gas and nutrient fluxes through incubation techniques. At the end of the MHWs, the top 2 cm of each core was analysed to determine the biochemical composition and the degradation rates of sedimentary organic matter (OM). Our results show that both MHWs altered the benthic processes and the OM nutritional quality in both sandy and muddy sediments. In sandy sediments MHWs increased oxygen flux to the sediment and ammonium release, indicating enhanced oxidative processes and metabolic demand. There, the sedimentary protein contents increased by 32-33% after both events. On the other hand, in muddy sediments carbohydrate (CHO) contents decreased by ca. 43%, with a 57% reduction in CHO turnover time during the severe MHWs, suggesting an accelerated degradation of organic matter. Our results pinpoint that MHWs could concur to cause a possible “oligotrophication” of the lagoon sediments, ultimately disrupting the lagoon functioning. This study was conducted attending PhD program in Life, Environmental and Drug Sciences (UniCa, Cycle XXXVIII), funded by DM 352/2022 (Next Generation EU-PNRR) and IMC Foundation).

Experimental assessment of warming effects on vermetid reef metabolism along a complexity gradient.

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Coastal marine ecosystems and the services they provide are increasingly threatened by climate change. The Mediterranean basin, recognized as a climate change hotspot, is experiencing a rise in the frequency and intensity of heat extremes. Among coastal ecosystems, intertidal communities are particularly exposed to temperature fluctuations. Although they are adapted to such variability through physiological plasticity, the intensification of extreme thermal stress may negatively affect their metabolism and adaptative capacity. A key intertidal habitat in the Mediterranean Sea is the vermetid reef, a bioconstruction formed by the coralline red alga *Neogoniolithon brassica-florida* and the gastropod *Dendropoma cristatum*. These bioconstructions provide essential ecosystem services, including coastal protection and biodiversity support, but are endangered throughout the basin, have already collapse in the western Mediterranean, and remain among the most poorly studied marine habitats.
This study investigates the metabolic response of the vermetid reef habitat to thermal stress, considering varying levels of community complexity: vermetid reefs naturally covered by brown macroalgae, reefs naturally free of macroalgae and reefs where macroalgae were experimentally removed. Oxygen fluxes were measured as a proxy for community metabolism, using ad-hoc developed intertidal benthic chambers. The experiment was carried out on reefs located in northern Sicily and repeated different times throughout 2025, to obtain measurements before, during, and after the warmest period of the year for this area. We hypothesized that warming affects the metabolism of the vermetid reef, but that this effect is buffered by the associated biodiversity, particularly the presence of canopy-forming brown algae. This experiment defines a non-destructive method to measure the metabolism of intertidal communities directly in the field, addressing the lack of field-based marine climate change studies, especially on vermetid reefs. Understanding how different levels of structural complexity mediated the response to thermal stress is crucial for developing conservation strategies targeting this endangered ecosystem.

Effects of an Experimental Heatwave on Phytoplankton Morpho-Functional Traits from Diverse Vulnerable Mediterranean Ecosystems

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Global warming is changing aquatic ecosystem structure and functioning. Climate models predict a marked rise in the frequency, duration, and intensity of heatwaves, globally and particularly in the Mediterranean region. The question of what the impact of extreme rises in water temperature for an extended period on phytoplankton community will be is still open. Phytoplankton are photosynthetic aquatic microorganisms, playing a fundamental role in biogeochemical cycles and aquatic food webs. The cell is the basic biological unit of phytoplankton, and its morphological features, particularly cell geometric shape, volume, and surface to volume ratio (S/V) strongly influence physiological processes and adaptive capacity. These morpho-functional traits determine the ability to acquire light and nutrients, sinking rate, and resistance to grazing. In this proposal, we focus on morpho-functional traits of organisms incubated in a laboratory experiment simulating a summer heatwave, conducted in July 2024. The experiment involved two natural plankton communities, collected from an artificial lake (Bidighinzu Lake) and a coastal lagoon (Cabras Lagoon) in Sardinia (Western Mediterranean), including multiple trophic levels (from picoplankton to mesoplankton). Each community was incubated separately for 15 days and exposed at two cross treatments in triplicates: increased temperature (+ 5 °C) compared to the control at environmental temperature and the presence/absence of mesozooplankton. With the aim to understand which phytoplankton morpho-functional trait of each community persist and dominate during the heatwave, in this study we grouped phytoplankton according to several morphological traits: cell geometric shape, cell volume, cell area, cell S/V, colony, presence of flagella. We expect the affirmation of specific and different morpho-functional traits throughout each laboratory manipulation. This trait-based morphological approach can provide a valuable framework to know the effects of heatwaves on two different phytoplankton communities and therefore on the functioning of two diverse Mediterranean vulnerable aquatic ecosystems.

The overlooked dimension: horizontal heterogeneity of water quality and GHG concentrations in diverse lake ecosystems

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Lakes play a significant role in greenhouse gas (GHG) emissions, acting as either sources or sinks for climate-relevant gases and serving as important regulators of global carbon cycling. However, the combined pressures of global climate change and local anthropogenic stressors are driving rapid changes in these ecosystems, creating complex challenges that cascade through food webs and lake functioning, and ultimately influencing their capacity to emit or absorb GHGs. However, most estimates of lake GHG concentrations rely on a limited number of sampling points, often neglecting spatial heterogeneity. Variability across nearshore and offshore zones, as well as between inflows and outflows, remains especially underexplored. This lack of spatial resolution constrains our understanding of lake processes and their contributions to regional and global biogeochemical cycles. To address this gap, we investigated fine-scale spatial variability in surface water concentrations of methane (CH4) and carbon dioxide (CO2), along with key water-quality parameters, across three morphologically and trophically distinct lakes in Northern Italy (Maggiore, Iseo, and Alserio). We used the F*ast Limnological Automated Measurements* (FLAMe) system for high-frequency, spatially explicit, real-time data collection. To complement these surface measurements, we also collected vertical water-column profiles and compared them with data from long-term monitoring programs. Preliminary results revealed pronounced spatial heterogeneity in water quality and GHG concentrations. Clear gradients emerged between littoral and pelagic zones, with inflowing rivers strongly shaping water chemistry and gas dynamics. Littoral areas, often underrepresented in traditional lake studies, emerged as hotspots of both variability and GHG production, underscoring their ecological and biogeochemical importance. Furthermore, our findings highlight the need to pay greater attention to small, shallow lakes: despite their modest surface area, their abundance and active metabolism make them significant contributors to global carbon cycling.

Effects of an experimental heatwave on a plankton community from a Mediterranean artificial lake

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Global warming is profoundly altering aquatic ecosystems, with climate models predicting a significant increase in the frequency, duration, and intensity of heatwaves. These prolonged periods of unusually high temperatures are becoming more common globally, and especially in the Mediterranean, recognized as one of the most vulnerable areas. Artificial lakes, crucial for essential ecosystem services, are particularly sensitive to these changes. This scientific proposal investigates the impact of a simulated summer heatwave on a natural plankton community collected from Bidighinzu Lake, an artificial lake located in Sardinia (Western Mediterranean). In July 2024, we incubated a multi-trophic level plankton community (including picoplankton, nanoplankton, microplankton and mesoplankton) in laboratory for 15 days, applying two combined treatments in triplicates: a + 5°C water temperature increase and the presence/absence of mesozooplankton as apical predator. Temperature, dissolved oxygen, conductivity and pH were monitored daily, while water samples for analyses of algal nutrients, chlorophyll a, and the different biological planktonic components were collected every 3-4 days. Preliminary results suggest significant taxonomical shifts in several planktonic trophic levels under warming, changing the predator-prey relationships in the community. In addition, the affirmation of potentially harmful cyanobacteria throughout the laboratory manipulation deserves particular attention in relation to the Bidighinzu Lake's use for producing potable water, such as a lot of other Mediterranean artificial lakes. This study provides new scientific insights on the heatwave effects on Mediterranean planktonic communities considering the entire planktonic trophic web, that are still very limited for freshwater environments.

Resilience of intertidal habitats under multiple stressors: insights from a global meta-analysis

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Intertidal ecosystems are among the most dynamic and ecologically significant environments on the planet, providing essential services and serving as sentinel systems for detecting environmental change. Despite that, their resilience to the increasing biotic and abiotic stressors remains poorly explored. The cumulative and interactive effects of multiple pressures, such as pollution, resource exploitation, habitat modification, and climate change, on community-level responses require urgent synthesis, as previous research has frequently concentrated on individual stressors. This study proposes a global meta-analysis, based on a comprehensive review and statistical synthesis of peer reviewed research from diverse geographical regions, to identify, quantify, and compare the primary drivers shaping intertidal community resilience and to assess the relative importance of these stressors in determining its three components - resistance to change, recovery capacity, and reorganization potential. A review of ~90 case studies on intertidal ecosystems shows that 20–25 (25–30%) explicitly address resilience, often in relation to multiple stressors, marine heatwaves, and anthropogenic disturbances. Extreme heat and marine heatwaves are the most cited stressors (47 studies), followed by cumulative stressors (15), physical disturbances for example storms and low-tide exposure (15+), ocean acidification (11), and anthropogenic impacts such as trampling (8).The results will fill a critical knowledge gap by advancing our understanding of how multiple drivers interactively affect intertidal community stability and recovery potential. Ultimately, this synthesis will support evidence-based recommendations for coastal ecosystem management and conservation by identifying which stressors most strongly compromise resilience and highlighting where mitigation and intervention efforts could be most effective. This research will contribute to the development of more adaptive and integrated strategies to protect intertidal biodiversity and ecosystems in the context of global change.

Seasonal changes in sedimentary organic matter quantity, composition and degradation rates in the below-ground compartment of a seagrass meadow

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Sea warming caused by climate change poses severe threats to Mediterranean marine ecosystems. Here, meadows of the seagrass *Posidonia oceanica* are among most threatened habitats. While the effects of sea warming on *P. oceanica* leaves chemistry are increasingly made clear, the warming effects on the below-ground sedimentary compartment of seagrass meadows remain poorly assessed, also due to poorly known patterns of seasonal variations. To provide insights on the seasonal fluctuations in quantity, biochemical composition and degradation of organic matter (OM) in the below-ground compartment of two *P. oceanica* meadows in the surroundings of the Ischia Island, we collected sediment samples in summer and autumn at Lacco Ameno (LA) and Castello (CA). Samples were analyzed to quantify protein, carbohydrate, lipid, and phytopigment contents, and to evaluate OM ageing (protein-to-carbohydrate ratio), nutritional quality (algal fraction of biopolymeric C), extracellular enzymatic activities, C degradation rates and turnover times. At both stations, below-ground OM contents, but carbohydrates, were lower in autumn than in summer. Phytopigment contents did not show any change, while the algal fraction of biopolymeric C and the protein-to-carbohydrate ratio resulted higher in LA in autumn, suggesting a fresher and more labile nature of organic loads. OM biochemical composition differed significantly between the two seasons in both stations, with seasonal differences mostly explained by lower lipid contents in autumn. Extracellular enzymatic activities and C degradation rates were significantly higher in LA in both seasons, and varied seasonally only in CA, where values were significantly higher in autumn. Though limited to two seasons only, our results suggest that temperature seasonal variations in the seagrass below-ground, as well as local variations, can largely influence OM quantity, nutritional quality, biochemical composition and C degradation rates. This study is part of the project BORIS (P2022R739J; CUP F53D23008230001) funded by the PRIN PNRR 2022 program.

Climate vulnerability assessment of coastal lagoons food provisioning ecosystem service.

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Coastal lagoons provide many ecosystem goods and societal benefits to humanity, but their ability to pursue the provision of ecosystem services (ESs) under changing climate is under threat. Among these services, food provisioning from small-scale fisheries and aquaculture is essential for the subsistence and economy of local communities. While several frameworks have guided research for assessment of climate vulnerability (CV) of fish species, ecosystems, and human communities across multiple scales, significant challenges remain. We assessed the CV of food provisioning ES in fifteen Sardinian coastal lagoons, considering either species (SV) or habitat vulnerability (HV). HV was assessed considering Biological Quality Elements, the presence/impact of invasive alien species, and the lagoon susceptibility to warm temperatures (using a water exchange capacity index). The SV metric was based on the unweighted means of species-specific biological traits (0.33; lifespan, habitat specificity, temperature specificity) and site-specific indicators (0.67; Thermal Safety Margin-TSM and stock status via CMSY++). The total SV was obtained as the sum of each SV weighted by its relative importance in the ESs biophysical flow. The CV of food provisioning ESs was obtained as the unweighted mean of SVs and HVs. The Nora and Tortolì lagoons showed the highest TSM scores, suggesting they may represent potential thermal stress hotspots. Stock assessment results revealed considerable spatial variability in stock conditions across sites and species. The highest HV score occurred in S'Ena Arrubia (0.92), and Cabras (0.71), while San Giovanni (0.25) and Avalè su Petrosu (0.27) lagoons showed lower scores, suggesting they hold relatively healthier environmental conditions. The CV of the food provisioning ESs across Sardinian lagoons ranged from moderate-low (0.33) up to moderate-high (0.64). We anticipate that integrating our findings with social vulnerability and climate hazard/exposure data will support the formulation of targeted management priorities.

Multidisciplinary approach to forecast carbon sink capacity by small freshwater ponds

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Wetlands are among the world's most productive ecosystems, providing crucial services including carbon sequestration, and greenhouse gases (GHG) mitigation. However, human pressures and warming increasingly threaten these ecosystems. Particularly, reduced water levels due to rising temperatures can lead to the emergence of organic matter stored in sediments, increasing decomposition and GHG emissions. Understanding wetland responses to environmental changes is important for effective management and conservation. This study investigated the effects of pond morphometry (area, depth, water volume), organic and inorganic nutrient inputs, and seasons on GHG fluxes (CH_4, CO_2, N_2O). Using hydrographic drones, gas-flow measurements, and C and N isotopic analysis, we assessed nutrient sources and GHG emissions in small freshwater wetlands within the Castelporziano Presidential Estate (Central Italy). We hypothesized that reduced morphometry increases GHG emissions, especially under high nutrient loading, due to rapid water warming and lower aquatic vegetation biomass. Ponds near cultivated fields were larger and showed elevated $\delta^{13}C$ and $\delta^{15}N$, likely due to animal waste inputs, and elevated CH_4 emissions. Conversely, forest-surrounded ponds, being smaller and shallower, warmed faster and showed higher CO_2 fluxes. Overall, moist soil surrounding each pond emerged as hotspots for CH_4 and N_2O emissions, particularly during summer with high temperatures and low rainfall. CH_4 and CO_2 emissions increased with seasonal water temperature, peaking in July, while N_2O emissions were more substrate-specific and lacked consistent seasonal trends. Larger ponds had proportionally lower sediment volumes and displayed lower CO_2 emissions, suggesting their potential as carbon sinks. These findings highlight the importance of pond morphometry, land-use context, and seasonal dynamics in regulating wetland GHG fluxes. The progressive ponds' drying due to global warming could increase GHG-emission, triggering a vicious cycle exacerbating climate change. This highlights the urgent need for management and conservation strategies to protect these ecosystems and their services in an ever-changing climate.

Denitrification and N_2O emissions in constructed wetland systems

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This research aims to evaluate the role of three common wetlands macrophytes, *Phragmites australis*, *Typha latifolia*, and *Glyceria maxima*, in nitrogen removal processes, with a focus on the conditions affecting the emissions of nitrous oxide (N_2O), a potent greenhouse gas. Nutrient and gas fluxes were measured using mesocosms containing the three plant species, along with a control bare sediment, following validated experimental protocols for the analysis of benthic biogeochemical dynamics. The mesocosms were placed in tanks filled with water collected from the field site and maintained under controlled laboratory conditions. Experiments were conducted in summer (biomass peak), autumn (senescence phase) and spring (growth phase), across a NO_3^- gradient (50, 100, 200, 300, 500, and 800 µM). During each incubation, key physicochemical parameters (water temperature, conductivity, pH, and dissolved oxygen concentration) were measured. Water samples were collected at three time points (initial, intermediate, final) for the analysis of dissolved nitrogen nutrients and gasses. Benthic fluxes were calculated for each experimental condition. Vegetated sediments were found to be more efficient at converting NO_3^- to N_2 via denitrification than bare sediments. However, the effect of NO_3^- pulsing on denitrification stimulation differed significantly between plant types. It can be hypothesized that *Phragmites australis* played a more beneficial role due to its greater submerged surface area for biofilm colonization, which facilitated enhanced opportunities for contact between denitrifying bacteria and water column NO_3^-. N_2O analyses are underway and could inform the widespread application of phytoremediation by identifying environmental conditions that maximise N removal while minimising the risk of greenhouse gas emissions.

High-Frequency Growth and Carbon Monitoring in Olea europaea Using IoT-Based TTCarbon Sensors

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Climate change is significantly altering the structure and function of agroecosystems, including woody perennial crops such as Olea europaea (olive trees), which are increasingly recognized for their role in carbon sequestration and ecosystem resilience across Mediterranean landscapes. Following the recent inclusion of woody crops in the EU Carbon Removals Certification Framework (Regulation EU 2024/3012), this study presents a pilot case using TTCarbon IoT-based dendrometers to continuously monitor stem radial growth in olive orchards. By integrating high-frequency dendrometer data with species-specific allometric equations, we dynamically estimate aboveground biomass and carbon stocks, enabling continuous Monitoring, Reporting, and Verification (MRV) in accordance with the EU's QU.A.L.ITY standards. This real-time monitoring captures diurnal and seasonal physiological responses to climate variability—capabilities that traditional field inventories and remote sensing methods lack. These data provide key insights into vulnerability and resilience hotspots within agricultural ecosystems and allow for more adaptive and evidence-based management interventions. The TTCarbon system represents a technological and methodological advancement for climate-smart agriculture. It enables the tracking of climate impacts on tree growth in near real time and supports both adaptation and mitigation strategies through accurate carbon accounting. As agriculture moves toward greater transparency and sustainability under evolving EU climate policies, sensor-based monitoring offers a scalable and actionable tool to enhance the resilience of agroecosystems and contribute meaningfully to sustainable development goals.

L’ecotossicologia tra regolamentazione e nuove sfide per la sostenibilità ambientale

4

Ecotoxicological Assessment of PVA on *Danio rerio* Embryos: a Comparative Study Between PVA Standard Powder and Commercial PVA-based Powder Dishwasher Pods

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Water-soluble polymers (WSPs) represent a significant category of synthetic polymers widely applied across several industrial, medical, and consumer products. Despite their extensive production and usage, WSPs escape current regulations as either plastics or chemical contaminants, resulting in a lack of production estimation, monitoring, and circular economy action plans. Consequently, WSPs are freely released into aquatic ecosystems, raising concerns about potential hazards to organisms and human health. This study aims to evaluate the potential effects of one of the most abundant WSPs, polyvinyl alcohol (PVA), comparing the standard powder, and commercial PVA-based powder dishwasher pods, on *Danio rerio* embryos exposed for 120 hpf (hours post-fertilization) to the estimated concentration (0.1 mg/L) for the civil wastewater of Milan-Nosedo. Firstly, the potential presence of additives was evaluated using ^{1}H-NMR spectroscopy. Then, the effects across molecular, cellular, physiological, and organism levels were evaluated through a multi-tier approach. Specifically, we assessed proteomics and metabolomics analyses, genotoxicity (micronuclei formation, apoptosis, and necrosis), reactive oxygen species (ROS) levels, acetylcholinesterase (AChE) activity, as well as mitochondrial respiration and glycolysis. Additionally, heart rate was evaluated as a physiological endpoint, while behavioural parameters (*e.g.* distance moved, turn angle, and thigmotaxis) were used to assess swimming behaviour. ^{1}H-NMR results revealed minimal differences in the spectrum of powder pods compared to the standard PVA, indicating a low amount of additives. Our results revealed a significant increase (\textit{p

Oxidative stress related effects in nestlings of the European starling (*Sturnus vulgaris*) grown close to perfluoropolymer plant

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Per- and polyfluoroalkyl substances (PFAS) comprise a large, heterogeneous group of chemicals that raises concerns for both human and environmental health. Recently, the attention has shifted toward emerging PFAS, expected to be less persistent, bioaccumulative and toxic than long-chain relatives, but more used and discharged in environment. However, up to date, the information on the occurrence, the fate and the potential toxicity of emerging PFAS, both individually and in mixture, in natural ecosystems is very limited. Thus, there is an urgent need for the implementation of comprehensive monitoring programs to support the exposure assessment and to explore biological effects of environmentally relevant PFAS. This study, aimed at evaluating the adverse effects induced by the contamination from a perfluoropolymer plant (PFP) located in the Western sector of the Po River valley (Northwestern Italy). From 2022 to 2024, before breeding season, nest-boxes for the European starling (*Sturnus vulgaris*) were installed in the surroundings of the PFP and in a rural area (RA) serving as control. The first-laid egg was collected to measure PFAS levels, while blood samples were collected from 8-10 days old nestlings to assess oxidative stress related endpoints. In detail, the modulation of the activity of the main antioxidant (SOD, CAT and GPx) and detoxifying (GST) enzymes as well as changes in lipid peroxidation levels (LPO) and relative telomere length (RTL) were evaluated. PFAS contamination measured in eggs from PFP was significantly higher compared to RA. Accordingly, a modulation of antioxidant enzymes, followed by an overall increase in lipid peroxidation levels and RTL shortening, were observed in nestlings from the PFP compared to RA. Our results showed that the exposure to environmentally relevant mixture of PFAS can induce adverse effects on free-living organisms, suggesting the necessity of field studies to assess the risk of these emerging compounds.

Assessment of the adverse effects induced by the exposure to environmentally-relevant concentrations of a conventional and three emerging PFAS to *Daphnia magna*

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Per- and polyfluoroalkyl substances (PFAS) are a class of over 4,700 synthetic chemicals, known for their high thermal and chemical stability, as well as hydrophobic and oleophobic properties. These features have led to their widespread use in products such as non-stick coatings, firefighting foams, and waterproof textiles. However, their extensive use has caused continuous release into the environment, making them ubiquitous in all environmental compartments. Due to their proven risks, some conventional PFAS have been banned and replaced by newer compounds, which are presumed to be less harmful. Nevertheless, studies on the effects of these substances on organisms and humans remain limited. This study aimed at assessing and comparing the potential adverse effects induced by a 21-day exposure to a conventional (PFOA) and three emerging (ADV MFS-N2, ADV MFS-N3, and ADV MFS-M3) PFAS on the cladoceran *Daphnia magna*. Organisms were exposed to three environmentally-relevant concentrations (150, 1500, and 3,000 ng/L). Effects were evaluated at both sub-individual and individual levels, including energetic (total caloric content) and oxidative stress related (activity of antioxidant and detoxifying enzymes, lipid peroxidation) biomarkers, morphological traits (e.g., head, spine, carapace, valve, and total body length), swimming behavior and survival. Results showed negligible effects after PFOA exposure, limited to a reduction in total body length. In contrast, exposure to ADV MFS-N2, ADV MFS-N3 and ADV MFS-M3 induced significant negative effects across multiple endpoints. Exposure to ADV MFS-N2 and ADV MFS-N3 exerted negative effects on the considered biochemical biomarkers and morphological traits. Whereas ADV MFS-M3 modulated the swimming behaviour of the exposed organisms. These findings highlight the urgent need for further research on the environmental fate and toxicity of emerging PFAS alternatives, which may pose a risk to aquatic ecosystems.

Bioaccumulation and oxidative stress biomarkers in *Procambarus clarkii* exposed to environmentally relevant concentrations of gadolinium

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Gadolinium (Gd), a rare earth element extensively utilized in medical imaging and industrial applications, is increasingly present in aquatic ecosystems. This study investigates tissue-specific accumulation and antioxidant responses in *Procambarus clarkii* after 14-day exposure to environmentally relevant Gd concentrations (0.1, 1, 10, and 100 µg/L). Gd accumulation occurred in the gills and hepatopancreas at higher concentrations (10 and 100 µg/L), while levels in muscle remained below quantifiable limits. Antioxidant responses varied across tissues, and non-metric multidimensional scaling (NMDS) revealed no consistent pattern, indicating limited activation likely linked to low tissue burdens and brief exposure. However, superoxide dismutase (SOD) activity significantly increased in the gills and hepatopancreas at higher Gd concentrations. In contrast, glutathione peroxidase (GPx) activity showed inconsistent trends, while glutathione S-transferase (GST) activity was elevated in hepatppancreas and muscle only at 0.1 µg/L. Lipid peroxidation was most pronounced in the gills. The Integrative Biomarker Response-Threshold (IBR-T) index indicated low-dose effects consistent with hormesis, reflecting biologically relevant changes at minimal Gd concentrations. Overall, *P. clarkii* exhibited tissue-dependent Gd accumulation and oxidative responses, though biomarker activation patterns were inconsistent.

Assessment of Extracellular Protein Functionality in the Earthworm Eisenia fetida Using an Integrated Hemolytic Assay for Ecotoxicological Monitoring

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The assessment of the impact of bioaccumulable pollutants on the extracellular fraction of model organisms is crucial for understanding ecotoxicological risks. In this study, the hemolytic activity of acellular coelomic fluid from Eisenia fetida was analyzed on sheep erythrocytes as a model to monitor the functionality of extracellular proteins exposed to environmental contaminants. An integrated approach was applied, based on three distinct experimental tests: (I) a control test with unexposed coelomic fluid to establish the functional baseline, (II) a direct test involving exposure of erythrocytes to the pollutants without coelomic fluid to estimate the intrinsic toxic effect of the contaminant, and (III) a mediated test in which the coelomic fluid was pre-exposed to the pollutant before the hemolytic assay on erythrocytes, in order to evaluate changes in protein lytic activity. The control with unexposed coelomic fluid showed significant intrinsic lytic capacity supported by pore-forming protein lysenin. The direct and mediated exposure tests made it possible to explore, respectively, the toxic potential of the pollutants on erythrocytes and the vulnerability of the coelomic protein components to functional modifications. The hemolytic assay applied in these three complementary modes represents an innovative model for distinguishing inhibition, activation, or chemical–protein interaction effects, leaving open the possibility for further investigation of specific mechanisms of action. This approach emerges as a useful tool for ecotoxicological research and for environmental monitoring aimed at evaluating extracellular protein functionality.

Capitale naturale, servizi ecosistemici e contabilità ambientale

5

Environmental accounting of *Cystoseira sensu lato* macroalgal forests of the Cilento coast (Marine Protected Area of Santa Maria di Castellabate).

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Cystoseira sensu lato (*s.l.*) macroalgal forests are among the most complex and productive ecosystems along the rocky coasts of the Mediterranean Sea. They provide food and shelter to a wide range of organisms and provide essential ecosystem services, including carbon sequestration and protection from coastal erosion. However, in recent years, these habitats have declined significantly in many areas of the Mediterranean, mainly due to human impacts such as coastal urbanization and water pollution. This study is part of the European LIFE project "REEForest," which aims to restore *Cystoseira s.l.* in the Marine Protected Area (MPA) of Santa Maria di Castellabate. An environmental accounting model was applied to calculate the biophysical value of natural capital (NC) in subtidal rocky habitats, both in the donor and receiving sites involved in the restoration activities. This approach allows for quantifying the biotic stocks of NC and serves as a foundation for assessing the flows of ecosystem services and the impacts associated with their use. Results show that the NC at the donor sites of Punta Licosa is $2.95\times10^{12}\pm 2.36\times10^{11}$ sej/m^2, while at the receiving sites of Punta Pagliarola it reaches $3.38\times10^{12}\pm 4.46\times10^{11}$ sej/m^2. These differences reflect the environmental characteristics of the two areas, as well as the different protection regimes within the MPA. The environmental accounting model was implemented based on samples collected during the winter survey, but the study will be further developed with data from the spring/summer survey, the vegetative growth season of *Cystoseira s.l.* In conclusion, this study highlights the ecological importance of *Cystoseira s.l.* habitats and the value of environmental accounting as a tool for planning effective long-term protection, conservation, and restoration strategies.

An integrated framework for assessing the sustainability of management strategies for *Posidonia oceanica* banquettes along the Sicilian coastline

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In recent years, the growth of tourism has intensified the recreational use of Sicilian beaches, leading to more frequent cleaning operations aimed at removing waste. However, these cleaning activities often involve *P. oceanica* banquettes, which are often removed for aesthetic reasons, despite their important ecological role. Consequently, hundreds of cubic meters of *P. oceanica* banquettes and sediments from each beach are removed every year. This becomes a broader issue along the Mediterranean coasts deserving attention in terms of management and public perception of *P.* oceanica banquettes. In this context, our study aims to propose an integrated methodological framework to assess the ecological and socio-economic implications of different *P. oceanica* banquette management practices. Sampling activities were carried out along the Sicilian coastline to record GPS coordinates, thickness, length, and width along each strand based on the season's deposition. Fresh samples of P. oceanica banquettes were collected to estimate their biomass and the associated concentrations of nutrients and other chemical elements. In Spring, banquette deposits accounted for a total volume of 45,334 m^3 and a surface area of 109,464 m^2. In Fall, the total volume was 181,890 m^3 and the surface area was 237,749 m^2. Chemical analyses allowed to quantify biomass and carbon stock of P. oceanica banquettes and, therefore, their potential loss due to banquette removal. Furthermore, cost-benefit analyses were conducted to evaluate multiple management scenarios, including landfill disposal, in situ maintenance, and reintroduction into the marine environment. In conclusion, our study aimed to highlight the need to adopt sustainable management practices that recognize the ecological value of P. oceanica banquettes and the importance of their protection.

Integrating Environmental Impact Assessment and Ecosystem Services Accounting

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Environmental impacts due to urbanisation are increasingly affecting human well-being. Urban metabolism consistently contributes to environmental pollution and degradation, while existing green infrastructures are often insufficient to counterbalance these pressures through the supply of ecosystem services. In this context, this study proposes a novel framework that integrates ecosystem service accounting and Life Cycle Assessment to quantify the mismatch between ecosystem services supply and demand in urban systems. This approach was applied in two study areas (Province of Salerno and Naples, Southern Italy), selected as representative case studies with different urban and environmental profiles. Regulating ecosystem services provided by urban tree vegetation, including air pollution removal, carbon sequestration, and avoided runoff, were assessed using the i-Tree Canopy software. These services were quantified in both biophysical and economic terms to account for ecosystem services supply. In parallel, the Life Cycle Assessment methodology was used to evaluate the environmental impacts associated with urban metabolism, which were used as proxies for ecosystem services demand. Results highlighted marked differences between the two Provinces. Salerno exhibited a significantly higher tree cover (63.4%) compared to Naples (24.4%), as well as a greater potential for additional plantable areas. The ecosystem services supply in Salerno was higher, with carbon sequestration notably exceeding the demand, thus resulting in a surplus. In contrast, Naples showed a critical imbalance, with the current carbon sequestration ecosystem service supply meeting only about 4% of the estimated demand. The total economic value of the regulating ecosystem services of the two Provinces amounted to about 13.5 billion euros per year. In conclusion, the proposed integrated approach offers a replicable and scalable tool for identifying spatial mismatches in ecosystem services supply and demand. It can support urban planners and policy-makers in enhancing green infrastructure strategies and advancing sustainability goals in urban areas.

NUS Food Crops to support food production, local community economy and ecosystem services in Mediterranean Areas under Climatic Risk

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Mediterranean agricultural systems are increasingly exposed to salinization and desertification driven by climate change. In these areas where the extreme conditions of the land, limit agronomic productivity leading to economic and social crise, it is very important to find alternative strategies for resilient and sustainable food production to support local communities. Neglected and underutilized plant species (NUS), traditionally consumed across the Mediterranean basin, represent promising alternatives due to their high nutritional value, low input requirements, and adaptability to marginal environments. This study, part of the PRIMA project "VENUS", explores the agroecological and nutritional potential of selected Mediterranean NUS by integrating ethnobotanical knowledge with stress tolerance indices related to salinity, drought, and soil constraints. The potential of provision services of these plants is explored as well as their marketability, nutritional value and environmental co-benefits of their production, and they are compared with equivalent commercial plant based food most, typically produced in not-limited agricultural environment. Data extracted by international databases and literature review highlight the significant economic and ecological potential of these crops in Mediterranean areas under land degradation and climate risk. The next step of the project is to evaluate the local capacity building for crop and trading of these species and the creation of marketing initiatives for the engaged actors.

Is Aquaponics a sustainable food production system?

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In the context of growing global food demand and accelerating environmental degradation, farming systems are under increasing pressure to meet sustainability targets. Recent projections suggest that current improvements in agricultural productivity will be insufficient to feed the global population by 2050, potentially leading to unsustainable land expansion and use. Aquaponics represents a promising alternative: an innovative food production system that integrates aquaculture with hydroponics in a closed-loop cycle, where fish waste is biologically converted into nutrients for plant growth, while plants purify the water that can be reused. This integrated approach has the potential to reduce environmental impact and improve resource efficiency. By limiting water consumption, avoiding synthetic fertilizers, and minimizing nutrient runoff, it helps preserving natural capital stocks, soil health, and biodiversity while ensuring the generation of multiple ecosystem services among which water purification and food provisioning. The environmental and social benefits of aquaponics align with several Sustainable Development Goals (SDGs), notably SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action) and SDG 15 (Life on Land). However, challenges remain regarding scalability, energy use, and economic viability. This study aims at assessing the environmental sustainability of aquaponic systems through the Life Cycle Assessment (LCA) methodology. Particular attention is given to critical hotspots such as fish feed composition and water management practices, characterized by high energy demand and greenhouse gas emissions generation. The outcomes are compared with environmental indicators calculated for conventional agricultural and aquacultural systems to evaluate the environmental sustainability of aquaponics. In conclusion, this study highlights the need for assessing the environmental sustainability of alternative food production systems to address food security and sustainability challenges.

Loss of Natural Capital due to Fishing Impacts on Coralligenous Habitat in the Tremiti Islands Marine Protected Area.

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Coralligenous habitat represents one of the most important biodiversity hotspots in the Mediterranean Sea. Structured by calcareous encrusting algae and hosting a wide array of sessile and mobile marine species, it provides key ecosystem services such as coastal protection, carbon sequestration, and nursery areas. However, increasing anthropogenic pressures, particularly from fishing activities, pose serious threats to its integrity. This study aimed to assess the loss of natural capital associated with the degradation of coralligenous habitat due to fishing activities in the Tremiti Islands Marine Protected Area (MPA), Southern Italy. A multidisciplinary approach was adopted, integrating sampling activities, field observations, environmental accounting and spatial analysis. The biophysical and economic value of the natural capital stock was first estimated using an environmental accounting model. To assess fishing impacts, structured questionnaires were administered to divers and tourists, identifying areas where lost or abandoned fishing gear is frequently observed. Underwater surveys and image analysis were then conducted to quantify physical damage to benthic communities. Spatial data were integrated into GIS to generate thematic maps of fishing pressure and habitat vulnerability. The results revealed a 15% loss of coralligenous natural capital, corresponding to an economic disvalue of approximately €840,000. This degradation was primarily due to the presence of entangled nets, fishing lines, and other abandoned gears causing structural damage to the habitat. The study provides a replicable method to evaluate the impacts of fishing on vulnerable habitats in the Mediterranean Sea. Its outputs are relevant for informing conservation priorities, supporting the sustainable management of MPAs. Promoting such interdisciplinary assessments is essential to safeguard biodiversity while ensuring the generation of ecosystem services in response to growing anthropogenic threats

Conservazione e gestione di specie e habitat minacciati

6

Multi-taxon assessment of animal diversity across a mosaic of natural and semi-natural habitats in the Regional Natural Reserve WWF Oasis "Lago di Serranella"

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European protected areas (PAs) host thousands of species and habitats of high conservation value due to their restricted distribution, rarity, and centrality in maintaining functionality and resilience of natural ecosystems. In 2024, the European Commission launched the "EU biodiversity strategy for 2030", foreseeing the expansion of the current network of Natura 2000 PAs and the restoration of degraded ecosystems. To make such an effort successful, it is pivotal to increase knowledge about how biodiversity is distributed within the existing PAs and in their surroundings, to guide their expansion. The Regional Natural Reserve WWF Oasis "Lago di Serranella" is a PA located approximately 18 km inland of the Adriatic coast in Central Italy, within the Abruzzo region. The Reserve, established in 1990, belongs to the Natura 2000 network as both Special Area of Conservation (SAC) and Special Protection Area (SPA). Its territory encompasses the confluence of the Sangro River and the Aventino River. A dam, built in 1981 downstream of the rivers' confluence, created a large wetland, the Serranella lake, favouring the development of rich hygrophilous vegetation. This wetland represents an important stopover site for dozens of migratory bird species and hosts one of the main Italian populations of European pond turtle (*Emys orbicularis*), continuously monitored in the context of the "URCA PROEMYS" LIFE project. Between 2024 and 2025, we collected field data of different animal taxa (Insects, Birds, Herptiles, Mammals) through a mix of opportunistic and systematic sampling surveys, across the different habitats characterizing the Reserve (e.g., hygrophilous woodlands, mixed broadleaved forests, olive groves and vineyards, xerophilous scrublands). The data were later analysed in GIS and R environments to summarize the main animal diversity facets, and how they vary in space and time. Our work permitted to better characterize the biodiversity of the Reserve, contributing to design evidence-based conservation actions.

Assessment of fishing gear resistance to the invasive blue crab *Callinectes sapidus* in mesocosm

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The recent expansion of the invasive blue crab *Callinectes sapidus* along Mediterranean coasts has posed serious ecological and economic challenges, particularly for small-scale fisheries. One of the major issues reported by local fishing communities is the significant economic loss resulting from the destruction of fishing gear and the target catch eaten by the crabs. To mitigate these impacts, it is essential to understand which materials used in fishing gear construction are most resistant to the mechanical damage caused by this invasive species. The objective of this study was to assess the breaking strength of six different types of nets commonly employed by local fisheries in the fabrication of passive fishing gear (gillnets, trammel nets and fyke nets). Experiments were carried out in mesocosm using panels of different nets positioned to create a physical barrier between the offered food items and the crabs. For each experiment (R=5) a single adult male blue crab was introduced into each tank and its behavior was video recorded for 24 hours. At the end of the experiments, all net panels were examined for signs of damage and the time taken for the crab to break the material was recorded. The results revealed differences in material resistance showing that not all the tested materials are susceptible to crab-induced breakage. More in details, of the two fyke nets tested only one suffered damage, while polyamide monofilament resulted the most susceptible to tearing or cutting by the crabs. Conversely, the thicker polyamide multifilament showed a significantly higher structural integrity, resisting tearing even after repeated attempts by the crab to access the bait. These preliminary results suggest that some materials may be better suited for use in areas heavily infested with blue crabs, potentially reducing economic losses associated with gear damage and lost catches.

Analysis of the environmental and trophic niches of crab spiders (Araneae: Thomisidae) through Citizen Science

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Understanding ecological niches is essential for evaluating how species react to environmental changes and shifts in trophic interactions driven by climate change. Yet, combining both abiotic and biotic components of these niche remains a complex and resource-intensive task. Citizen Science platforms offer a cost-effective solution by providing large-scale, openly accessible, and multi-taxa datasets. However, spiders are often underrepresented in these datasets, largely due to public discomfort or fear. Among spiders, the Thomisidae family (Sundevall, 1833), which includes brightly coloured species frequently spotted on flowers with captures prey, stands out as a promising group for studying ecological niches using Citizen Science data. This research utilizes 627 Italian observations from the iNaturalist platform, focusing on three Thomisidae species — *Misumena vatia* (Clerck, 1757), *Thomisus onustus* (Walckenaer, 1805) and *Synema globosum* (Fabricius, 1775) — to investigate their ecological niches on both the environmental and trophic dimensions. Each record included visual documentation of spiders on flowers with prey. We explored their associations with the Köppen's clime classification by examining niche metrics such as overlap, equivalency and similarity, unfilling, expansion, and stability. The results revealed that *M. vatia* shows a preference for Alpine-Temperate regions, whereas *T. onustus* and *S. globosum* are more commonly found in Mediterranean-Temperate climate. The same parameters indicated the greatest environmental overlap between *T. onustus* and *S. globosum*. Additionally, bipartite network analyses demonstrated that all the three considered species primarily hunted on Asteraceae flowers, particularly targeting members of the Apidae family. Nonetheless, network structure, dietary overlap, and specialisation exhibited minor variations across climatic regions. Overall, this study emphasizes the potential of Citizen Science to capture complex ecological relationships, illustrating how climate shapes interactions among spiders, their prey and flowering plants. These findings are important for understanding how climate change could impact trophic dynamics in arachnid communities, often overlooked in ecological monitoring.

Conservation challenges posed by the invasive blue crab *Callinectes sapidus* in Sicilian coastal wetlands: insights from the Stagnone di Marsala lagoon and the Trapani and Paceco salt pans.

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Mediterranean coastal wetlands, including lagoons and saltmarshes, are critical biodiversity hotspots and provide essential ecosystem services such as nursery habitats, nutrient cycling, and water filtration. These fragile ecosystems are increasingly threatened by climate change, anthropogenic pressures, and biological invasions. The blue crab *Callinectes sapidus*, a decapod crustacean native to the western Atlantic, has recently established stable populations in several Mediterranean regions, including the Stagnone di Marsala lagoon and the Trapani saltmarshes (western Sicily, Italy). This species displays high ecological plasticity and reproductive capacity, enabling rapid expansion in brackish and shallow environments, where it may outcompete native communities. Within the framework of FAO-GFCM project, we conducted a multidisciplinary study combining monitoring of some ecological variables, habitat characterization and a systematic literature review to assess the potential impacts of *C. sapidus* on local biodiversity and ecosystem functioning. Our results confirmed a stable and reproducing population, with a marked presence of ovigerous females and juvenile stages, particularly in spring, indicating active recruitment and successful settlement. Habitat analyses revealed the blue crab's preference for structurally complex and productive environments, such as vegetated lagoon areas, where it may exert top-down pressure on native invertebrate communities and disrupt key ecological processes. Given the ecological relevance and protected status of these sites (Natura 2000), the spread of *C. sapidus* poses a tangible threat to long-term conservation goals and the provision of vital ecosystem services. Moreover, its presence may compromise traditional artisanal fisheries and the ecological balance of these transitional environments. We highlight the importance of adopting integrated ecosystem management strategies that combine early detection, continuous monitoring, stakeholder engagement and the exploration of controlled commercial exploitation as a complementary mitigation tool. Our study underscores the need to align invasive species control with broader conservation objectives, ensuring the ecological integrity and resilience of Mediterranean coastal wetlands in the face of ongoing global change. Keywords: Coastal wetlands, Biological invasions, Blue crab, Habitat conservation, Mediterranean lagoons.

Long-term monitoring as a valuable ecological and management tool: insights from Long-Term Monitoring of the *Posidonia oceanica* meadow at Lacco Ameno (Ischia Island, Italy)

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The decline of biodiversity and the degradation of marine habitats are pressing challenges in the current context of climate change and growing anthropogenic pressures. *Posidonia oceanica* meadows are key ecosystems in the coastal waters of the Mediterranean, due to their ecological value and the multiple services they provide. However, these meadows face serious threats such as rising sea temperatures, increased sedimentation and turbidity, anchoring, and coastal development. Understanding their long-term responses is thus essential to develop effective, science-based conservation strategies. The *P. oceanica* meadow off Lacco Ameno (northern Ischia Island, Italy) provides a remarkable case study. Systematically investigated since the 1980s, and integrated as site IT13-002-M in the Italian Long-Term Ecological Research Network (LTER-IT), this meadow has been the focus of a unique coastal benthic long-term monitoring. This monitoring integrates data on meadow structure (shoot density at a small spatial scale), spatial patterns of genetic diversity, plant phenology, and influence of environmental variables (mainly temperature), enabling the study of meadow dynamics, the detection of regression/recovery patterns, and the assessment of impacts due to climate changes and human activities. Data recorded so far show clear signs of structural alterations increasing with time, including reduced shoot density and altered spatial integrity. Plant and animal associated communities are consequently impacted. This case study is an example of how continuous ecological observations reveal ecosystemic changes that, if analysed in time, may provide early warning signals of degradation and can be used to inform management and define strategies for targeted conservation efforts.

Phenological and Structural Traits of *Posidonia oceanica* (L.) Delile as Indicators of Marine Protected Area Effectiveness

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Assessing the ecological condition and resilience of the *Posidonia oceanica* (L.) Delile prairie require the use of phenological and structural traits as reliable indicators. This study investigates *P. oceanica* prairie inside and outside the Marine Protected Area (MPA) "Costa degli Infreschi e della Masseta" (Southern Tyrrhenian Sea, Italy), to evaluate the effectiveness of MPA protection measures through the prairie conservation parameters. During autumn 2024 and summer 2025, 8 sites (6 inside and 2 outside the MPA), located at a depth of 15 m, were sampled by SCUBA diving. At each site, 3 stations, at least 10 m apart, were sampled with a 40×40cm sampling square. Shoot density was assessed through 3 random replicates. 6 orthotropic shoots were also collected at each site for phenological analysis. Data were analyzed using two-way ANOVA to test differences between areas (inside *vs*. outside the MPA) and season (autumn *vs.* summer). Analyses were also performed to detect the relationships among shoot density, leaf length, and number, and photosynthetic tissue. A significant difference was found between the areas ($p = 0.002$), with a significantly higher shoot density outside the MPA in both seasons: 392.50 shoots/m^2 in autumn and 376.67 shoots/m^2 in summer outside the MPA; 318.82 shoots/m^2 in autumn and 263.54 shoots/m^2 in summer inside MPA. Seasonally leaf length and photosynthetic tissue varied, with maximum values in summer, while no significant differences were observed in leaf number. A positive and significant correlation emerged between the length of adult and intermediate leaf ($r = 0.56$, $p < 0.001$). In contrast, photosynthetic tissue was negatively correlated with leaf length ($r = -0.40$, $p = 0.124$ in adult; $r = -0.92$, $p < 0.001$ in intermediate). These results support the role of MPAs in maintaining seagrass also in surrounding areas.

Testing an integrated protocol for the restocking of *Pinna nobilis* in the Northern Adriatic: from juvenile collection to reimplant in natural habitats

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Since 2016, the protected species *Pinna nobilis* (Linnaeus, 1758) has been impacted by a widespread epidemic, causing Mass Mortality Events throughout the entire Mediterranean. The Northern Adriatic was affected in 2019, with mortality up to 100% in marine populations, in particular on bio-geogenic outcrops locally known as "tegnùe" and "trezze". Within the Interreg IT-SI TRECap project, a comprehensive operative protocol for the restocking of *Pinna nobilis* was tested in the Veneto region waters, integrating different established protocols and conservation actions into a unique pipeline. Activities were coordinated with similar actions conducted by Shoreline soc. coop. in Friuli Venezia Giulia and NIB in Slovenian waters. Larval collectors to monitor the species recruitment were placed at different locations over the Northern Adriatic at the start of 2023 spawning season, including at the Acqua Alta Oceanographic Tower (AAOT) off the Venice lagoon and the "*Tegnùe di Porto Falconera*" Natura2000 site near Caorle. Collectors were sorted during the following winter, leading to the recovery of several alive juveniles (total length 1.8-10.2 cm). After a few days of maintenance in lab facilities, 36 individuals were transferred to an in-field enclosure located at the AAOT at 14 m depth, in order to reach proper size for the reimplant. The individuals status and growth were monitored in the following months, with only six individuals surviving through the summer of 2024. "*Tegnùe di Porto Falconera*" area was selected as a suitable testing site for the reimplanting. In accordance with MISE requirements, individuals were preliminarily tested by the University of Trieste for the presence of the pathogen *Haplosporidium pinnae*, using non-invasive approaches. The area was preliminarily mapped and characterized using photogrammetric approaches. The three surviving individuals were successfully reimplanted in early February 2025, protected by cages. Monitored is ongoing. Weaknesses and strengths throughout the entire pipeline are highlighted.

Mixed methodologies for transdisciplinary applications: the case study of an urban mediterranean Marine Protected Area (Sicily, Italy)

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Transdisciplinary Place-Based Research, participatory co-management and active stakeholders' involvement are often overlooked and oversimplified concepts when dealing with MPAs. Here, we analyze the results of mixed methodologies applied in the urban MPA of "Capo Gallo – Isola delle Femmine" (Palermo). A focus group supported by a pile-sorting exercise allowed to select the priorities expressed by multiple stakeholders (N = 73, 10 categories). The obtained list of priorities resulted from an initial free listing task, and two rounds of exclusions. Scientists and fishers showed a common priority (the most salient to all participants) and were selected for further investigations. To measure scientists' interests a scoping review was set up to synthetize: temporal trend, subject, approaches, conservation level of the scientific sources produced. Accessibility of marine resources, benefits generated and the overall support of MPA management were assessed with fishers through a semi-structured questionnaire. The need for enforcement and control (31%) was the main priority. An increasing temporal trend of scientific sources has been observed five years after the establishment of the MPA. Most of the studies applied a monitoring approach (49%). Research efforts mainly targeted single-species (46%), only 14% focused on comparison among management zones. 52% do not report accurate georeferences. The 72% of fishers perceive the MPA as a very negatively-influencing driver of change. All fishers do not believe the MPA improves the availability of natural resources and natural spaces, while a moderate percentage reported a high level of support to the MPA (57%). Overall, our analysis shows how a multitool approach can efficiently highlight specific knowledge gaps and different stakeholders' perception, often difficult to disentangle with traditional approaches. This may be fundamental to make scientific data available and accessible to policy makers and stakeholders, to consistently support the application of co-design and bottom-up management processes.

Ecologia del suolo: dalla conoscenza alla gestione sostenibile

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Ecological Consequences of Introducing *Pseudomonas* extremaustralis (PGPR) into Soil Bacterial Communities

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Plant growth-promoting rhizobacteria (PGPR) are increasingly applied to enhance crop productivity and support sustainable agriculture. Among them, *Pseudomonas* spp. have demonstrated multiple beneficial traits, including nutrient mobilization, phytohormone production, and suppression of soilborne pathogens. However, there is growing evidence that the introduction of PGPR may also impact native soil microbial communities by altering their composition, diversity, and functional interactions. In this context, the aim of the study (part of project: PRIN 2022LPPFTY, -TREASURE) was to analyze the bacterial community assemblage of soil, after inoculation with *Pseudomonas extremaustralis*. To this end, three bacterial concentrations (10^6, 10^8, and 10^{10} CFU) and three inoculation methods were tested on soils on which *Hordeum vulgare* L. (barley) plants were grown. The inoculation approaches included: soaking seeds in bacterial suspensions prior to sowing (SEED), immersing roots of pre-germinated seeds in bacterial solutions before planting (ROOT) and irrigating the soil with bacterial suspensions after planting pre-germinated seeds (SOIL). Control treatments followed the same procedures but used sterile distilled water in place of bacterial solutions. Each treatment was replicated five times. At the end of the experiment (2 months), DNA was extracted from soil and the 16S gene regions were sequenced. The results highlighted that, regardless of the inoculation methods, the bacterial concentration impacted on the bacterial communities, as the soil with 10^{10} bacterial CFU showed higher richness and Shannon index, than the others. However, the inoculation method also had an impact on soil bacterial community, as they showed significant difference in bacteria assemblage, in particular in the soil inoculated with ROOT method. This study demonstrates that PGPR application can modify soil bacterial community structure, highlighting the importance of optimizing both the dose and method of application. This is fundamental to balance plant benefits with potential shifts in native soil microbial communities, thus supporting more sustainable agricultural practices.

Ecotoxicological impact of Marine Biopolymers potentially used to improve the soil quality of degraded soils

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Climate change, altering the precipitation patterns, is intensifying soil degradation due to the reduction of soil moisture, posing serious risks to global food production. In this framework, the present research aimed to evaluate if the addition of polymers, obtained by marine organisms, improved water retention in degraded soils and if it caused soil toxicity (PRIN PNRR 2022M7S2J SeaForSoil Project). To achieve the aims, sixteen marine biopolymers, such as cyanobacterial (BC1–2) and macroalgal biomasses (BM1–4), biosurfactants (BS1–4) and exopolysaccharides (EPS1–6), were added to soils (1% weight). Based on their soil wettability and phytotoxicity, BC2, BM2, BS4 and EPS6 were selected as the best biopolymers. Then, their toxicity (mortality, biomass, and body length, after 7 and 28 days) was tested on *Steinernema feltiae* S. and *Eisenia fetida* S. Moreover, the effects of the selected biopolymers were also evaluated on the growth of the crop *Lactuca sativa* L. (height, root and shoot biomasses, and leaf traits in two-month-old specimens). The findings highlighted that the addition of BS4, BC2 and BM2 caused slight toxicity on both *S. feltiae* and *E. fetida*. The addition of EPS6 significantly increased the biomass and length of *E. fetida* and promoted the crop production of *L. sativa*. In conclusion, considering the different sensitivity of the tested organisms to the addition of the investigated polymers, the exopolysaccharide EPS6 emerged as the most promising biopolymer in improving soil water retention and enhancing crop production without causing soil ecotoxicity.

Fire-induced changes in soil enzymatic activities in beech and pine forests: implications for microbial functionality and ecosystem resilience

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Wildfires are among the main disturbances affecting forest ecosystems, with significant impacts on soil quality and microbial biodiversity. The intense heat generated during fires causes major physical, chemical, and biological changes in soils, altering nutrient availability, organic matter, and microbial community structure. These disruptions affect biogeochemical cycles, reduce soil fertility and water retention, and increase erosion risks, ultimately compromising ecosystem resilience. This study investigates post-fire changes in soil quality in beech and pine forests in the Maiella National Park (Central Italy), using soil enzyme activities as indicators of microbial functionality and ecological recovery. Seven enzymes (dehydrogenase, urease, phosphatases, glucosidases, and oxidases) were analyzed to evaluate microbial responses and nutrient cycling under different fire intensities and environmental conditions. Soils from sites affected by wildfires in 2017 and 2023 were compared to adjacent unburned controls. Results show contrasting responses: in some cases, fire stimulated enzymatic activity, likely due to the colonization by heat-adapted microbes and increased availability of organic substrates from combustion residues. In other cases, enzyme activity decreased, indicating strong microbial stress and reduced substrate availability. The observed variability reflects the complex and site-specific effects of fire, influenced by vegetation type, litter composition, fire severity, and pre-existing microbial communities. These findings contribute to the BIOSFeR^{3}a project, which explores how microbial and functional biodiversity supports the resistance, recovery, and regeneration of ecosystems affected by wildfires, climate change, and human pressures. Understanding post-fire soil enzymatic dynamics provides essential insights for sustainable forest management and ecological restoration in fire-prone regions. *Project: "BIOdiversità Specifica e Funzionale per la Resistenza, Resilienza e Recupero ai disturbi ed al cambiamento climatico [BIOSFeR^{3}a]", funded by Italian Ministry of University and Research, "National Biodiversity Future Center - NBFC PROJECT", CUP B83C22002930006*

Linking agricultural practices to soil functioning: insights from physico-chemical and biological indicators

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Sustainable agriculture strongly depends on plant - soil - microorganisms interactions to regulate nutrient cycling, enhance stress resilience and maintain biodiversity. Recent researches underscore the strategic role of microbe-rich soil zones, as rhizosphere and rhizosheath, which act as dynamic interfaces supporting nutrient turn-over and plant growth. In parallel, the adoption of pollinator-friendly plant mixes (PM) has emerged as a complementary strategy to boost above-ground biodiversity and strengthen landscape connectivity. This two-year study aims to investigate how different soil management practices and plant types affect biological (enzymatic activities, 16S rRNA profiling) and physico-chemical properties in microbe-rich soil zones. Two field experiments were planned: 1) wheat cultivation under organic amendment and mineral fertilization (NPK) regimes and 2) two different PM, compatible with EU CAP ecoschemes, sown on untreated soil. For both experiments, control plot consisted of native spontaneous species without amendment/fertilization. Preliminary results from the first year revealed that: 1) soil management did not affect the investigated properties, although, soil treated with organic amendment started to show a different pattern in enzymatic activities respect to the other soil treatments; 2) PM significantly affected the microbial community metabolic activity and enhanced microbial richness, highlighting the dual ecological role of these plants in supporting both aboveground and belowground biodiversity. These findings emphasize the pivotal role of diversified plant communities and rhizosphere processes in sustaining soil functionality. Integrating plant–microbe interactions into management practices emerges as a key strategy for developing resilient and ecologically sustainable agroecosystems. This study was carried out within the Agritech National Research Center and funded from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1032 17/06/2022, CN00000022). The content reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

Hydrating capabilities of biopolymers from marine thermophilic bacilli and their potential to counteract soil dehydratation

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In the framework of the PRIN PNRR 2022M7S2J *SeaForSoil* project, the exploitation of biopolymers from marine extremophiles, which play an important role *in situ* for survival in adverse environmental conditions including dehydration, could contribute to the development of new strategies to increase soil water retention in water scarcity conditions. To investigate the hydrating capabilities of biopolymers (BSs) produced by thermophilic bacteria, *Bacillus licheniformis* B3-15, *B. horneckiae* SBP3 and *Bacillus* sp. s7s-3ng, isolated from shallow hydrothermal vents of the Eolian Islands, in this study we evaluated the following characteristics: i) wetting properties, by measuring the reduction of the water contact angle on a polystyrene surface, ii) structural changes at increasing hydrating states (from 0 to 160% w/w of water content), using ATR-FTIR spectroscopy, and iii) water uptake from air at 90% of relative humidity, and the water-releasing rate under desert-like solar intensity conditions (>1300 W/cm^2), using the gravimetric method. After growth under optimized conditions for 48h, the crude extract yield was the highest for BS B3-15 (1.5 g/L), followed by BS s7s-3ng (1.1 g/L) and BS SBP3 (0.950 g/L). Although all were chemically attributed to lipopeptides, each BS possessed different chemical structures and consequently different properties, with BS s7s-3ng being the most active in increasing the surface wettability (=38), suggesting its use to easily spread wetting over a large area of solid surfaces. BS-s7s-3ng and BS SBP3 were more efficient in capturing liquid water (80%) than BS B3-15 (60%). BS SBP3 showed the highest water uptake from air (68%), and the slowest release of 90% of the up-taken water weight (within 13h) than BS s7s-3ng (7h) and BS B3-15 (4h), under exposure to high solar irradiation. As non-toxic wetting and moisturizing agents, these biopolymers could compete with industrially manufactured additives in agriculture to counteract soil dehydration.

Ruolo dell’Ecologia in conservazione, restauro e pianificazione

8

Application of Ecosystem-Based Management System (EBMS) to coastal habitat protection and restoration

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Coastal marine ecosystems of the Mediterranean Sea, such as coralligenous habitats, play a crucial role in biodiversity and ecosystem services. However, they are increasingly threatened by anthropogenic pressures and climate change, highlighting the urgent need for innovative strategies to ensure their protection. This study supports the development of a Digital Twin of the Ocean (DTO), aimed at creating a digital representation of the marine ecosystem. Continuously updated with experimental data, the DTO serves as a tool to support conservation and management activities (e.g., identifying the most suitable areas for restoration). A key component of the DTO is the availability of water column data and benthic observations, which allow for the ongoing validation of the digital model, enabling the creation of realistic "what if scenarios." This activity stems from two complementary projects: EFFECTIVE, which aims to develop scientific knowledge and integrated guidelines for applying Ecosystem-Based Management to the protection of the Mediterranean's Blue Natural Capital; and RENOVATE, which focuses on restoring ecosystem services compromised by the development of the Port of Civitavecchia through active and passive compensation measures. This study presents the measurement activities supporting the development of the DTO in two restoration areas of the coralligenous biocenosis (Habitat 1170). Using scuba divers, CTD stations, and autonomous mobile platforms, key data were collected for the study of the habitat and validation of the DTO. These data include continuous seabed temperature measurements to identify the duration, frequency, and intensity of potential marine heat wave events; CTD profiles to monitor water column stratification; and total suspended solids (TSS)/turbidity, a parameter that significantly affects the life of benthic organisms. This information supports the ecological assessment of the sites and the validation of digital models useful for planning restoration interventions.

Supporting animal-mediated services in disturbed small green areas of the city

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Supporting animal-mediated services in disturbed small green areas of the city AUTORI: Biella Paolo, Università degli Studi Milano - Bicocca, Milano, Italia Brambilla Giulia, Università degli Studi Milano - Bicocca, Milano, Italia Labra Massimo, Università degli Studi Milano - Bicocca, Milano, Italia; National Biodiversity Future Center (NBFC), Palermo, Italia ABSTRACT In recent decades, human activities have highly affected global biodiversity through intensive agriculture, pollution and urbanization, leading to a significant decline in species diversity. As a consequence, the services provided by biodiversity can be affected in these areas. In this context, it is crucial to implement strategies that support and preserve communities. We developed the "Urban Biodiversity Enhancement kit" within the National Biodiversity Future Center, spoke 5. This tool aimed to increase biodiversity at the local scale, focusing on the enhancement of habitat quality in green spaces. The kit is composed of a bird nest box supporting biological control, and to enhance pollination, it includes a solitary bee's nest and a mix of native, insect-pollinated, herbaceous seeds with bioinoculants to enhance plant survival. The tool was distributed to 18 Italian big cities, with a total of 175 areas managed by 103 different local entities, including community gardens, allotments, universities and schools. This variety of entities, directly involved also in the monitoring of the effectiveness of the tool, provides a solid basis in order reverse biodiversity decline and evaluate the society perception on this topic. In addition, thanks to the horizon project "BUTTERFLY- Mainstreaming pollinator stewardship in view of cascading ecological, societal and economic impacts of pollinator decline", we established a multi-actor network (living lab) in Lombardy with 27 actors from urban and farmland areas, where collect, integrate, manage and share ecological and spatial information on a wide range of known and lesser known pollinators and pollination services, quantify direct and indirect economic values and co-create tools for a proactive pollinator stewardship in vulnerable sectors. These initiatives not only supported the creation of microhabitats for biodiversity in urban areas but also increased public awareness on the importance of environmental conservation.

Designing biocompatible 3D units for *Ericaria amentacea* habitat restoration: enhancing the ecological value of artificial coastal structures

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In the last three decades, an increasing number of man-made marine hard defence structures have been built as a rapid and cost-effective means of coastal protection. The idea of integrating ecological principles into urban infrastructures is relatively new and challenging. Using coastal structures to host endangered species holds a significant promise for biodiversity conservation in coastal cities worldwide. Nevertheless, marine infrastructures provide unconventional substrates for benthic communities due to a lack of surface complexity, orientation, exposure, structure, and texture, affecting the recruitment, survival, and growth of organisms. Additionally, most of the approaches are limited to the implementation of bare substrates, although specifically designed for enhancing biodiversity through settlement facilitation. This study presents a preliminary investigation into the development of biocompatible units specifically designed to restore macroalgal forests, i.e. *Ericaria amentacea* habitats, implementing the *ex-situ* outplanting (therefore positioning in the field vegetated substrates) in the Ligurian region (Northwestern Mediterranean Sea), performing an actual forestion of artificial coastal infrastructures, enhancing their ecological value. The research evaluates various designs and material formulations of cantilever prototypes for their ability to support algal settlement and growth and resist hydrodynamic forces once deployed on the artificial reef. Laboratory tests have been performed to assess mechanical properties, including flexural and compressive strength, density, as well as the water absorption of the restoration structures. Laboratory cultures explored different material performances in promoting algal growth. Preliminary field evaluations under wave action highlight investigated performance in durability and compatibility within marine environments. Aligning with the EU Nature Restoration Regulation requirements, our study is a step forward to the development of innovative, nature-based solutions for mitigating anthropogenic impacts due to the establishment of artificial infrastructures at sea.

"Protect the natural world": is it enough, or do we need to take more action?

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"Gran Bosco della Mesola" (1,058 ha) is one of the last and best-preserved remnants of the lowland forests that once covered the northern Adriatic coast. Since 1977, it has been a nature reserve managed by Carabinieri per la Biodiversità, Punta Marina section. The reserve eatures dunes, woodlands, and especially ponds and canals, which underwent severe degradation in the early 2000s. This led to the launch of a LIFE project in 2003-2004 (LIFE/-NAT/IT/7147) aimed at both conserving habitats and species within the Mesola Forest and improving water quality in the canals. We carried out ecological studies in 2000, 2004 and 2006, 2013, and 2024, assessing the situation both before and after the restoration efforts. Significant ecological changes have occurred over time within this protected area, despite hydraulic restoration and seasonal water input from Canal Bianco. Primary production and aquatic communities have been drastically altered by: saltwater intrusion (Muresan et al., 2020; Gaglio et al., 2023); spread of the invasive species *Procambarus clarkii* (Mazzotti et al., 2007); introduction of non-native fish like common carp (*Cyprinus carpio*) and grass carp (*Ctenopharyngodon idella*) for recreational purposes in nearby canals—species that later colonized the reserve—(Tapia & Zambrano, 2003). Carp foraging and the constant grazing activity of grass carp keeps causing high turbidity, which prevent the regrowth of macrophytes, now nearly absent (Hootsman, 1999). This has profoundly changed the trophic networks of the canals, leading to the disappearance of some benthic functional groups and the dominance of others. These findings highlight the need for conservation strategies that extend across the entire surrounding landscape, rather than focusing solely on isolated protected areas, to ensure the proper maintenance of ecosystem functionality and the delivery of related ecosystem services.

Cymodocea nodosa meadows as a summer refuge for *Gongolaria barbata* recruits in the Venice Lagoon

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Due to multiple anthropogenic and climatic stressors, macroalgal forests are undergoing a rapid decline. These valuable ecosystems in the Mediterranean Sea support biodiversity and provide important ecosystem services. This highlights the importance of studies in this field regarding the adaptability of macroalgae to various environmental conditions. This research focuses on the macroalga, *Gongolaria barbata*, an element of great ecological value, especially prevalent in the lagoon areas of the Adriatic Sea. In winter, macroalgal forests of *G. barbata* expand. In spring, they coexist with forests produced by the seagrass *Cymodocea nodosa* and are then completely replaced by the latter in the summer, forming a cycle of seasonal alternation. It has been noted that several of *Cymodocea*'s physiological characteristics allow it to adapt even to situations not entirely optimal for its physiology within the lagoon environment. Within this general framework, the present study aims to highlight the importance of possible cooperation, both direct and indirect, between the two species, which will promote their growth in the lagoon. It is hypothesized that during the summer period, when *G. barbata* regresses, its new recruits can find shelter from strong solar radiation, thereby increasing their growth potential when protected by *Cymodocea*leaves. Simultaneously, it is speculated that *G. barbata* itself can provide nutrients to the substrate, which facilitates the expansion of *Cymodocea*. To support these hypotheses, during the spring period characterized by the reproductive phase of *G. barbata*, supports were set up within the macroalgal forests of the lagoon to allow new recruits to attach. These samples will then be moved from three initial sites to sites characterized by the presence and absence of *Cymodocea*. During the summer, the growth and physiological performances of *G. barbata* recruits will be evaluated in both the presence and absence of the seagrass. Various parameters will be evaluated from these samples, including growth, phenology, photosynthetic production, and respiration.

tidysdm: a tool for increased flexibility and explicit integration of time series in species distribution modelling

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Species Distribution Modelling (SDM, also known as Habitat Distribution Modelling) is a framework that allows reconstructing the potential range of a species based on its occurrences and environmental factors of interest. It is often used to inform habitat restoration (for example, by taking into account future climatic scenarios) and ecological planning (e.g. for invasive species). Tidysdm reaches a whole new level of flexibility compared with existing tools. This is achieved using the modular infrastructure of tidymodels. Tidymodels is a collection of R packages for machine learning, in which syntax, grammar and data structure are fully compatible with each other. This is why tidysdm does not need to create complete solutions from scratch: objects created within tidysdm can be directly fed to existing generic functions from other tidymodels packages. In addition to it, it provides metrics specific to SDM and functions to handle spatial data. Tidysdm is the first available piece of software to perform SDMs on time series. This is a task that is often achieved by splitting the observations into different time slices, but such an approach reduces the data used for each modelling step and may lead to biases. Finally, tidysdm allows full integration with pastclim, an R package facilitating the access to present-day climatic data and future scenarios (e.g. Worldclim, CHELSA), as well as palaeoclimatic reconstructions covering from thousands to millions of years. In short, tidysdm allows full flexibility when performing SDM, making it suitable to inform a larger range of ecological questions, and can natively incorporate time-scattered data, facilitating the study of climatic changes (especially the ones we are currently experiencing) on both large and small geographic scales.

Experimental seagrass restoration using facilitative interactions and functional metrics

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Seagrass meadows are key ecosystems in the Mediterranean coastal areas supporting rich biodiversity and providing numerous ecosystem services. However, these ecosystems are increasingly threatened by local anthropogenic pressures and climate change. Because their natural recovery after disturbance is slow, active restoration – increasingly incorporating innovative methodologies - has become an important tool for their conservation. In this context, we investigated a facilitation-based interaction technique through an experimental restoration intervention within the "Capo Gallo–Isola delle Femmine" Marine Protected Area. The transplantation was carried out on a *Posidonia oceanica* matte substratum and involved 16 one-square-meter grids, arranged into four experimental units and randomly assigned to one of the following treatments: *Cymodocea nodosa* only, *P. oceanica* only, a combination of both *P. oceanica* and *C. nodosa* shoots, and a control grid (matte only). Transplant performance is being monitored monthly using non-destructive methods, combining classical biometric techniques with metabolic measurements. This experiment represents an innovative approach to the restoration of *P. oceanica* meadows, leveraging the potential facilitative role of *C. nodosa* to enhance restoration effectiveness through interspecific interactions. In addition, traditional monitoring is complemented by metabolic measurements at both individual and community levels, providing functional performance metrics. Although results are still under evaluation, this study offers a potentially replicable and methodologically advanced model for future restoration efforts, aiming to strengthen the resilience of Mediterranean coastal ecosystems. Keywords: ecological restoration, *Posidonia oceanica*, *Cymodocea nodosa*, metabolism, biotic interactions

Restoration of Mediterranean quarry soils with compost from marine organic waste: first insights from the PRIN 2022 PNRR EMBRACE project

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Organic amendments, rich in stable organic matter, can foster the recovery of degraded soils by enhancing their chemical and physical properties, sustaining microbial communities, and promoting natural revegetation. This is especially relevant in Mediterranean climates, where soil organic matter depletion is a widespread and serious issue. In a circular economy framework, the EMBRACE project (PRIN 2022 PNRR) aims to valorise marine waste in terms of energy and matter recovery, using the resulting by-products to restore degraded soils in Mediterranean ecosystems. To this end, two composts were produced from the sequential anaerobic and aerobic digestion of *Posidonia oceanica* litter and fish market waste, with and without the addition of natural zeolites from quarry waste, and tested for their ability to promote the recovery of quarry soils. Seasonally, natural revegetation is assessed through phytosociological relevés, evaluating species richness, evenness and composition. In parallel, the amended soils are characterized from a chemical, physical, biological and toxicological perspective, the latter carried out using *Lepidium sativum* L. and *Sorghum saccharatum* L. seed germination and shoot elongation as endpoints. Results obtained so far showed that the addition of organic matter significantly enhances revegetation in the amended soils as compared to the untreated controls, with structural and functional differences in plant community diversity induced by different treatments. Furthermore, no phytotoxic responses were observed in both endpoints, indicating instead mild phytostimulatory effects. The soil microbial community function also changes in reaction to various treatments, with the soils enriched with compost overall exhibiting improvement. These early findings highlight the potential for scaling up ecological restoration efforts with reclaimed materials, while simultaneously addressing the socio-economic issue of marine litter accumulation on tourist coastal areas.

Identification of artificial substrates for the recruitment and growth of *Lithophyllum stictiforme*: a technique for the future restoration of coralligenous habitats in the Mediterranean Sea.

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The coralligenous habitat is a key subtidal ecosystem in the Mediterranean Sea, considered as a biodiversity hotspot due to its structural complexity and ecological services it provides. This habitat is primarily built by crustose coralline algae (CCA), which form biogenic structures that support diverse marine communities. Despite its ecological importance, this habitat is under increasing threat from anthropogenic pressures and climate change, which impair its stability and functioning. To date, active restoration efforts within coralligenous habitats have largely focused on gorgonians, with little to no research targeting the foundation CCA species. A preliminary field experiment conducted in 2022 using artificial tiles (ceramic and terracotta) deployed at 28m depth showed recruitment of a single CCA species (*Titanoderma* sp.), but no key bioconstructors were observed. This work aims to test, under controlled mesocosm conditions, the suitability of different artificial substrates for the specific recruitment of *Lithophyllum stictiforme*, a key framework-building species in coralligenous assemblages. Adult thalli were collected and induced to release spores in laboratory tanks where five types of substrates (ceramica, terracotta, granite, glass, plastic and limestone) were placed on the bottom. Recruitment success on each substrate was monitored over four months. Results showed that *L. stictiforme* did not colonize any of the artificial substrates, despite successful spore release. These findings are consistent with previous field observations and raise important questions regarding the ecological succession of crustose coralline algae during initial phases of substrate colonization.

Coral restoration activity: insights from a pilot intervention on *Cladocora caespitosa* and *Eunicella cavolini* in the Tyrrhenian Sea

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Ecosystem restoration in marine environments faces increasing challenges due to the intensification of climate-related stressors, particularly thermal anomalies. As part of the RENOVATE project (*Ecosystem Approach to the Evaluation and Experimentation of Compensation and Mitigation Actions in the Marine Environment: the case of the Civitavecchia Port Hub*), we implemented a pilot coral restoration intervention in the coastal waters of Santa Marinella (Mano Aperta site, northern Latium), focusing on two species of the Mediterranean coralligenous assemblage: *Cladocora caespitosa* and *Eunicella cavolini*. The fragments used for restoration (120 and 60, respectively) originated from bycatch collected through small-scale local fishing in the ports of Civitavecchia and Santa Marinella and were kept for recovery in a controlled environment prior to reintroduction. Survival is the primary indicator to be considered when evaluating the effectiveness of ecological restoration activities, especially in the case of benthic habitats and ecosystem-engineering organisms such as corals. Following reintroduction, the organisms were monitored monthly to assess a range of vital descriptors including necrosis, bleaching, tissue loss, and color fading. Continuous temperature data were recorded at the depth of the restoration pilot site to better interpret coral performance patterns. We present the first results of this activity, including data on coral survivorship and thermal anomalies recorded at the restoration site. These results represent a crucial step toward understanding the environmental thresholds that influence coralligenous restoration outcomes in the Mediterranean and offer valuable insights for refining protocols in future interventions under climate stress scenarios.

Ecologia del Paesaggio ed analisi spaziale degli ecosistemi

9

A Trait-Based Hierarchical Modelling Approach for Invasive Alien Plants

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Invasive alien species are among the main global drivers of biodiversity loss, posing major challenges to nature conservation and causing substantial ecological and economic impacts. This study, part of the PRIN PREVALIEN project funded by MUR & Next Generation EU, examines 130 alien vascular plants, including invasive species of European Union concern (EU Regulation No 1143/2014) and potential future candidates, to identify functional patterns and predict habitat suitability beyond their native ranges. Global occurrence data for these species were retrieved from the GBIF and iNaturalist platforms and classified according to positional accuracy into local (500 m) scales. These occurrence data were then used to calibrate hierarchical species distribution models (SDMs). To identify functional groups (FGs) based on ecological similarities among species, we compiled a comprehensive database of morphological traits (e.g., height, seed mass), ecological traits (e.g., ecological indicator values for nutrients and temperature), and phenological traits (e.g., blooming period). An optimized Gower distance was used to calculate functional dissimilarities among species. Functional clusters were identified using multiple clustering algorithms and validated with bootstrap randomization to ensure robustness. Principal Coordinates Analysis (PCoA), combined with trait-environment vector fitting, was used to elucidate key traits driving cluster differentiation. By integrating these functional groups with hierarchical SDMs, habitat suitability will be projected for each species and mapped according to functional cluster memberships. Pixel-wise values will represent Functional Groups Weighted Means (FG-WMs), aggregating habitat suitability, with each species' contribution weighted by its functional group and constrained by its dispersal capacity. This combined trait-based and spatially explicit methodology enhances the ability to forecast invasion risks, thereby facilitating the development of early-warning systems and targeted management interventions.

FAIR PAs: a Framework for Assessing Invasive alien plant Risks in Italian Protected Areas

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This project, funded by the Italian Ministry of Research under NextGeneration EU and PON-AIM 2014-2020 DM1062, aims to design an integrated framework for assessing the invasive alien plant risks in Italian protected areas (PAs). The framework supports conservation efforts and prioritizes vulnerable habitats by evaluating species' likelihood of introduction, establishment potential, and impacts on biodiversity and improve prioritization of most species. The species' likelihood of introduction is estimated based on occurrence density within PAs, buffer zones, and broader Italian and European (e.g., Mediterranean) regions. For species not yet present in Italy, their potential introduction pathways are analyzed. Establishment potential is determined by evaluating habitat suitability as a proxy of the likelihood of persistence within PAs, buffer zones, and the broader Italy. Through species distribution models, we spatially express the likelihood of alien plants establishment. We consider the suitability of alien plants in each habitat in relation to their conservation value as an indicator of potential impact on biodiversity. Such impacts are quantified within PAs, buffer zones, and the broader Italian landscape. Habitat susceptibility to be invaded and biodiversity value assignment are aided by expert knowledge. This structured approach provides a comprehensive framework for quantifying invasion risk and will help prioritize the most threatened habitats in PAs based on the specific interactions between the PAs and the threat posed by each invasive alien plant. The assessment integrates expert knowledge, current and projected climatic suitability, and an ecosystem vulnerability indicator derived from habitat and species diversity data.

From binoculars to bytes: innovating bird monitoring with IoT technology

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Sensor-based monitoring is redefining field ecology, offering new perspectives for high-frequency, low-disturbance data collection. The *MonOrniTech* pilot project, launched in 2024 in the Lakes Lungo and Ripasottile Nature Reserve (Central Italy), aims to validate the use of Smart Nest Boxes (SNBs) as a scalable tool for long-term ornithological monitoring in protected wetland ecosystems. A total of 170 artificial nest boxes are deployed, equipped with embedded sensors for internal temperature and humidity, and integrated micro-cameras for image capture. Each unit autonomously records time-stamped data at 60-minute intervals, minimizing the need for direct human intervention. Larger boxes include camera traps to monitor reproductive success, and microclimatic conditions are contextualized through nearby ambient sensor stations. The system is designed to overcome key limitations of traditional visual census methods, which are often labor-intensive, temporally sparse, and intrusive. SNBs provide continuous, fine-scale biological and physical data, enabling the detection of occupancy, incubation patterns, and species-specific behaviors—even during nocturnal and early-season phases that are typically under-recorded. While this represents the first documented use of such technology in a European wetland context, its performance is supported by comparable applications in African and Asian field studies. The literature demonstrates high reliability in detecting reproductive phases and internal nest dynamics, confirming the suitability of SNBs for avian ecological research. By integrating IoT-based sensing into standard conservation workflows, *MonOrniTech* provides a methodological advance with potential for wide replication in Natura 2000 sites and beyond. The project is funded by the European Union – Next Generation EU and is currently in its initial data collection phase, with full analytical outputs expected by half year 2026.

Urban Green Infrastructures to support the quality of life and well-being of citizens: a participatory path based on Scientific Cafés

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Recent scientific evidence has highlighted the key role of urban green infrastructures (UGIs) – strategically planned network of natural and semi-natural areas [...] designed and managed to deliver multiple ecosystem services and enhance biodiversity within urban environments (European Commission 2014) – in improving citizens' quality of life and well-being. UGIs provide several ecosystem services (ESs), including heat mitigation, noise reduction, flood protection, rainwater runoff regulation, microclimate and air quality regulation, outdoor recreation and aesthetics. Following scientific evidence, European Union (EU) policies have acknowledged the need to integrate UGIs planning and management into political agendas. EU Biodiversity Strategy for 2030 promotes green infrastructure across rural and urban contexts, while the Green City Accord (2021) aims to improve quality of life for Europeans and accelerate implementation of the European Green Deal. Within this framework, the aim of this study – developed as part of the Horizon Europe Project ForestValue2 – was the setting up a participatory process in the Veneto region, north-eastern Italy, to define the priorities and actions to be included in the planning and management of UGIs. The participatory process based on Scientific Cafés approach has been implemented not only in Italy but also in other European countries involved in the ForestValue2 project (Ireland, Finland, Romania, Germany). The process involved two participatory methods: *Scientific Cafés* – public and informal discussions of socially questions to ensure effective communication and encourage open dialogue between scientists, practitioners, and civil society – and *Co-Design Workshops* – a group session where participants contribute to the development of project proposals. In a first step, a Scientific Café was held in Padua in September 2024 with several categories of stakeholders and experts. Participants, working in small, facilitated groups, prioritized key ESs and identified eleven strategic actions for the maintenance and enhancement of UGIs (four for supporting services, five for cultural services, and two for regulating services). Based on these results, a co-design workshop took place in summer 2025 in Vicenza, focusing on Bosco di Carpaneda, an urban woodland. Using on-site maps and group discussions, citizens collaboratively refined practical strategies for ES valorization, reflecting local preferences and needs. The results will be used to define guidelines for a multi-ESs management of UGIs.

Following the Flow: Vegetation Patterns Along Moisture Gradients in Apennine Wet Meadows

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Mediterranean high-mountain grasslands represent critical biodiversity hotspots, delivering essential ecosystem services. However, these valuable ecosystems are increasingly vulnerable to climate-induced stressors, particularly rising temperatures, and intensified drought conditions. Investigating how plant communities adapt across moisture gradients is essential to unravel ecological responses to escalating water stress and to effectively guide targeted conservation actions. Within the framework of the BIODIVERSA–PRESINMED project (”Preserving the singularity of Mediterranean high-mountain biodiversity hotspots: a Nature-based Solutions Approach”), we characterized plant community composition and ecological variability in Mediterranean mountain wet meadows, beginning our survey in the Quarto Santa Chiara Natural Reserve, situated in Maiella National Park, Central Apennines, Italy. This site comprises a mosaic of wet grassland habitats distributed along a natural gradient of soil moisture, offering an ideal setting to explore spatial variability in herbaceous communities shaped by hydrological conditions. Our fieldwork focuses on four plant communities representing different points along this gradient. In each community, we established three permanent areas, where vegetation is surveyed during the peak growing season using four nested 1×1 m plots per area. This sampling design provides the foundation for long-term monitoring of species composition and community dynamics across this environmental gradient, including future analyses of phenology and grazing pressure. This first research season represents an initial step toward building a comprehensive ecological profile of the area, which will be further developed in the coming seasons. In addition to describing floristic patterns across habitats, we aim to evaluate whether Ecological Indicator Values for Europe (EIVE) are aligned with this moisture gradient. Preliminary results suggest a clear differentiation in species composition and EIVEs among habitat types, with the occurrence of rare plant species for Italian Mediterranean mountains. Interestingly, we observe higher species richness in the drier communities and not in medium wet grasslands, pointing to potential shifts in ecological filtering.

Identification of priority areas for reforestation using landscape ecology methods: a case study in Siracusa, Italy

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In recent years, Sicily has experienced a reduction in forest areas due to fires, which have depleted the heritage accumulated through reforestation efforts over the past century. The new European Nature Restoration Law and the National Forestry Strategy (NFS) provide a fresh impetus by setting binding targets to restore degraded ecosystems and strengthen the resilience and ecological functionality of landscapes. These are particularly important in Mediterranean regions such as Sicily, where the effects of climate change, ecological fragmentation and human activity are severe. This study aimed to identify priority areas for reforestation in the Siracusa province, particularly within state-owned areas managed by the Department of Rural and Regional Development (DSRT). The methodology aimed to provide tools that would integrate spatial complexity and management constraints into reforestation planning. Priority areas were selected by excluding those subject to specific constraints, such as Natura 2000 areas, pasture areas, or areas affected by fire within the last five years. This enabled us to focus on areas that could actually be used for forestry operations, in line with the provisions of the Nature Restoration Law and the NFS. We applied a forest structural connectivity model based on graph theory (Conefor) to the selected areas. We used this model with different dispersal distances (500 m, 1,500 m and 3,000 m) to assess connectivity at a multitaxa level. This type of analysis enables us to move beyond point planning and focus on optimising the ecological functionality of the landscape. Once the priority areas had been identified, the most suitable plant species that respected the local ecology were also selected. This study emphasises the importance of adopting an integrated, landscape-based approach to reforestation that combines ecological effectiveness with the effective implementation of interventions.

Linking seabed roughness and benthic habitat structure and composition in the Lagoon of Venice

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The Lagoon of Venice is a complex mosaic of benthic habitats, which are strongly controlled by benthic fluxes (exchanges of nutrients, oxygen, sediment, organic matter, contaminants, etc.) between the bed and the overlying water column. Turbulent energy production and dissipation, bed shear stress and velocity gradients control these fluxes and vertical gradients of such parameters in the benthic boundary layer depend in turn on the bed physical features, i.e. its hydrodynamic roughness, defined by sediment type/size and morphology, and are strongly mediated by biology. Biology-mediated processes can enhance or reduce seabed stability at several space-time scales, so that biogenic seabed roughness is essential for understanding benthic fluxes, thereby dictating habitat classification, and informing conservation efforts. To support the characterization and comparison of biogenic benthic roughness in relevant habitats, two sites were selected: (i) a subtidal flat presenting seagrass/algae coverage and a dense colony of *Pinna nobilis* in the central lagoon; (ii) the edge of a creek entering an intertidal flat in the northern lagoon, with seabed featuring sponges, oysters and other epifaunal and vegetation cover. Both sites have an average water depth of 1.5 – 2 m. For each site, a photogrammetric survey over a 72 m2 area (12 x 6 m) was carried out by scientific divers. Structure-from-Motion (SfM) analysis of the collected images allowed to produce a digital terrain model with a high spatial resolution (accuracy under 1 cm). Preliminary analyses on the local spectrum of altimetric fine-scale variability are presented, and related to biogenic features. Main results support the linking of physical bed roughness to habitat structure and composition.

Ecologia ed educazione alla sostenibilità

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Insects as alternative protein sources for feed and food: a sustainable response to the global food crisis.

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The rise in the global population leads to increased demand for food, especially animal proteins. The current food system, primarily built on intensive cattle, pig, and poultry farming, is unsustainable over the long term because of its significant environmental effects: excessive water and soil use, high greenhouse gas emissions, pollution, and deforestation. Some production systems inspired by the circular bioeconomy can offer effective and rapidly applicable solutions. These systems include insect farming to produce food and feed using waste and by-products from local agri-food chains (Errico et al, 2021). Insects provide several key benefits: higher production efficiency (insects are more effective at converting food into protein), lower environmental impact, high nutritional value, and less waste (Goutam Roy Chowdhury et al., 2017). Many insects, such as *Tenebrio molitor* larvae, can be farmed using food by-products and organic waste, supporting a circular economy and cutting waste impact. Promoting insects as an alternative protein source is not just a food issue but a key environmental and social strategy for sustainably addressing future challenges. Schools, as centres of education and innovation, have a crucial role in leading this cultural shift toward greater ecological responsibility. The FoPA (Alternative Protein Sources) Working Group at the Regenerative Circular Bioeconomy Laboratory of the Sustainability Department at the ENEA Trisaia Research Centre (MT) has gained solid experience in sustainability education through the presentation of our insect farms, where two beetles, *Tenebrio molitor* and *Alphitobius diaperinus*, are reared for scientific purposes. Particularly significant was the experience with young people who participated in training courses organised for local schools and universities, through experiential workshops, Open Days and guided tours of the activities of our working group at the Trisaia Centre. These initiatives can help raise awareness among young people about the connections between the environment, society, and the economy. Greater understanding can promote cultural acceptance of environmental sustainability. References: Errico, S., Spagnoletta, A., Verardi, A., Moliterni, S., Dimatteo, S., & Sangiorgio, P. (2021). Tenebrio molitor as a source of interesting natural compounds, their recovery processes, biological effects, and safety aspects. Comprehensive Reviews in Food Science and Food Safety, 21(1), 148-197. https://doi.org/10.1111/1541-4337.12863 2. Goutam R C, Upasana D, Sufia Z, Abhijit M. Ecosystem Services of Insects. Biomed J Sci & Tech Res 1(2)-2017 BJSTR. MS.ID.000228

The Ecocentric Perspective like triggers of prevention and well-being for healthcare workers: work in progress at the ASL Napoli 2 nord.

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Ecopsychology allows the transition from an egocentric vision to an earthly citizenship, amplifying the awareness of a planetary belonging. Through an active practice in Nature, it helps to recover ancestral biophilia with a significant reduction of typical distress of our time. In the ASL Napoli 2 nord, for the workers well-being , individual and group mindfulness has been practiced since 2020. This year, the idea of introducing Green Mindfulness and EcoPsychology practices to improve the well-being of healthcare workers was born. This poster describes the experiential training project, along the lines of EcoPsychology, which will be offered to doctors and nurses of the ASL Napoli 2 Nord during 2026, with the aim of increasing their ecological awareness and their general well-being from a preventative perspective.

Site and stand features for nature-based health interventions: a systematic literature review

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Since the end of the 20th century, nature-based health interventions (NBIs)–activities that engage people in nature-based experiences to improve health and well-being–have assumed increasing importance worldwide with special regard to countries with advanced economies and stressful lifestyles of people. NBIs refers to spending time in a natural environment to walk, run practice tai chi or meditation techniques in order to improve the metabolism and helps to achieve relaxation and physical recovery. In literature, some studies have highlighted that NBIs–e.g., nature-based education, wilderness therapy, leisure activity, horticulture therapy, forest bathing and therapy–have positive impacts on the human immune system and mental health by reducing stress and anxiety. However, the natural sites where these activities are carried out must have some key features in order to optimize the positive effects of NBIs for human psycho-physical health. In this context, this study has conducted a systematic literature review in order to identify the key site and stand features for areas suitable for NBIs with special regard to forest bathing and therapy activities. To this end, the literature review conducted on the Scopus database (https://www.scopus.com) identified 70 peer-reviewed publications that were in-depth analysed. The results showed that the three most important site features are: accessibility, roughness and slope. A site to be suitable for "forest bathing" must be easily accessible, but at the same time not in the immediate vicinity of roads or parking lots, in order to avoid noise pollution disturbing the participants in the activity. Furthermore, the site must be characterized by low surface rockiness and a limited shrub and dead wood layer on the ground. Slope is another key variable as flat sites or those with a moderate slope (less than 10-15%) must be preferred. Another important aspect to improve the forest bathing activity is the presence of water elements (streams, waterfalls, small lakes) that can be important to stimulate the auditory, tactile and visual senses of the participants. Regarding the stand features, the results highlighted that the most important features are: tree species composition, age and stand structure. Tree species composition is the most important characteristic as it is closely linked to the quantity of Biogenic Volatile Organic Compounds-BVOC (d-limonene, a-Pinene e b-Pinene, b-Myrcene, Camfene) emitted by the tree species in the forest. Finally, some studies identified in literature have identified high forests (more than 60-70 years old) characterized by a diversified horizontal and vertical structure as ideal sites for NBIs.

Increasing connectivity between actors for a healthy and sustainable transition of the food system combining smart sales intermediaries with knowledge and communication/education activities

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Faced with today's major environmental challenges, the food system remains one of the most critical sectors due to its deep impact on the environment and people's lives. The European SWITCH project aims to promote healthy and sustainable diets across Europe by overcoming barriers related to accessibility and knowledge sharing. The project's actions, implemented in six European SWITCH Food Hubs, are based on three pillars: increasing KNOWLEDGE, enabling ACTIONABILITY, and promoting FACILITATION. In Rome, the local Food Hub coordinated by Agro Camera translated these goals into concrete actions. One of the three key interventions focused on strengthening the connection between citizens (consumers) and small local producers through a PILOT study based on the SPESABUS initiative. SPESABUS connects sustainable small-scale food producers with consumers, who value direct contact as a key benefit. Shortening the supply chain and supporting agrobiodiversity and sustainability-focused producers are considered essential to the food system transition by SWITCH. Recognizing that knowledge and education are fundamental for conscious choices and ecological transition, SPESABUS marketing activities were combined with informative and educational actions to: a) highlight the sustainability efforts of producers; b) educate consumers through concise messages about sustainable food practices. An agroecology questionnaire was developed to assess producers' sustainability levels, complemented by a video story from each producer. Key elements were extracted and turned into short educational messages. In addition, positive nutritional messages were created for the products offered, along with sustainable recipes featuring those same products. These materials were shared through SPESABUS social media channels. The effectiveness of the initiative was measured through consumer appreciation, analyzed via feedback and social media interactions, providing valuable insights into the impact of the awareness-raising and promotional activities.

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