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Indice

PARTE I

Presentazioni orali

L'ecotossicologia per la conservazione della biodiversità

1

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Behavioral and physiological responses of a Mediterranean coral to emerging contaminants

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Corals are fundamental elements of rocky shore coastal ecosystems, which are threatened by several local and global stressors including wastewater and river discharges, tourism and climate change. Among these, the impact of contaminants of emerging concern (CECs) still needs to be thoroughly investigated. The aim of this study was twofold: *i)* monitoring the health status of the Mediterranean zooxanthellate solitary coral *Balanophyllia europaea* in the Tyrrhenian Sea and *ii)* assessing sensitivity to polystyrene nanoparticles (PS NPs, 50 nm) and rare earth elements (Gadolinium, Gd) at low concentrations (10 µg/L–1 mg/L) on *B. europaea* adults (chronic, 28d) and larvae (acute, 48h, chronic, 28d). The natural population was monitored via mucus microbiome analysis and untargeted whole-organism metabolomics. Bench-studies on PS NPs and Gd ecotoxicity involved coral adults, evaluating mortality, predatory ability, photosynthetic efficiency, zooxanthellae count, pigment density and oxidative stress biomarkers, and coral larvae evaluating behaviour, mortality, metamorphosis and histological alterations. Results showed that both microbiome and metabolic profile were highly influenced by sampling times and environmental conditions. Bench-studies revealed no mortality in either larvae and adults, while acute Gd and PS NPs exposure caused a reversible alteration of larval swimming behaviour at 1 mg/L, and the chronic exposure caused structural depletion of surface cilia for PS NPs and 50% nonsense metamorphosis (metamorphosis without settlement) for Gd. Adults showed a mild reduction in photosynthetic pigments of zooxanthellae after 28 days with no alteration of photosynthetic efficiency and oxidative stress biomarkers. Overall data showed that larval swimming and adult mucus microbiomes provide effective, non-invasive indicators for early toxicity and wild coral health monitoring. Furthermore, these results emphasize the need to consider the vulnerability of early life stages in conservation strategies, highlighting how CECs can alter critical developmental processes in Mediterranean coral species.

Occurrence, fate, and microbial impacts of pharmaceuticals and personal care products (PPCPs) in the elsa river (Italy): a multi-compartment approach (water, sediment, and biota)

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Freshwater systems are among the most threatened ecosystems worldwide, facing degradation from multiple anthropogenic pressures, including the introduction of emerging contaminants such as pharmaceuticals and personal care products (PPCPs). To evaluate the occurrence, distribution, and ecological risk of PPCPs across environmental compartments, a multi-matrix study was conducted along the Elsa River (Tuscany, Italy). Seventeen PPCPs, spanning six therapeutic classes, were quantified in surface water, bed sediments, and muscle tissue of the bioindicator fish (*Squalius squalus*) across seven sampling stations influenced by agricultural, industrial, and urban inputs, including three municipal wastewater treatment plants (WWTPs). Concurrent microbiological analyses assessed effects on microbial community structure and abundance. Ten PPCPs were detected across the environmental matrices, with steroid hormones and analgesics/antipyretics being the most prevalent. Contamination levels increased from upstream to downstream, particularly in water and sediments, after WWTP discharge points. Caffeine was found at all sites and across all matrices, serving as a clear indicator of continuous anthropogenic pressure along the entire river. The steroid hormones almost consistently exceeded the proposed WFD EQS limits in nearly all matrices and sampling sites. Risk quotient (RQ) analysis showed low risk (RQ < 1) for most compounds in water, though ibuprofen and steroid hormones frequently reached RQ >1. In sediments, amoxicillin, ibuprofen, caffeine, and steroid hormones posed high risks to benthic organisms, while all steroid hormones exhibited high RQs in biota. Microbiological assays revealed some shifts in microbial communities concurrent with elevated PPCP loads. These findings confirm WWTPs as principal contaminant sources and underline the urgent need for integrated multi-compartment monitoring, wastewater treatment upgrades, and targeted mitigation.

Multi-tier ecotoxicological evaluation of a commercial PEG-based formulation on zebrafish embryos

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Water-soluble polymers (WSPs) are widely used in industrial, medical, and consumer applications. Their large-scale production and the lack of dedicated regulatory frameworks contribute to their continuous and uncontrolled release into aquatic environments. Although WSPs have been traditionally considered environmentally safe based on conventional apical (eco)toxicological assays, growing evidence indicates that they may induce sub-lethal effects in aquatic organisms. So far, most studies have focused on pure polymers, overlooking the complexity of commercial formulations actually entering the environment. Among WSPs, polyethylene-glycol (PEG) is one of the most widely used, particularly in pharmaceutical products, such as laxatives, often composed of high-molecular-weight PEG and formulation additives that may significantly alter environmental fate and (eco)toxicity. This study aims to investigate the potential effects of two formulations of the same PEG-based laxative: (*i*) pure PEG-4000, (*ii*) PEG-4000 (5 g in 10 mL) dissolved in purified water and combined with two additives (potassium sorbate, citric acid). *Danio rerio* embryos were exposed to both treatments at equivalent PEG concentration of 0.1 mg/L. A multi-tier approach was applied to assess effects from molecular to organism level, including metabolomics, biomarkers of oxidative stress and neurotoxicity, cardiac activity, morphometric parameters, histology, (immuno)histochemistry, spontaneous coil-tailing activity, and swimming behaviour. Results revealed formulation-dependent responses. Embryos exposed to PEG+additives showed significantly ($p < 0.05$) lower reactive-oxygen species (ROS) production and ethoxyresorufin-O-deethylase (EROD) activity. Conversely, cardiac activity exhibited divergent responses, decreasing significantly in embryos exposed to pure PEG, but increasing significantly following exposure to PEG+additives. Moreover, both treatments altered swimming pattern under dark conditions and stress-related behaviour under light conditions. Although some analyses are still ongoing, these findings suggest that additives in commercial WSP-based formulations play a key role in modulating the toxicity of WSPs. Overall, this study highlights the importance of assessing complete commercial formulations to improve the environmental risk assessment of WSPs.

From soil to barn swallows: trophic transfer of sewage sludge-derived trace elements and nestling physiological condition in agroecosystems

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Sewage sludge, the solid by-product of wastewater treatment, is increasingly applied to agricultural land as a soil amendment. However, wastewater treatment plants are not specifically designed to remove trace contaminants, which may accumulate in sludge and subsequently enter ecosystems. Understanding the bioaccumulation and trophic transfer of these contaminants, as well as their effects on wildlife, is therefore essential for evaluating the sustainability of sewage sludge management. To assess the bioaccumulation and trophic transfer of trace elements derived from sewage sludge, we quantified the concentrations of 11 trace elements across a simplified agroecosystem food web, including soil, plants, insects, and barn swallows (*Hirundo rustica*), comparing farms with and without sludge application. Particular attention was given to barn swallows, which act here as top predators and may serve as bioindicators of contaminant exposure. Potential effects on nestlings were assessed using growth, haematocrit, and telomere dynamics as biomarkers of physiological condition. Multivariate analyses revealed distinct contamination profiles across the four matrices, driven by differences in the distribution of individual contaminants. In addition, patterns of contaminant transfer across trophic levels varied among trace elements. Finally, barn swallow nestlings raised in sludge-amended areas showed no significant differences in growth or telomere shortening compared with those from control areas. However, haematocrit values increased with contamination levels, reflecting either an increase in red blood cell concentration, indicating a systemic inflammatory response, or a reduction in plasma volume due to dehydration, a condition often associated with elevated metal exposure. The limited differences in trace element concentrations and the absence of clear adverse effects between sludge-amended and control areas suggest that sewage sludge application has only minor impacts on the studied agroecosystem. Nevertheless, further research is needed to better understand the ecological consequences of sludge use by investigating additional toxicity endpoints and considering other species as ecological indicators.

Ecotoxicological assessment of wastewater treatment polymers in *Daphnia magna*

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Wastewater treatment plants are essential infrastructures for protecting aquatic ecosystems, as they remove chemical and biological contaminants from domestic, industrial, and agricultural effluents before environmental discharge. Wastewater commonly contains fine suspended and dissolved solids, including inorganic and organic particles, whose small size makes their removal particularly challenging. Among available technologies, coagulation and flocculation are widely applied for colloid removal and rely on polymeric compounds of either synthetic or natural origin. Although only a limited fraction of these compounds is expected to remain in the treated effluent, their extensive use raises concerns regarding potential impacts on aquatic ecosystems.To evaluate the ecotoxicological effects of selected flocculants and coagulants, *Daphnia magna* was used as a model organism. Due to the limited information available on the environmental occurrence, fate, and toxicity of these polymers, a preliminary range-finding test was performed. Based on the 48-h immobilization assay, EC10 concentrations were selected and applied in a 14-day chronic exposure experiment under environmentally relevant conditions. The tested compounds were selected from a previous study identifying the most effective treatments for the removal of organic matter and plastic particles from wastewater. Polyacrylamides, starch-based, and tannin-based compounds were evaluated as flocculants, while poly-aluminum chloride was tested as a coagulant. Effects were assessed from organismal to cellular levels, including immobilization, growth, behavior, reproduction, feeding activity, oxidative stress, neurotoxicity, and energy metabolism biomarkers. Preliminary results suggest markedly higher toxicity associated with synthetic flocculants, with immobilization rates ranging from 90% to 100%. In contrast, naturally derived compounds exhibited lower toxicity while maintaining high removal efficiency for both chemical contaminants and plastic particles, highlighting their potential as more sustainable alternatives for wastewater treatment applications.

Toxicity assessment of perfluorooctanoate (PFOA) in a freshwater microcosm

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The presence of per-and poly-fluoroalkyl substances (PFAS) in environment poses a serious risks to organisms due to their persistence, bioaccumulation and negative effects. Among PFAS, perfluorooctanoate (PFOA) has been recognized as one of the most hazardous compounds. Despite extensive research on PFOA toxicity, its effects on ecosystem structure and functioning remain poorly understood, as most studies focused on classical model organisms providing limited information on ecosystem-level responses. The aim of this study is to investigate the potential ecosystem-level toxicity induced by PFOA, using microcosms which contain a simplified freshwater ecosystem. The microcosm-experiment was conducted at Wageningen University. Microcosms containing a 3cm sediment layer, 12L of natural pond water, phytoplankton and zooplankton communities, macroinvertebrates (*Asellus aquaticus, Gammarus pulex* and *Physella acuta*) and a macrophyte (*Myriophyllum spicatum*), which were exposed for seven weeks to four PFOA-concentrations (1000μg/L; 100μg/L; 10μg/L; 1μg/L). Each treatment was replicated four times and the control six times. Ecosystem processes were evaluated weekly through measurements of dissolved oxygen fluctuations and physicochemical water parameters, while PFOA concentrations in the water were monitored at selected time point. The focal endpoints evaluated were connected to ecosystem structure and functioning: 1) measurements of phytoplankton biomass (chlorophyll-a); 2) organic matter decomposition; 3) zooplankton community composition; 4) macroinvertebrate abundance and feeding activity; 5) macrophyte growth and biomass. At the end of the experiment oxidative stress biomarkers were used to assess potential negative effects at sub-individual level on macrocrustaceans. Our preliminary results showed no significant effects of PFOA on ecosystem functioning parameters, although the results of some endpoints are not available yet. However, based on previous findings on oxidative stress biomarkers, we expect PFOA exposure to alter the oxidative status of the investigated macroinvertebrates. Overall, these results highlight the value of ecosystem-level approaches for assessing the effects and ecological risks of PFAS in aquatic environments.

Reading rare earth element signals through multiple matrices: a benthic community at a Mediterranean shallow hydrothermal vent

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The rare earth element (REE) signal recorded in a coastal system depends on which organism is used to read it, yet how differently co-occurring species capture that signal is rarely examined directly. REEs are increasingly recognised as emerging contaminants of global concern, yet their behaviour remains comparatively understudied in marine environments. Shallow-water hydrothermal vents enrich coastal waters and sediments with REEs, providing a natural laboratory for examining the transfer from the sediment to biota. At the shallow CO_2-vent system of Levante Bay (Vulcano Island, Southern Tyrrhenian Sea, Italy), we examined REE transfer across multiple matrices: sediment and three co-occurring, functionally distinct benthic organisms that intercept REEs through complementary exposure pathways, sampled at a low-pH (7.5) and a high-pH (8.16) site: the seagrass *Cymodocea nodosa*, the sea anemone *Anemonia viridis* and the goby *Gobius incognitus*. Bio-Sediment Accumulation Factor values (BSAF) remained below unity in every matrix at both sites, indicating limited transfer despite marked hydrothermal enrichment. Post-Archean Australian Shale (PAAS) normalised patterns, diagnostic anomalies, and multivariate ordination indicated that a single sediment source was not merely reflected in the organisms. Instead, it was reworked into three distinct biotic signatures. These signatures ranged from a passive, light REE-enriched profile to a biologically fractionated, heavy REE-enriched one, with the goby exhibiting a low, weakly structured profile. Across these analyses, matrix identity structured REE accumulation more consistently than the pH gradient. Reading the REE signal across multiple matrices, therefore, resolves features of its distribution that no single bioindicator captures, providing diagnostic information directly relevant to monitoring the quality and conservation status of coastal ecosystems.

Environmental conditioning modulates the biological effects of glitter particles in freshwater crayfish

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Glitter particles are increasingly recognized as a potential source of microplastic contamination in aquatic environments, yet their effects on freshwater invertebrates remain poorly investigated. This study assessed the accumulation and biological effects of pristine, non-conditioned glitter particles (NCG) and environmentally conditioned glitter particles (CG) in the red swamp crayfish *Procambarus clarkii*. Crayfish were exposed under laboratory conditions to three glitter concentrations, 0.067, 0.134, and 0.268 g/L, alongside a control treatment. Since no significant concentration-dependent responses were detected, subsequent analyses focused on glitter type and individual glitter burden in the gastrointestinal tract.Both NCG- and CG-exposed groups showed markedly higher gastrointestinal burdens than controls. Oxidative stress biomarkers and elemental analyses in the hepatopancreas revealed significant treatment-related differences in glutathione peroxidase (GPx) activity and in several elements, including Cr, Cs, Ga, Si, Tl, and Zn. Moreover, glitter burden was positively correlated with glutathione reductase (GR), GPx, carboxylesterase activity measured using pNPB as substrate (CE-pNPB), and N-acetyl-β-D-glucosaminidase (NAG), indicating activation of antioxidant, detoxification, and lysosomal pathways with increasing particle accumulation.Multivariate analyses provided stronger evidence of treatment effects than individual biomarkers alone. Principal component analysis highlighted treatment-related shifts in integrated biochemical and elemental profiles, while PERMANOVA demonstrated a significant effect of treatment on the overall physiological status of crayfish. Integrated Biomarker Response analysis using the IBR-T approach further supported these findings, revealing a higher biological response in crayfish exposed to non-conditioned glitter (IBR-T = 1.88; 5/13 biomarkers modulated) than in those exposed to conditioned glitter (IBR-T = 1.73; 4/13 biomarkers modulated).Overall, these findings demonstrate that glitter particles can induce measurable physiological alterations in freshwater crayfish and suggest that environmental conditioning may influence both the magnitude and nature of biological responses. Glitter should therefore be considered an emerging contaminant of ecotoxicological concern.

From contamination to conservation: ecotoxicological insights into pharmaceutical impacts on plankton communities

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Pharmaceutical compounds (PCs) are one of the main classes of emerging contaminants, raising concern due to their potential impact on aquatic ecosystems. Among the most widely prescribed PCs worldwide, acyclovir (ACV), carbamazepine (CBZ), diclofenac (DCF), and propranolol (PRP) are frequently detected in marine environments, due to the limited removal efficiency of conventional wastewater treatment plants. Consequently, marine organisms are continuously exposed to PCs residues, yet their ecotoxicological effects remain largely unexplored. In this study, we investigated the acute toxicity of ACV, CBZ, DCF, and PRP on key marine phyto- and zooplankton species, including the microalgae *Dunaliella tertiolecta*, *Phaeodactylum tricornutum*, and *Skeletonema pseudocostatum*, as well as the invertebrates *Amphibalanus amphitrite* and *Paracentrotus lividus*. Ecotoxicological responses were assessed over 72h by investigating growth and chlorophyll inhibition, mortality, developmental anomalies and behavioural alterations, following exposure to both environmentally relevant and elevated concentrations of the tested PCs. No ecotoxicological effects were observed at environmentally realistic concentrations. Conversely high concentrations of all four PCs significantly affected both primary producers and consumers. PRP exhibited the highest toxicity, followed by DCF, ACV, and CBZ. An environmental risk assessment, based on observed ecotoxicological responses, highlighted a high risk associated with DCF and PRP exposure, while ACV and CBZ showed a medium risk potential. Overall, these findings reveal that all PCs can affect multiple trophic levels of marine planktonic communities, emphasizing the need to monitor their occurrence and concentrations in marine ecosystems to support strategies for ecosystem and biodiversity conservation.

Wastewater treatment plant bypass flows as an underestimated source of microplastics to surface waters

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Microplastics (MPs) are widespread across environmental compartments and originate from land-based sources such as urban runoff, agriculture, wastewater treatment plants (WWTPs). Among these sources, WWTP bypass flows remain largely unknown, despite their relevance as contaminant inputs. Bypass flows may be activated during intense rainfall events, whose frequency is expected to increase due to climate change. During these events, untreated wastewaters are released into rivers discharging into receiving lake. Due to its semi-closed shape, long hydraulic residence time, and ecological importance, Lake Como represents a case study for evaluating how episodic untreated discharges and continuously treated effluent inputs influence contaminant dynamics in freshwater ecosystems. MPs were identified through fluorescence microscopy after Nile Red and Bengal Rose co-staining, while polymer composition and mass were determined by Pyrolysis–Gas Chromatography–Mass Spectrometry (Py–GC–MS). Results indicate that bypass flow events increase MP loads in the river flowing into the lake, contributing an estimated ~200 kg/year. Overall, lake showed low pelagic concentrations but pronounced accumulation in littoral zones and shallow sediments. Fine particles (<50 µm) and fragments dominated. Polyethylene (PE) and Polypropylene (PP) were the main polymers in waters, with Styrene Butadiene Rubber (SBR) prominent in stormwater, while sediments and hypolimnetic samples showed greater diversity (PE, PP, and Nylon 6,6). Results indicate that episodic bypass discharges may represent an underestimated pathway for MP inputs into freshwater ecosystems. Although pelagic concentrations remained generally low, MPs accumulated in littoral areas and shallow sediments, creating potential hotspots of exposure for benthic and nearshore organisms. The predominance of small particles (<50 µm) is of ecological concern, as these size fractions are more readily available for ingestion across multiple trophic levels. Under future climate scenarios, the increasing frequency of intense rainfall events may enhance untreated wastewater releases, potentially increasing MP exposure and ecological risks in freshwater food webs.

Mitochondrial DNA copy number as an early-warning tool for environmental monitoring: evidence from cross-taxon in a site of national interest in eastern Sicily

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Growing anthropogenic impacts on ecosystems pose a serious threat to biodiversity and environmental health, with effects that extend along food webs right up to humans. In this context, the identification of sentinel organisms and early-warning molecular biomarkers is a priority, especially from a One Health perspective, which recognizes the intrinsic connection between the health of ecosystems, animals, and humans.In this regard, variation in mitochondrial genome copy number (mtDNAcn) represents a promising candidate because of its vulnerability to oxidative stress. Although mtDNAcn is already recognised in clinical practice as a marker of oxidant-mediated diseases, its use in wild organisms remains unexplored, representing a frontier of scientific and translational interest.The contribution reported here aims to address this gap through three investigations conducted at a Site of National Interest (SNI) in eastern Sicily, characterized by historical and widespread contamination, which represented one of the most concerning sources of Hg at Mediterranean scale.In the first study, the leafhopper *Opsius heydeni* — a sap-feeder on *Tamarix spp*., plants known for accumulating heavy metals — shows a mtDNAcn reduction in the SNI compared to the control site. The second research, conducted on three commercial fish species, confirms a relationship between mercury bioaccumulation levels and mtDNAcn variations. Furthermore, the findings appear species-specific — a decrease in *Mullus barbatus* and *Pagellus erythrinus*, and an increase in *Diplodus annularis* were observed — reflecting ecological and physiological differences. The third study introduces the blue crab *Callinectes sapidus*, an alien and edible species, as a potential bioindicator in Mediterranean Sea, detecting a mtDNAcn reduction in SNI specimens.Overall, these outcomes support mtDNAcn as a promising early-warning tool capable of reflecting oxidative stress triggered by contaminants in phylogenetically distant taxa. Further comparative researches across animal species are recommended to strengthen its use in integrated environmental monitoring, in line with a One Health approach.

Beyond PCBs: new PCB metabolites in a terrestrial ecosystem around a PCB landfill in Brescia province

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Polychlorinated biphenyls (PCBs) are persistent organic pollutants banned under the Stockholm Convention but still detected in contaminated soils, biota, and food matrices after production stopped. In northern Italy, the Caffaro chemical plant in Brescia, operated as one of Europe's largest PCB manufacturers until the 1980s and, now designated as a Site of National Interest (SIN) for this contamination. The distribution and the concentration of parent PCB congeners in this region have been documented but less attention has been given to their transformation products including sulfonated PCBs ($PCB - SO_3H$), hydroxylated-sulfonated PCBs ($OH - PCB - SO_3H$), and hydroxylated PCBs (OH-PCBs). These metabolites are product during biotic and abiotic degradation and can have different environmental mobility, bioaccumulation and toxicity profiles that are still unknown. Recent investigations revealed PCB-SO H and OH-PCB-SO H as novel categories of intermediates of PCB degradation in soil, accounting for about 1% of parent compounds. These metabolites tend to bioaccumulate in earthworms although their ecotoxicity is still unknown. Additionally, their behavior in the soil-plant ecosystems and the possibility of their entry into food chains have not been adequately elucidated. This study investigated PCB and PCB metabolite levels in soils, plant biomass, and other media collected around a historical PCB landfill in Passirano (Brescia province), where industrial waste from Caffaro and other industrial plants was stored in a landfill. The main aim was to assess whether this localized contamination source could generate measurable concentration gradients across the surrounding environment and to evaluate possible transfer pathways from soil to vegetation. The results contribute to a better understanding of PCB cycling in legacy-contaminated agricultural soils and underline the need to include metabolite monitoring alongside parent congeners in environmental risk assessments.

Comparative toxicity of road wear particles (RWPs) generated from different asphalt surfaces

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Vehicular traffic generates the so-called Tire Road Wear Particles (TRWPs), debris produced by the wear of both tires and road pavements. Asphalts, in turn, can be modified with recycled rubber from End-of-Life Tires (ELTs) and polymers to improve their mechanical performance and reduce traffic noise. Therefore, the aim of this study was to determine whether the incorporation of recycled rubbers and polymers into asphalt mixtures affects the toxicity of obtained particles. Since TRWP toxicity is strongly influenced by environmental factors, such as road runoff, as well as by the wide plethora of chemicals derived from vehicular traffic, the particles used in this study were produced under controlled laboratory conditions to specifically investigate the effects of rubbers and plastics used in the asphalt mixtures. As these particles do not contain the fraction originating from tire tread abrasion, they are referred to as Road Wear Particles (RWPs). The resulting powders were characterized by Scanning Electron Microscopy (SEM) coupled with Energy-Dispersive X-ray Spectroscopy (EDS). Aqueous suspensions of RWPs were then prepared by stirring for 72 h, followed by a 48 h settling and subsequently characterized by Dynamic Light Scattering (DLS). Zebrafish larvae were exposed to 10 and 100 µg/L of RWP suspensions from 0 to 120 hours post-fertilization (hpf). Adverse effects were assessed using a comprehensive battery of biomarkers related to cellular stress, neuro-genotoxicity, heart rate alterations, and swimming behavior. All endpoints were integrated into the Biomarker Response Index (BRI) to obtain a toxicity scale of the tested materials. The main findings indicate that particles generated from modified asphalts do not exhibit a clear increase in toxicity, as particles derived from conventional asphalt frequently showed comparable toxic effects. These results are further supported by a previous study in which environmentally TRWPs were found to be more toxic when associated with conventional asphalt.

Effects of pristine and aged microplastic leachates on behavioural responses of soil arthropods

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In agriculture, plastic mulching films enhance nutrient efficiency and provide thermal insulation. However, the use of mulches has been debated due to its potential to adversely affect the biodiversity of agroecosystems. The present study aimed to evaluate the behavioural responses of the arthropods *Folsomia candida* (springtails) and *Porcellionides pruinosus* (woodlice) to leachates released from LDPE and PP additive-free plastic granules. The leachates of pristine and artificially aged LDPE and PP were tested at three different concentrations, ranging from environmentally relevant levels to a worst-case scenario of soil contamination. Avoidance behaviour was evaluated to assess its potential impact on soil habitat function, while aggregation status to identify possible functional impairments in the woodlice population. The loss of aggregation behaviour can in fact expose individuals to dehydration and reducing their fitness. The results showed no statistically significant avoidance responses in arthropods to either treatment. In contrast, useful data on the potentially higher hazard posed by LDPE than by PP were obtained by evaluating the disaggregation behaviour of woodlice. Disaggregation assays revealed that plastic leachates may influence social behaviour. Unlike PP, LDPE induced a statistically significant impairment of gregarious behaviour at the highest tested concentration (150 mg/kg d.w.). Furthermore, pristine LDPE exhibited more pronounced disaggregation than aged LDPE, suggesting that weathering may modulate behavioural responses depending on the polymer type and the endpoint. The differing chemical reactivities of LDPE and PP are hypothesised to have contributed to the observed effects, given their distinct product release profiles. In particular, PP produced larger amounts of low-molecular-weight oxygenated compounds, while LDPE showed higher relative amounts of long-chain alkanes. Therefore, it is suggested that high levels of plastic leachates can adversely affect soil arthropods, and that the aggregation behaviour of woodlice might be a more informative and sensitive biological endpoint than avoidance alone.

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) comprise a large class of synthetic chemicals characterized by high thermal and chemical stability, as well as hydrophobic and oleophobic properties. These characteristics have led to their widespread use in numerous industrial and consumer products. Their extensive application has resulted in continuous environmental release, making PFAS ubiquitous contaminants. Due to growing concerns regarding their persistence and toxicity, several legacy PFAS, such as perfluorooctanoic acid (PFOA), have been restricted or phased out and replaced by newer compounds, which are assumed to be less hazardous. However, information on their environmental impacts remains limited. This study evaluated and compared the ecotoxicological effects of a 21-day exposure to PFOA and three emerging molecules (ADV MFS-N2, ADV MFS-N3, and ADV MFS-M3) in *Daphnia magna*. Organisms were exposed to environmentally relevant concentrations (150, 1500, and 3000 ng/L), selected based on levels detected in the discharge channel of a fluorochemical plant and freshwaters of the receiving river. Effects were assessed at both sub-individual and individual levels by measuring energetic biomarkers (lipids, proteins, carbohydrates, and total caloric content), body size traits, swimming behavior, and survival. PFOA exposure caused slight adverse effects, mainly consisting in a reduction in total body length. In contrast, ADV MFS-N2 induced significant adverse responses across multiple endpoints, indicating a higher toxic potential than the legacy compound. These findings highlight the need for further investigation on the environmental fate and ecotoxicological effects of emerging PFAS, as their widespread occurrence may pose risks to aquatic ecosystems and potentially to human health.

New models for new contaminants: integrating literature gaps and gadolinium toxicity in brittle stars

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Historically, marine ecotoxicology has relied on a limited range of model organisms, primarily sea urchins (Echinoidea), resulting in an incomplete representation of the functional biodiversity of coastal ecosystems. This study combines a thorough 20-year literature review of underutilised echinoderm classes (Asteroidea and Ophiuroidea) in ecotoxicology with an original experimental investigation into the biological effects of gadolinium (Gd), a rare earth element of significant concern due to its release from medical contrast agents.By systematically analysing 74 peer-reviewed publications (2005-2025), we first mapped taxonomic and methodological gaps. Crucially, the review highlighted that brittle stars possess several welfare-friendly endpoints (e.g., behavioural and regenerative traits) that are highly valuable within a modern 3Rs vision (Replacement, Reduction, Refinement), despite a strong historical bias in literature towards trace elements and destructive bioaccumulation endpoints. To address these knowledge gaps, a 7-day laboratory exposure experiment was conducted using two Mediterranean brittle star species, *Ophiactis virens* and *Amphipholis squamata*, exposed to a Gd concentration gradient (from 1 to 750 µg/L). Sub-lethal biochemical responses were investigated using a range of cellular biomarkers, including superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), glutathione S-transferase (GST), glutathione reductase (GR), and lactate dehydrogenase (LDH).Experimentally, exposure to Gd triggered early and significant alterations in oxidative stress biomarkers in both species. Distinct species-specific sensitivity profiles and significant metabolic changes were observed even at environmentally realistic concentrations. Combining the review's theoretical framework with novel experimental data demonstrates that brittle stars represent robust, highly sensitive models capable of diversifying benthic bioindicators within an ethically refined ecotoxicological framework.

Interactions of PLA microplastics with *Schmidtea mediterranea*

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Poly-lactic acid (PLA) is a biodegradable, bio-based thermoplasticderived primarily from renewable resources such as corn starch or sugarcane. It's widely used in packaging, biomedical devices, textiles, and increasingly in 3D printing, owing to its ease of processing, compostability, and relatively low environmental impact.While it is generally considered non-toxic in its bulk form, its degradation products, such as lactic acid and related oligomers, and micro/nanoplastics, may pose risks to aquatic ecosystems. This study investigates the potential effects of PLA microplastics (MPs) on *Schmidtea mediterranea*, a freshwater planaria, recognized for its regenerative capability and sensitivity to environmental stressors, positioning it as promising bioindicator in toxicological research. Exposure experiments were designed to evaluate the effects of PLA MPs through the alimentary route, while comparative analyses withMPs derived from the conventional plastic polyethylene terephthalate (PET), were also performed. Environmentally relevant PLA and PET MPs were produced throughmechanical fragmentation of bigger particles, enabling the generation of MPs with realistic chemical and morphologicalcharacteristics. Through size fractionation the desired size distributions of both models were selected, and a detailed physicochemical analysis was performed revealing their characteristics. Alimentary exposure experiments to the planaria indicate that the MPs were effectively introduced in the digestive system of the planaria, with the PLA MPs not to exert significant toxic effects, likely due to the organisms' ability to efficiently eliminate the ingested particles (Bernardeschi, 2025).

PFAS toxicity in earthworms: an integrated multi-biomarker and multi-variate assessment

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Per- and polyfluoroalkyl substances (PFAS) occur in terrestrial ecosystems as complex mixtures, and their ecological effects are more accurately characterized through the integration of multiple complementary biomarkers rather than single-endpoint assessments. In earthworms, innate immune and stress-response pathways provide sensitive indicators of contaminant-induced physiological alterations across different levels of biological organization. The present study aimed to investigate the potential synergistic or antagonistic effects of PFAS mixtures in earthworms using a multi-biomarker approach. To this end, a suite of molecular and cellular biomarkers was evaluated, including haemocyte morphometric alterations, reactive oxygen species (ROS) production, catalase (CAT) activity, phenoloxidase (PO) activity, acetylcholinesterase (AChE) activity, and γ-aminobutyric acid (GABA) levels. Biomarker responses were assessed in earthworms exposed either to five individual PFAS compounds or to an equimolar five-component mixture under a one-fifth dosing design (individual PFAS: 0.12, 0.84, and 45.8 µM; PFAS mixture: 0.6, 4.2, and 229 µM total concentration).Across all endpoints allowing direct comparison, the observed effects of the PFAS mixture were consistently lower than the sum of the corresponding single-compound effects, indicating predominantly sub-additive interactions. Observed-to-additive ratios ranged from approximately 0.18 to 0.66 for haemocyte morphometry, AChE activity, and ROS production, while PO activity exhibited an even stronger sub-additive response. No evidence of synergistic interactions was detected for any biomarker. Multivariate ordination analysis integrating the five fully crossed endpoints revealed a two-dimensional response pattern, with PFOA and the PFAS mixture clustering separately from ether-based and short-chain PFAS congeners. Together with the observed haemocyte spreading phenotype, these findings indicate a coherent, multi-level disruption of immune and oxidative stress pathways in earthworms. Overall, the results suggest that PFAS mixtures act predominantly through sub-additive mechanisms, with the combined biological response largely driven by the most toxic constituent present in the mixture.

Setup of freshwater mesocosms to evaluate exposure and effects on macroinvertebrate communities to WWTP wastewater receiving textile discharges

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Per- and polyfluorinated alkyl substances, PFAS, have emerged as contaminants of global concern due to their extensive industrial use, environmental persistence, mobility, and potential adverse effects on ecosystems and human health. The LIFE-CASCADE project aims to develop innovative analytical methods and wastewater treatment technologies to improve the detection and removal of these emerging contaminants from textile industry effluents. Within this framework, a mesocosm experiment was conducted using artificial ditch systems to investigate PFAS dynamics, bioavailability, and ecological effects associated with wastewater discharged from the Bulgarograsso WWTP (Como, Italy). Mesocosms represent a more realistic way to evaluate community dynamics than single species tests. Five stainless steel canals were established and supplied with different water sources: one received background water as a control, while the others were fed with WWTP outflowing water before and after ozonation. Chemical and biological analysis were conducted before treatments (T-1), after 1 hour from the treatments (T0), after 1 day (T1, acute effect evaluation), and after 15 and 30 days (T15 and T30, chronic effect evaluation). The experiment was designed to evaluate the suitability of the mesocosms, verify the effectiveness of macroinvertebrate colonization, and identify the temporal scale at which potential PFAS-related (or other chemical) effects on aquatic communities could be detected. Chemical analyses revealed that PFPeA and PFHxA were the dominant compounds across treatments. An increase in short-chain PFAS concentrations was observed between T0 and T1, suggesting the possible transformation of precursor compounds. Similar concentration patterns detected in both ozonated and non-ozonated treatments indicate a limited effectiveness of ozonation in reducing PFAS loads under the tested conditions. Preliminary analyses of macroinvertebrate communities showed a decrease of 25 % of macroinvertebrates collected at T1 versus control, and about 30% at T15, with a prevalence of *Chironomidae* among the individuals, while full diversity and abundance analyses are ongoing.

Do biodegradation and photodegradation on leaves change the impact of polycyclic aromatic hydrocarbons on terrestrial ecosystems? Insights from laboratory data and modelling results

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Polycyclic aromatic hydrocarbons (PAHs) constitute a class of organic contaminants, that can derive from the incomplete combustion of wood and fossil fuels and vehicular traffic. Once emitted they can be found in air as gas or particulate phase. Plants can remove PAHs from the air through the so-called Forest Filter Effect (FFE) accumulating these compounds in leaves and transferring them to soil. Moreover, phyllosphere microorganisms can contribute to the biodegradation of PAHs. However, no studies are available so far about the presence and source of PAH metabolites in plant leaves.In this work, new aspects of FFE were investigated through several laboratory experiments. More specifically, the study was designed to evaluate for the first time the contribution of light and microbial communities of *Quercus ilex* leaves to the degradation of deuterated PAHs. Such degradation was investigated by observing the production of deuterated hydroxy-PAHs. This was performed using an UHPLC-HRMS (LC-Orbitrap). In addition, a dynamic multimedia fate model (SoilPlusVeg) was used to predict the fate of PAH and their metabolites in a terrestrial ecosystem.Hydroxy-PAHs were produced both in light and dark conditions, while their appearance in sterile controls was negligible, highlighting the degradation ability of native phyllosphere microbial communities.Laboratory data and model predictions showed that FFE can be enhanced by photo- and biodegradation, because these reactions could help to maintain a high air to leaf PAH gradient, since these compounds could be continuously removed. Additionally, the metabolites produced, being more polar and less hydrophobic, are likely washed off during rainfall, and transported to the terrestrial environment, restoring the PAH gradient.Further and more realistic studies are necessary to better quantify the contribution of phyllosphere biodegradation and photodegradation on PAH removal from air and their precise role in FFE. PAH metabolite ecotoxicity needs also to be evaluated.

Conservazione, gestione, restauro di specie, habitat ed ecosistemi

2

Coordinatori: Mariachiara Chiantore, Gianluca Sarà, Valentina Asnaghi, Paolo Biel-
la

Genetic composition of coral-associated Symbiodiniaceae algae across the Mediterranean Sea

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Symbiotic dinoflagellates of the family Symbiodiniaceae play a fundamental role in shallow water coral physiology, ecology, and resilience to environmental change. Variations in symbiont composition can influence the response of host coral to thermal stress and other environmental stressors, making the characterization of coral-algal associations particularly relevant in the context of climate change. Despite their ecological importance, information on the large-scale distribution and composition of symbiotic algae in Mediterranean scleractinian corals remains limited. In this study, we assessed the genetic diversity of Symbiodiniaceae algae associated with two scleractinian species, namely *Balanophyllia europaea* and *Cladocora caespitosa*, using high-throughput sequencing of the Internal Transcribed Spacer 2 (ITS2) rDNA. A total of 204 coral samples were investigated across latitudinal and longitudinal gradients of environmental parameters at nine sites in the Mediterranean Sea, including Italy, France, and Cyprus. While *B. europaea* consistently harboured *Philozoon* dinoflagellate algae, colonies of *C. caespitosa* showed a major proportion of *Philozoon* ITS2 sequences at the western sampling sites and of *Breviolum* ITS2 sequences at the eastern sites. The potential roles of host species, site, and environmental conditions in shaping the coral-algal associations were tested via statistical analyses. Considering the ongoing warming of the Mediterranean Sea, this molecular characterization of coral-associated Symbiodiniaceae algae represents a baseline for comparisons with future trajectories. In addition, the results obtained in this study may have implications for restoration initiatives, with relevance for conservation and management strategies of the two investigated coral species.

A living lab approach to enhance local pollinator conservation across urban and agricultural landscapes

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Biodiversity supports essential ecosystem services, with pollination playing a crucial role in both natural ecosystems and agricultural production. However, pollinators are increasingly threatened by multiple factors and are consequently declining, making ecological restoration and habitat management at local and landscape scales widely recognized strategies to support pollinator communities and the services they provide. To tailor ecological restoration efforts in a densely urbanized region, the Lombardy Living Lab was established as a collaborative network connecting protected and recreational green areas, community allotments, farms and society representatives in and around Milan. Developed within the EU Horizon projects Butterfly and ProPollSoil, the Living Lab provides a unique opportunity to evaluate how management and restoration practices affect pollinators and the ecosystem services they support across urban and agricultural landscapes. In 2026, to establish a baseline of pollinator and flowering plant diversity in relation to ecosystem services, we conducted surveys in cherry, blueberry and apple orchards. We identified the pollinator assemblages most relevant to crop pollination and yield across different landscapes and farm environments. First results indicate that pollinator communities differ among crop species and are influenced by co-flowering wild plants. Moreover, we investigated the role of pollinators throughout the entire cherry supply chain, confirming its strong dependence on insect pollination and emphasizing the need for targeted pollinator support measures. To further assess how habitat enhancement actions (reforestation and flower strips) influence pollinator diversity, we investigated flower-visiting and ground-nesting pollinators across the Living Lab. Preliminary findings reveal strong differences between sites with enhanced habitats and those without, underscoring the importance of habitat quality and resource availability for pollinator conservation. These results provide a baseline for developing actions aimed at reversing pollinator decline while increasing awareness of the fundamental role pollinators play in biodiversity conservation, ecosystem functioning and sustainable food production.

Enhancing biodiversity associated with trees in urban ecosystems through research, policy and management

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Urban biodiversity is critically undermined by the loss and mismanagement of habitat trees—living or dead trees that provide essential microhabitats for highly specialized organisms. Although urban tree planting initiatives are widely promoted, urban forests often lack age diversity, with mature and senescent trees being rare or absent.In our research project, we monitored biodiversity associated with different urban trees across two study areas in Italy (Milano and Pesaro) and investigated the biological communities associated with habitat trees by assessing biodiversity across multiple taxonomic groups. Biodiversity was studied to address the question of what contribution habitat trees and the micro-niches they provide make to habitat provisioning for biodiversity. Abundance and diversity were therefore analyzed across the full height of the tree in order to describe patterns of vertical distribution. Our findings demonstrate that habitat trees support a high abundance and diversity of invertebrate communities, including rare and protected species, many of which depend on specific microhabitats and vertical patterns exists. This evidence highlights that urban tree management interventions can have substantial and often underestimated ecological impacts. For example, simplifying tree structure with damaging pruning techniques or reducing tree height can negatively impact urban biodiversity. In response, we propose integrating ecological criteria into arboricultural practice and urban policy related to green infrastructure by developing standardized approaches for identifying, mapping, and retaining habitat trees. Such approaches support the creation of ecological networks and promote uneven-aged urban forests as a strategy for long-term resilience. We further emphasize key conceptual tools for policy and practice, including ecological non-substitutability, net benefit assessment in tree management, and others. We argue that effective nature restoration in urban environments must explicitly include the conservation of habitat trees, as these structures are ecologically non-substitutable in the short to medium term and they biodiversity they sustain cannot persist in poorly structured urban forests.

Ecology of serpentine ecosystems in the Mediterranean basin biodiversity hotspot

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The Mediterranean Basin biodiversity hotspot covers around 2,300,000 km^2. Here, occurr mafic and ultramafic outcrops (serpentine outcrops s.l.), naturally fragmented ecosystems that host a rich flora adapted to their edaphic extreme conditions. Moreover, these outcrops are also subjected to pressure from metals and rare earth elements extraction. Despite the numerous studies on individual or local outcrops, has been lacking a comprehensive assessment of the serpentine's outcrop distribution, ecological characteristics, and conservation status across the Mediterranean Basin. This study provides the first harmonized digital map of Mediterranean Basin serpentine outcrops and investigates their climatic, geographical, and protection status.Serpentine outcrops cover 24,056 km^2 (the 1.15% of the Mediterranean Basin), of which 5,255 km^2 (22%) fall inside protected areas, including just 44 of the 94 mapped outcrops. Nearly 3,126 km^2 (60%) are concentrated in just three complexes: Troodos (Cyprus), Pindos and Mirdita (Greece and Albania). Regarding the ten Mediterranean biodiversity hotspots (area of 417,267 km^2) identified by Médail (1997), 34 outcrops are inside and cover 11,442 km^2 (2.7%).Most outcrops occur at medium elevations and have a typical sub-Mediterranean climate, with moderated temperatures, annual precipitation around 700mm, high temperature seasonality, and relatively low climate change velocity. Human footprint values are generally lower than the Mediterranean ones.We compiled records of 521 taxa for 42 outcrops, represented by Brassicaceae (19%), Asteraceae (17%), Caryophyllaceae (10%) and Poaceae (5%). According to the IUCN Red List, 3% of the taxa are assessed as Critically Endangered, 7% as Endangered and Vulnerable and 6% as Near Threatened while 58% as Not Evaluated.Our results highlight important conservation gaps despite the exceptional biodiversity hosted by serpentine ecosystems. The harmonized database and digital map provide a baseline for future ecological, biogeographical, and conservation studies, supporting management and protection of the Mediterranean Basin serpentine outcrops.

Open access big data about groundwater-dwelling crustaceans highlight priority areas and knowledge gaps for conserving European groundwater-dependent ecosystems

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Open access big data are crucial to investigate the spatial arrangement of biodiversity facets, its drivers, and the existing and potential threats to the persistence and functionality of ecosystems.Groundwater-dependent ecosystems (GDEs), including purely subterranean aquatic environments as well as groundwater-fed springs and the hyporheic zone, host diversified metazoan communities, where crustaceans usually represent the most species-rich and abundant group. Groundwater-dwelling crustaceans play pivotal functions in GDEs, such as nutrient recycling and bioturbation. Furthermore, they often show restricted distributions and high sensitivity to environmental variations, making them particularly vulnerable.Despite the ubiquity of crustaceans in GDEs, open access datasets about these organisms have been poorly available until very recently. In 2024, we compiled EGCop, the first expert-validated, open access dataset encompassing all the known species of European obligate groundwater-dwelling copepods (Crustacea: Copepoda), which represent a preponderant portion of the metazoan diversity and biomass in groundwaters. Taking advantage of EGCop and spatially explicit environmental predictors at European scale, we implemented various GIS and ecological modelling techniques to highlight candidate priority areas for conserving European GDEs and their crustacean diversity.We found that groundwater copepods' diversity is not comprehensively represented within the existing network of European protected areas. In this context, the species richness hotspots and the endemicity areas that our analyses delineate in distinct European karst regions are strong candidates to deliver conservation actions. We also found that different copepod species show distinct responses to environmental variability at local-to-regional scale and have potential distributions extending far beyond their known ranges, suggesting the need for additional sampling campaigns across less explored European regions to fill existing knowledge gaps.As these patterns are likely shared with other groundwater-dwelling crustacean groups, the obtained results are being complemented with additional analyses to expand their taxonomic scope, thus providing more comprehensive conservation-relevant information.

Mangrove species occurrence in relation to habitat types across the critically endangered mangrove ecosystems of the Maldives

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Mangrove ecosystems provide critical ecological functions and socio-economic benefits worldwide yet remain among the most threatened coastal habitats. Although global assessments indicate a recent transition from net mangrove loss to slight net gain, this trend is not consistent across regions. In the Maldives, mangroves are classified as Critically Endangered by the IUCN and face increasing pressure from multiple anthropogenic stressors, including infrastructure development, land reclamation, improper waste disposal, and plastic pollution, alongside recent climate-driven dieback which affect approximatively 26% of mangrove-containing islands.Despite the strong dependence of Small Island Developing States on mangroves for livelihoods, food security, and coastal protection, ecological knowledge of species distribution patterns in the Maldives remains limited. Unlike large estuarine systems, where longitudinal gradients in salinity and inundation strongly structure vegetation communities, Maldivian mangroves occur as small, fragmented stands scattered across heterogeneous coastal habitats. This study investigated habitat preferences and environmental constraints shaping the distribution of five dominant mangrove species across 40 sites in the Maldives, including embayment, pond-based, and marsh-based systems.Significant associations between species occurrence and habitat type were detected for all species (Chi-square tests, $p < 0.05$). *Bruguiera cylindrica* was strongly associated with marsh-based habitats, whereas *B. gymnorrhiza* was less frequent there. *Lumnitzera racemosa* occurred most frequently in pond-based mangroves and was more often found in low to intermediate salinity conditions. In contrast, *Rizophora mucronata* and *Ceriops tagal* were predominantly associated with embayment habitats characterized by high salinity.These findings suggest that habitat type and associated hydrological conditions act as important environmental filters shaping mangrove species distribution in the Maldives. This study provides baseline ecological information for evidence-based conservation, restoration, and management strategies under ongoing anthropogenic and climate-related pressures.

Beyond coverage: assessing the quality of marine protection in Italy through the MPA guide framework

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Protecting marine biodiversity is a global priority, and effective Marine Protected Areas (MPAs) are key tools for supporting the conservation and recovery of marine ecosystems, while boosting local socio-economies. However, the recent emphasis on expanding the spatial extent of protected marine surface has raised concerns about the proliferation of ”paper parks”, i.e. areas where legal designation is not matched by effective regulation, management and enforcement. Assessing not only how much of the sea is protected, but also how it is protected, is therefore essential to evaluate progress towards national and international conservation targets, especially the “30×30” target.This study aims to assess the quality of marine protection in Italy by applying the MPA Guide framework to nationally designated MPAs and other marine area-based conservation designations, including marine Natura 2000 sites. We compiled information from official MPA websites, the Natura 2000 database, Protected Planet, and ProtectedSeas to evaluate key attributes related to stage of establishment and level of protection. In particular, we focus on the degree to which each site meets criteria associated with different levels of protection and implementation, distinguishing between formally designated areas and areas where conservation measures are likely to produce real socio-ecological outcomes.By integrating multiple publicly available sources, this work provides an overview of the current state of Italian marine protection under a common assessment framework. The analysis will help identify gaps between formal and effective protection to support the development of more transparent and comparable conservation assessments. Overall, this study contributes to ongoing efforts to move beyond area-based targets alone and to promote marine conservation strategies that are socio-ecologically meaningful, effectively managed, and aligned with international biodiversity goals.

Soundscape as a tool for monitoring seagrass meadow condition and human impacts

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Soundscape analysis is increasingly recognized as a valuable approach in functional marine ecology. Nevertheless, further investigation is needed to clarify how habitat-related characteristics, environmental and biological factors, and anthropogenic pressures affect acoustic metrics. This study examined the influence of seagrass meadow condition, seasonal variability, and human disturbance on soundscape structure and dynamics. To achieve this, the soundscape of *Posidonia oceanica* meadows was investigated across 16 sites located within two Mediterranean Marine Protected Areas (in Sicily and Sardinia), using 6,600 recordings of 5 minutes each.The findings highlighted a complex soundscape characterized by strong spatial variability. Diel patterns emerged as the main factor shaping acoustic dynamics, with nighttime periods showing a marked increase in fish vocalizations and invertebrate snapping activity. Several acoustic metrics were positively associated with greater meadow density and intermediate levels of coverage, indicating that structurally complex meadows supported a more diverse acoustic environment. In addition, meadows developed on sandy bottoms negatively affected nearly all acoustic metrics when compared with those growing on rocky substrates, which provide both a higher number of ecological niches for sound-producing organisms and act as reflective surfaces for sound propagation. Boat-generated noise was widespread throughout the study areas and represented the main determinant of low-frequency sound pressure levels, while also causing significant reductions in acoustic complexity and diversity indices. However, dense meadows showed lower low-frequency sound pressure levels suggesting that the seagrass canopy functioned as an acoustic attenuator of noise pollution.Overall, the acoustic metrics captured the dynamic relationships among habitat structure, biological activity, and anthropogenic influence. These results demonstrate that soundscape analysis represents a robust complementary method for evaluating the functional condition of *P. oceanica* meadows and support the inclusion of soundscape within conservation and management strategies.

Colonization of *Posidonia oceanica* artificial wrack piles by dune plants: is it feasible?

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Wrack depositions play fundamental ecological roles in coastal environments, including contributing to the formation of embryonic dunes and providing nutrients to dune plants. Despite their importance, wrack depositions are considered as a nuisance, and they are frequently removed from beaches. In Italy, the wrack made of portions of *Posidonia oceanica* (L.) Delile is often moved from beaches to the toe of adjacent dunes, ecologically/economically relevant habitats, or used to build artificial piles on inland beach areas during grooming activities. However, whether these piles can be colonized over time by dune plants and used like a barrier to protect the coastline by erosion has not been investigated so far. Here, we present the preliminary results of a planting experiment performed on a beach in Tuscany where *P. oceanica* piles were created by the local municipality. Specifically, we evaluated whether two dune plant species (*Thinopyrum junceum* and *Calamagrostis arenaria*) commonly used in dune restoration interventions can survive and colonize such piles over time. Nursery raised plants were planted on the wrack pile in October 2025 and monitored periodically to determine their survival and the number of culms produced. Seven months after planting, all *C. arenaria* plants and most of *T. junceum* plants (94.4 ± 5.6%) were still alive and had produced new culms. These preliminary findings indicate that artificial wrack piles could be valorised by planting dune building species, but long-term monitoring is necessary to evaluate the effectiveness of this practice in terms of ecosystem services provided such as increased coastal protection and biodiversity support.

Unraveling seasonal biochemical and physiological dynamics in ligurian *Ericaria amentacea*: a reference framework for restoration monitoring of an endangered Mediterranean seaweed

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Seasonal environmental variability strongly influences the physiology and biochemistry of intertidal macroalgae, affecting their ecological performance and adaptive capacity. This study investigated seasonal changes in the brown alga *Ericaria amentacea* through an integrated analysis of photosynthetic pigments (chlorophyll a, chlorophyll c, and fucoxanthin), nutritional parameters (carbon, nitrogen, and protein content), oxidative stress markers (malondialdehyde, MDA), antioxidant enzymes (superoxide dismutase, SOD, and glutathione S-transferase, GST), secondary metabolites (phenolic and flavonoid compounds), and phytohormones (abscisic acid, ABA, and indole-3-acetic acid, IAA). Marked seasonal variations were observed across all measured variables. Photosynthetic pigments, nitrogen, and protein concentrations were highest during winter and spring, indicating enhanced growth and metabolic activity under cooler conditions and lower irradiance. In contrast, these parameters decreased during summer, suggesting reduced investment in photosynthesis under elevated temperature and light stress. Conversely, MDA levels, antioxidant enzyme activities, and phenolic and flavonoid contents increased from late spring to summer, reflecting greater oxidative stress and the activation of protective mechanisms. Phytohormone profiles also showed clear seasonal trends. ABA peaked during summer, consistent with its role in stress responses, whereas IAA was more abundant during periods of active growth and reproduction. Correlation analyses revealed negative relationships between photosynthetic variables and antioxidant or phenolic responses, indicating a shift in resource allocation from growth to cellular protection under stressful conditions. Overall, *E. amentacea* exhibits pronounced seasonal metabolic adjustments that enhance its ability to cope with fluctuations in temperature, irradiance, and desiccation. These findings provide a valuable baseline for monitoring natural populations and supporting restoration and conservation efforts for this threatened Mediterranean habitat-forming seaweed.

Restoration of habitat functions after seagrass transplantation: sedimentary and biogeochemical responses along a degradation–recovery gradient in the Gulf of Palermo, Sicily

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Anthropogenic pressures have caused widespread *Posidonia oceanica* seagrass meadow degradation throughout the Mediterranean Sea. Although restoration initiatives have been increasingly implemented, restoration success has been assessed predominantly through structural plant descriptors (*e. g.*, shoot density, cover, growth rates). Conversely, much less attention has been paid to the recovery of habitat functions that regulate sediment dynamics and underpin key ecosystem services, including sediment trapping, blue carbon storage and nutrient and trace element retention.This study evaluates whether seagrass restoration recovers key habitat functions, particularly sediment trapping, carbon storage and trace element retention, by comparing natural, restored (15 years after transplantation) and degraded (dead *matte*) *P. oceanica* meadows in the Gulf of Palermo. Sediment cores were analysed for grain size, carbon and trace element concentrations, whereas sediment chronologies and accumulation rates were reconstructed using the CF:CS model based on ^{210}Pb profiles to evaluate how habitat degradation and restoration influence sediment accumulation and the capacity of sediments to preserve coherent environmental records.The three habitat types showed distinct sedimentary and biogeochemical characteristics. In particular, in the restored meadow, sediment texture and accumulation rates were more similar to those of the natural meadow than to dead *matte*, suggesting a recovery of sediment trapping and stabilization functions. Conversely, the dead *matte* displayed lower sediment retention and reduced temporal resolution, suggesting diminished preservation of recent environmental signals. Moreover, despite its recent reduced sediment accumulation, it retained substantial legacy carbon stocks and trace element retention, suggesting its continued ecological importance as a long-term blue carbon reservoir and biogeochemical sink.These results suggest that assessing the recovery of habitat functions, particularly those related to sediment dynamics, provides complementary insight into restoration success beyond those obtained from plant structural descriptors alone. Their recovery regulates sediment accumulation, carbon burial and trace element retention ultimately supporting long-term ecosystem services and environmental archives.

Nest-site selection in the critically endangered Italian spring goby: from opportunistic macroplastic use to targeted habitat enhancement

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The Italian spring goby (*Orsinigobius punctatissimus*) is a critically endangered freshwater fish endemic to the Padanian plain, inhabiting springs and resurgences. Over recent decades, habitat loss, pollution, and climate change have driven a range contraction, fragmenting populations and reducing the availability of reproductive substrates. Springs and resurgences are additionally exposed to increasing plastic contamination, raising questions about whether plastic debris may functionally substitute for natural nesting substrates. During a monitoring campaign, we repeatedly observed *O. punctatissimus* using macroplastic items as nest sites, suggesting opportunistic exploitation of these wastes. Building on these observations, the present study was aimed at 1) assessing whether the species shows a preference for specific macroplastic types and 2) evaluating whether the provision of artificial substrates could enhance reproductive success. To address the first aim, we systematically collected 193 macroplastics across ten reproductive sites during peak breeding season, categorizing each by type and recording egg presence. Hunting shotshells, whose small, enclosed cavity structurally resembles natural nesting sites, were disproportionately selected for oviposition relative to their availability. To address the second aim, 134 hollow bricks were deployed at eight springs. Fish density increased by 970% following brick placement, r esulting in values 1348% higher than those of control sites . Small holes were preferentially used, especially when the invasive red swamp crayfish (*Procambarus clarkii*) was abundant, suggesting a trade-off between nest size and protection from predators and competitors. These findings highlight the novel use of macroplastics as opportunistic nests, suggesting that cavity structure drives substrate selection. Furthermore, targeted artificial substrates offer an effective conservation strategy to overcome nest-site limitations and buffer the negative effects of invasive species on reproduction.

Restoring ecological complexity: estimating epiphytic community for seagrass restoration success

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Seagrass restoration effectiveness remains uncertain probably due to the unique features of each species, the wide range of practices and methodologies used in transplanting actions, and suitability of reference sites.This is a space-for-time substitution to evaluate the effectiveness of restoring the ecological complexity of *Posidonia oceanica* meadows, hypothesising that in successful operas the differences in structural epiphytic diversity between restored and local meadows will be reduced through time since transplanting. In summer 2025 seven Mediterranean sites, where restoration was conducted at different times using similar techniques, were investigated. In each site, the macro- and micro- epiphytic diversity of basal, intermediate, and terminal portion of transplanted *P. oceanica* leaves were compared to nearby meadows used as reference conditions. Overall, dissimilarity in leaf macroepiphyte community between restored and natural plants significantly decreased with restoration age, with an decrease in similarity from the basal to the apical portion of the leaf, while this pattern was not observed for the microepiphyte community.Although results encourage the restoration effectiveness, they also highlight that the aim of restoring ecological complexity should be strongly time-dependent and that 8 years may still not be enough for the epiphytic community of *P. oceanica* meadows to be restored.

Accelerating reproductive timing in Mediterranean Fucales: an experimental approach for optimizing restoration strategies

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Mediterranean marine forests formed by Fucales are key coastal ecosystems supporting high levels of biodiversity.*Cystoseira compressa* (Esper) Gerloff & Nizamuddin 1975 habitats are recognised as highly relevant within the framework of the Nature Restoration Regulation, as the enhancement of its distribution can directly contribute to improving habitat quality, biodiversity, and ecological connectivity, thereby contributing to achieve restoration targets in Mediterranean coastal ecosystems.One of the major challenges for its recovery through *ex-situ* outplanting is the limited and highly seasonal availability of fertile material, constraining the transition from small-scale interventions to scalable restoration efforts.Can we anticipate the reproductive period to control and enhance reproductive output? In this study we tested an innovative, restoration-oriented approach for *C. compressa*: by manipulating temperature and photoperiod, we simulated an accelerated seasonal transition to induce earlier maturation under controlled conditions. In addition, we assessed whether periodic emersion, mimicking natural low-tide exposure, acts as a key ecological trigger to enhance reproductive responses in intertidal species.The controlled experiment started three months before their reproductive timeframe: we compared natural vs. accelerated scenarios, crossed with emersion treatments, while monitoring donor populations along the Ligurian coast (NW Mediterranean, Italy). We tracked maturity, fertility and gamete release, integrating these measurements with photosynthetic and metabolic performance to elucidate the physiological mechanisms linking environmental cues to fertility.By identifying key drivers of reproductive outputs, this work provides a physiological and experimental framework to optimize timing and efficiency of *ex-situ* cultivation and outplanting. Our findings contribute to the development of scalable, climate-informed restoration strategies for Mediterranean macroalgal forests, supporting active restoration interventions.

Does marine animal forests density affect local biodiversity?

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Marine Animal Forests (MAFs), such as those formed by gorgonians, play a vital role in enhancing local biodiversity by creating complex three-dimensional habitats, and provide a wide range of ecosystem services, including carbon sequestration, nutrient cycling, and constitute nursery grounds for species of commercial interest. Despite their ecological importance, MAFs face significant threats including climate change, overfishing, and pollution, resulting in the loss of biodiversity and ecosystem functions. In the Mediterranean Sea, the red gorgonian *Paramuricea clavata* contributes to the three-dimensional complexity of rocky benthic habitats. While previous studies have established that benthic biodiversity is generally higher within gorgonian forests than in no forest/absence of forest? areas, the relationship between forest density and associated benthic diversity remains poorly understood. Determining optimal gorgonian density who maximize diversity is crucial for designing effective restoration plans that promote both self- and other species' recruitment, sustainability and ecosystem services.In this study, we evaluated what is the *P. clavata* forest density that maximize affects alpha and beta diversity of understory benthic communities. Sampling was conducted within the Réserve Naturelle Marine de Cerbère-Banyuls (NW Mediterranean Sea). In thirty 1 m² quadrats all *P. clavata* colonies were counted and measured to characterize the demographic structure of the forest. Within each quadrat, an understory sample (22.5 ´ 22.5 cm) was then scraped and metabarcoding analyses using COI and 18S markers were performed.The density of gorgonians emerged as a key driver of both alpha and beta diversity, affecting biodiversity indices, composition and structure of the understory, and abundance of taxa (i.e Porifera, Bryozoa increase with the *P. clavata* density). These findings suggest that determining the optimal gorgonian densities should be a priority before implementing conservation and restoration efforts, to preserve the beneficial effects of MAF and maintain the ecological complexity of these habitats.

Inside the coralligenous: diversity and distribution of cryptic sponges

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Coralligenous formations represent one of the most complex and species-rich benthic habitats in the Mediterranean Sea, providing a wide variety of ecological niches for cryptic sponge communities. These assemblages, including boring and cavity-dwelling species, play a key role in bioerosion, carbonate turnover, and the maintenance of habitat structural complexity. In this study, cryptic sponge assemblages inhabiting coralligenous concretions were investigated at eight locations distributed along the Italian coastline, encompassing the Ligurian, Tyrrhenian, Adriatic, and Ionian Seas. Coralligenous blocks collected by SCUBA diving were sectioned and examined using stereomicroscopy coupled with image analysis. Sponge abundance was quantified as Sponge Occupied Surface (AOS), while the Void Area Fraction (%VAF) was measured to estimate the availability of internal microhabitats. A total of 121 sponge species were recorded. Marked differences were detected between coralligenous rims and banks, with rims characterized by higher internal porosity, greater sponge cover, and increased species richness. Among the investigated areas, Ligurian rims hosted the most extensive sponge occupation and the highest variability in community composition. In contrast, banks from southern Italy generally supported lower sponge abundance, likely reflecting the combined effects of sediment accumulation and competition with algal assemblages. The sponge communities from Tavolara (Tyrrhenian Sea) were clearly distinct from those of the other sites, suggesting an important influence of depth and habitat morphology on assemblage structure. Extrapolation of local AOS estimates to the regional distribution of coralligenous habitats indicated that cryptic sponges make a substantial contribution at the ecosystem scale, with the greatest overall extent estimated for Apulia due to its broad coralligenous coverage. These results underline the importance of internal habitat architecture in determining cryptic sponge diversity and support the inclusion of three-dimensional habitat features in future conservation and monitoring programs.

Key dynamics and actors in the sea urchin fishery: network analysis of a complex social-ecological system

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Small-scale fisheries (SSF), such as the sea urchin (*Paracentrotus lividus*) fishery along Mediterranean coasts, are complex and diverse social-ecological systems (SES) undergoing major pressures including climate change, biodiversity loss, and changes to social and economic drivers. SSF require multi- and transdisciplinary research approaches to understand the complex dynamics between humans and nature and to design actionable management measures tackling both ecological and socio-economic sustainability. Social-ecological network (SEN) analysis represents a promising tool to model these systems. Through its capacity to visualize and analyse interactions among actors within a particular system, it allows to combine knowledge from natural and social scientists and co-create system knowledge to jointly disentangle complexity in ecosystems and fisheries value chains. Here, we build social-ecological networks of two sea urchin fisheries case studies (Sardinia in Italy, Catalonia in Spain). Interdisciplinary knowledge on different SES sub-systems based on local experts in ecological and social science field work in the focal regions was assembled through workshops and surveys. The resulting networks represent the multi-trophic dynamics among macroalgae, sea urchins and fish predators, as well as their fisheries value chains and their governance systems. These two Mediterranean SES share similar ecological components and trophic interactions. Our hypothesis is that the observed differences in system outcomes (low vs. high sea urchin abundances, occurrence of barrens) result from differences in the human dimension of the SESs. SEN metrices show the network differ in density, and highlight diverse role across actors in shaping the flow pathways that connect humans with nature in each region. The identification of central figures within complex SES helps to identify leverage points for management interventions and can serve as a discussion baseline with stakeholders to facilitate participative decision-making. This work shows the utility of using SENs as a tool to advance co-learning in multidisciplinary teams.

Effects of shifting fishing effort towards small-scale gears: insights from two Mediterranean case studies

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Fisheries resources are vital to sustaining coastal communities and meeting the increasing global seafood demand. In the Mediterranean Sea, the definition of sustainable fisheries relies on the concept of maximum sustainable yield and related stock-specific reference points, which guide the regulation of the fleet effort. Despite recent conservation efforts, many fish stocks remain overexploited, highlighting the need for management strategies that reconcile conservation objectives and fisheries profitability. Trawling is widely recognised as one of the fishing practices with the highest impacts on marine ecosystems, due to its effects on benthic habitats, low selectivity, multi-species catches, and high bycatch rates. Small-scale fishing gear, like longlines or gillnets, on the other hand, generally show higher selectivity and lower habitat disturbance, potentially allowing a more sustainable exploitation of the stocks. However, the ecological and socioeconomic consequences of redistributing fishing effort among different gear categories remain poorly quantified, particularly when accounting for stock dynamics and fleet responses in a spatial explicit framework.In this modelling exercise, we applied a spatially-explicit management strategy evaluation framework to two Italian macro-regions (the north Tyrrhenian Sea and the Adriatic and Ionian basins) to investigate the effects of alternative fishing effort allocations on the stock-fishery dynamics of the European hake (*Merluccius merluccius)* and its associated fisheries. We tested a range of effort multipliers independently applied to trawlers, longliners, and gillnetters. The comparison of multiple indicators across different temporal and environmental conditions revealed that variations of trawler effort deliver the greatest impact on stock status and fishery productivity. On the other hand, under reduced trawler pressure, increased longline and gillnet effort can maintain comparable yields and revenues while supporting higher stock biomass.

Continuous video monitoring of fishways: first insights into fish assemblage and behaviour of native and invasive species in the upper Po River

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Fishways are key mitigation measures for restoring longitudinal connectivity at man-made obstacles in rivers, yet their ecological effectiveness is rarely assessed through continuous, non-invasive monitoring. Here we present the preliminary results from a video-based monitoring system installed on a fishway on the Po River (La Loggia dam, NW Italy), designed to automatically record videos of each passage event (passage date/time, direction, fish length, and species through automated video analysis) 24/7 over long-term periods. From winter 2025 to summer 2026, 13 fish species were detected, including eight non-native ones (six of which only recorded moving downstream). Preliminary data suggest temporal patterns in passage activity, with native rheophilic species beginning their activity earlier in the season. Barbel (*Barbus* spp.) and Italian chub (*Squalius squalus*) were the most frequently detected species, showing increased activity during early spring, with bidirectional movement (both upstream and downstream). Upstream passages of endangered species, including the Italian roach (*Rutilus pigus*) and hybrid population of marble trout (*Salmo marmoratus)* were recorded alongside invasive and ecologically problematic allochthonous species, underscoring the complexity of managing freshwater fish populations. Among the allochthonous species, wels catfish (*Silurus glanis*) and common carp (*Cyprinus carpio*) showed upstream passage activity starting in May.Beyond evaluating fishways performance, these results highlight the broader potential of continuous video monitoring as a tool for providing reliable data on the fish population composition, and on each species passage timing and behavioural and social dynamics that are rarely captured by traditional sampling methods, while also minimizing the negative impacts associated with other monitoring approaches. Knowledge of species-specific behaviour and timing could, in the future, support the design of selective passage systems aimed at reducing the potential detrimental effects of invasive allochthonous species exploiting fishway infrastructure.

Population-level habitat engineering by the endangered *Pinna nobilis* in lagoon refugia

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Since 2016, the Mediterranean fan mussel *Pinna nobilis* (L. 1758) has undergone severe Mass Mortality Events (MMEs) throughout its entire range, leading to a drastic decline of the species. However, for reasons not fully understood, some coastal transitional ecosystems still host large extant populations, acting as refugia for the species. *Pinna nobilis* plays a key ecological role by increasing habitat structural complexity and contributing to overall ecosystem functioning. In the present study, the ecosystem engineering role of the species in lagoon environments has been assessed through a multi-scale analysis of the spatial distribution and three-dimensional structure of relict fan mussel shell fields in the Venice Lagoon. Underwater Structure-from-Motion (SfM) photogrammetric surveys were performed in 2022 by snorkel divers at a subtidal flat 1.5 meters deep colonized by *Pinna nobilis* in the central lagoon of Venice. To acquire images, a multi-camera rig and specific protocols tailored for low-visibility conditions were applied. High-resolution (submillimeter) orthomosaics and Digital Elevation Models (DEMs) were produced. Based on the DEMs, we investigated how vertically emergent fan mussel shells, including both living and dead individuals, modify seabed roughness and near-bed hydrodynamics, shifting the seabed into a markedly higher stress regime even at moderate flow velocities, with implications for sediment mobilization, near-bed turbulence, and vertical biogeochemical fluxes. An extensive monitoring campaign carried out in 2024 at 40 stations in collaboration with the Veneto Region, within the framework of the Interreg IT-SI POSEIDONE project, allows for a first quantitative estimation of the broader ecological role of the species at the lagoon scale. The implications of dead shells persisting in an upright position for several years following MMEs are presented. The results are discussed in relation to future research and conservation perspectives for *Pinna nobilis* and other habitat-forming macroinvertebrates in coastal transitional ecosystems.

Analysing marine biodiversity research effort inside marine protected areas through a systematic review protocol: a Sicilian case study

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Systematic reviews (SR) are powerful tools to synthesise existing scientific knowledge. The information generated can be more accessible to policymakers, representing a fundamental support for science-informed management. In this study, we apply a SR protocol framework to investigate marine biodiversity research conducted inside Marine Protected Areas (MPAs), a well-established biological conservation measure, in Sicily, Italy. Sicily represents a critical case study for Italy and the Mediterranean region, where 7 MPAs are present - the oldest established in 1986 and the latest in 2018. To answer the research question: " *What is the ecological knowledge held by the scientific community on marine biodiversity of established MPAs at Sicilian regional level?"* a total of N=130 final records have been screened (initial N=529). S tudies performed inside the MPA were considered and synthetized following both structural, spatial and research approach criterias: *i)* subject of the study and conservation status, *ii)* response level of biological organisation analysed, *iii)* study approach, *iv)* driver of disturbance analysed (when applicable), *v)* accuracy of the spatial reference, *vi)* conservation level compared, *vii)* temporal trend, and *viii)* depth analysed. Results show 80% of the studies focused on monitoring the marine biodiversity of the MPAs, 11% on modelling, and only 4% applied multiple approaches. A considerable percentage (37%) focuses on single-management levels. Regarding sampling sites, 22% of the studies do not provide accurate georeferences. The majority of the studies specify depth (78%), with half of these (53%) focusing on marine biodiversity above 20 meters depth. With limited resources for biodiversity research implementation, and ambitious objectives set by European Biodiversity Strategy, such as the 30x30 initiative and the Nature Restoration Regulation, it becomes fundamental to collate already-existing scientific knowledge, to identify research gaps, low-data regions and ecosystems, supporting science-informed policies in building a coherent network of MPAs through an Ecosystem-Based Management approach.

Different environmental characteristics shape specific thermal tolerance in shallow and deep populations of a habitat-forming macroalga

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In recent years, an increasing number of studies have reported impacts of ocean warming and marine heatwaves on canopy-forming macroalgae, leading to physiological stress, reduced population size, and local extinctions. Warming events are projected to increase in intensity and frequency in the Mediterranean Sea, threatening the survival of these habitat-forming species. Therefore, understanding their thermal tolerance, which may vary across species, populations, and life stages, is essential to predict their persistence under future climate change.This study aims to evaluate the thermal sensitivity of two *Gongolaria elegans* populations originating from contrasting environments. Controlled laboratory experiments were conducted using *G. elegans* adults and recruits from a shallow population in a surface rockpool (0.5 m depth) at Port de la Selva and a deeper population (13 m depth) at the Medes Islands.Adults and recruits from both populations were exposed to five temperature treatments (21, 26, 27, 28 and 29 °C) for up to 35 days. Recruit survival and growth were monitored throughout the experiment, while adult thermal tolerance was assessed through changes in biomass.Preliminary results indicate differences in thermal sensitivity between populations. Adults from the deeper population were more vulnerable to elevated temperatures, showing biomass losses exceeding 60% after 28 days at 26 and 27 °C, and after only 14 days at 28 and 29 °C. In contrast, adults from the shallow population exhibited greater thermal tolerance, with biomass losses remaining below 60% under all temperature treatments. Recruits were considerably more sensitive than adults, exhibiting high mortality at temperatures above 26 °C.These results demonstrate intraspecific variation in thermal tolerance associated with population origin and life stage. Accounting for such variability is essential to assess the future persistence of canopy-forming macroalgae under ongoing climate warming.

Risposta degli ecosistemi al disturbo: impatti, adattamenti e strategie di mitigazione

3

Coordinatori: Francesca Garaventa, Chiara Gambardella, Sarah Magozzi

Functional and compositional diversity peak at intermediate fire frequencies when modeling the plant-fire feedback

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Although fire is widely regarded as a disturbance, it is also recognized as an important driver of biodiversity, with its effects varying across ecosystems and fire regimes. As global change is expected to alter wildfire activity worldwide, understanding how fire influences biodiversity has become increasingly relevant. A major challenge is that vegetation and fire interact through feedbacks, whereby plant community composition influences fire occurrence and, in turn, is reshaped by it. To investigate how these feedbacks affect biodiversity, we analyzed the compositional and functional diversity of simulated plant communities across a gradient of fire frequencies. We extended an existing vegetation model to represent species-rich communities and parameterized it for Boreal and Mediterranean ecosystems. Fire events occurred stochastically, with average frequencies determined by community flammability, while species differed in their responses to fire, generating dynamic vegetation–fire feedbacks.Across both ecosystems, fire generally promoted both compositional and functional diversity, with diversity typically peaking at intermediate fire frequencies. Although the two diversity dimensions were positively correlated, they did not reach their maxima in the same communities. This suggests that some degree of functional similarity among species may be necessary to support the highest levels of species richness. These results stem from the vegetation- fire feedback, highlighting its importance for predicting ecosystem responses to global change, including biodiversity losses and wildfire regime shifts.

Topological rethinking: structure, dynamics and stability of ecological systems

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The structural architecture of ecological systems evolves across space and time, with profound implications for biodiversity conservation. Through the combined use of spectral graph theory and topological zigzag persistence, we previously unveiled the spatio-temporal evolution of an Algerian charophyte metacommunity, laying the foundations for a multi-purpose prioritization of conservation actions based on the relative role of nodes in preserving topological structures. In this study, we shifted focus from structural evolution to the evolution of dynamical responses to perturbation as shaped by the changing topology. To this end, we extended spectral graph theory to higher-order interactions, investigating how disturbance diffuses among communities, how it circulates along cyclic pathways, and how node- and edge-level perturbations couple to produce a unified picture of propagation across the whole system. Through targeted node removal, we further simulated how topological changes induced by the loss of specific communities translate into functional changes in system-wide responses to disturbance. Our results reveal stable seasonal oscillations, with the metacommunity cyclically moving across stages of high and low susceptibility to disturbance, alongside dramatic shifts induced by node removal - even with modest topological alterations - that either dampen or amplify metacommunity vulnerability. Overall, this framework moves beyond a purely structural description of ecological networks toward a dynamic understanding of how they absorb, transmit or attenuate perturbations.

Meiofaunal assemblage response to mitigation of deep-sea trawling in La Fonera canyon (Catalan margin, NW Mediterranean Sea)

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Submarine canyons are biodiversity hotspots and key ecosystems, connecting shallow and deep environments and sustaining valuable fisheries. Among the fishing techniques, bottom trawling is the most harmful due to its effects in overexploitation, habitat destruction, physical and biogeochemical alterations of the seabed. Along the NW Mediterranean continental slope, deep-sea trawling is practiced recurrently, mainly targeting the deep-sea shrimp *Aristeus antennatus*, fished at 500-800-m depths.Along the Catalan margin, the impacts of bottom trawling activities on the Palamós (also known as La Fonera) submarine canyon have been studied for years. The negative effects of this fishing practice were transferred by the scientific community to the fishing sector, and as a result, in 2013, the Palamós fishers guild initiated a self-regulated endeavor, to conduct a more sustainable fishery and protect fishing grounds along the canyon flanks. In late 2017, all trawling vessels from the Palamós harbor changed their gear to minimize the contact with the seafloor. But so far, several years after the introduction of such management measures, no comprehensive research study was conducted to assess their effectiveness in reducing the physical, biogeochemical, and ecological impacts on the seafloor.Here, meiofaunal assemblages from the Palamós Canyon were analyzed, in terms of abundance, biomass, richness of taxa, and taxonomic composition, comparing two sampling times (2011 vs 2024), before and approximately 7 years after the trawling fleet gear reconversion. The results indicate significantly higher abundance, biomass and richness of taxa in 2024 than in 2011, both in trawled and reference stations, with higher enhancement in trawled conditions. In 2024, total meiofaunal abundance decreases with increasing sediment depth, unlike 2011. Also, taxonomic composition significantly differs between sampling times, with dissimilarity between trawled and untrawled conditions lower in 2024.These preliminary results suggest that the reduction of bottom-trawling pressure after the trawling gear change could effectively promote the recovery of deep-sea meiobenthic assemblages, although long-term assessments are required to study the possible resilience of deep-sea ecosystems.

Distinct functional niches and responses to fire history of three Mediterranean woody resprouter species

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Fire strongly shapes plant functional strategies in Mediterranean ecosystems. When studying how plants respond to fire disturbance, species are frequently classified into broad categories according to their post-fire regeneration strategies, such as resprouters and reseeders. These classifications have improved our understanding of plant functioning, distribution, persistence, and recovery after fire. However, post-fire responses vary substantially both within and among species, and broad functional categories may overlook finer-scale variation at the population and individual levels. Consequently, whether woody resprouter species share similar trait syndromes and post-fire responses remains poorly understood. We investigated fire-related functional trait coordination in three widespread Mediterranean resprouters, *Arbutus unedo*, *Erica arborea*, and *Quercus pubescens*, across four fire-history conditions in north-western Italy. We measured ten functional traits related to aboveground biomass allocation, structural support, resource-use strategies, light capture, flammability, leaf economics, protection from disturbance, and plant architecture in 110 individuals. Principal component analysis and PERMANOVA were used to assess interspecific trait coordination, while ANOVA was used to evaluate trait responses to fire history and the associated role of plant architecture. The three species occupied distinct regions in the multivariate trait space, *Q. pubescens* exhibited the broadest trait space, whereas *E. arborea* occupied a narrower niche and partially overlapped with *A. unedo*. Fire history significantly modulated key traits at both interspecific and intraspecific levels. Structural traits consistently decreased with increasing fire frequency and severity, whereas leaf dry matter content, leaf C:N ratio, and relative bark thickness displayed species-specific responses. Plant architecture had a limited modulatory effect on trait–fire relationships, with a significant interaction on fire-trait relations detected only for basal stem diameter in *Q. pubescens*. Overall, our findings highlight distinct and flexible post-fire functional trajectories in the focal Mediterranean woody resprouters, emphasizing the importance of looking at plant life through a continuous and multidimensional lens when studying functional responses of woody plants to different fire history conditions.

Early biofilm development in biodegradable and traditional plastics through a mesocosm approach

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The increasing concern over the environmental impacts of conventional petroleum-based, non-biodegradable plastics has driven the development of innovative bio-based polymers (bioplastics) as more sustainable alternatives. However, knowledge of the microbial biofilms associated with these materials remains limited. Improving our understanding of biofilm colonization is essential for evaluating the environmental degradation of biopolymers and assessing their suitability as environmentally compatible materials in the event of accidental release. In this study, biofilm development on two biodegradable polymers, poly(3-hydroxybutyrate-co-hydroxyvalerate) (PHBv) and polylactic acid (PLA), was investigated in a marine environment and compared with that on a conventional plastic, polypropylene (PP). The experiment was conducted in mesocosms deployed in the Baltic Sea over a three-week period (June 2023). Plastic sheets were thermoformed, cut into 20 × 20 mm fragments, and mounted on frame holders containing nine replicates of each polymer. Biofilm formation, prokaryotic abundance, and microbial community composition were characterized using 16S rRNA gene metabarcoding. Sequence reads assigned to eukaryotes were also examined. Biofilms developed on all tested polymers, with biomass increasing over time and photosynthetic organisms becoming evident after three weeks of exposure. Distinct prokaryotic communities were associated with each polymer and with the control samples. Prokaryotic abundance generally declined throughout the exposure period, with the exception of PLA. Community composition also varied among polymer types: the biofilm associated with conventional PP more closely resembled that of the surrounding seawater, whereas PLA and PHBv supported microbial communities that were more similar to each other. Overall, these results indicate that microbial colonization is influenced by polymer type, with biodegradable plastics promoting the establishment of distinct bacterial biofilm communities during the early stages of marine exposure.

Does removal priority reflect habitat condition? Comparing the removal aid index and the Coralligenous assessment by reef scape estimate index in coralligenous reefs impacted by ghost gear

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Abandoned, lost or otherwise discarded fishing gear (ALDFG) represents a major source of disturbance for benthic habitats, causing mechanical damage, covering burrows and trapping mobile fauna. ALDFG removal is commonly considered a mitigation measure, but in structurally complex ecosystems such as Mediterranean coralligenous reefs it may involve ecological trade-offs. Old gear often becomes colonised with fragile, long-lived benthic species, making removal a potential source of further environmental damage. This study investigates whether a gear-based removal-priority index is consistent with a habitat ecological status index, and whether integrating the two can inform selective removal decisions. The coralligenous reefs affected by ALDFG at Santo Stefano al Mare (Ligurian Sea) were investigated within the PNRR-MER-Ghost Nets-M2 C4 I3.5 "Ripristino e tutela dei fondali e degli habitat marini" project. Multibeam Echo Sounder, Side Scan Sonar and Remotely Operated Vehicle surveys enabled seabed characterisation, gear georeferencing and visual assessment of associated benthic communities. Fifteen ALDFG items were recorded on mobile bottoms, rocky outcrops and coralligenous reefs. For each gear, the Removal Aid Index (RAI) was calculated to estimate removal priority by integrating environmental impact, seascape impact and technical risk. Habitat ecological status was assessed within gear-impacted sites, applying COralligenous Assessment by Reef Scape Estimate (COARSE) index to the basal, intermediate and upper layers. Results show that all recorded gears were classified as low or non-urgent removal priority according to RAI. COARSE indicated an overall good ecological status, reflecting the good status of the basal and upper layers, while the intermediate layer showed a moderate ecological status. This suggests consistency between RAI and COARSE. Nevertheless, the lower ecological status of the intermediate layer highlights layer-specific variability in the coralligenous assemblage, supporting COARSE as an ecological complement to gear-based assessments. Comparing the two indices may therefore strengthen ALDFG removal decision-making and support habitat-sensitive management.

Behavioural and physiological responses of *Paracentrotus lividus* to artificial light at night across habitat types

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Artificial Light At Night (ALAN) is a globally widespread anthropogenic stressor in coastal areas, affecting physiology and behaviour of several species, with cascading impacts on community and ecosystem level processes. However, little is known about how habitat structure modulates these effects. The sea urchin *Paracentrotus lividus* is an ecologically important species that exhibits behavioural changes when exposed to ALAN. It commonly inhabits both *Posidonia oceanica* meadows and rocky shores, two habitats that may differ in sheltering conditions (including those related to ALAN) and food availability. This study investigates the role of these two habitat types in modulating the effects of ALAN on the behaviour and physiology of *P. lividus*. We hypothesized that the response to ALAN would be more intense in rocky habitat than in *P. oceanica* habitat, due to less sheltering and food availability. An experiment was conducted in two 7-day runs around the new moon using six 500-L mesocosms, each containing six *P. lividus* individuals. Each mesocosm contained either rocky or *P. oceanica* habitats and it was equipped with LED systems that simulate a natural photoperiod and the ALAN condition (9.47 lux). Six mesocosms across the two runs (three per habitat type) were treated with a nocturnal dark regime and the other six with the ALAN scenario, in a fully crossed design with three replicates per condition. Righting behavior and attachment strength were assessed after five days. Grazing rate was quantified over four consecutive days and nights as the biomass loss of pre-weighed dried kelp. At the end of each run, respiration rate was estimated by incubating individual sea urchins in sealed chambers and measuring oxygen loss for 1 h using an oxymeter. Results will be discussed within the framework of the role of habitat structure in mitigating ALAN impacts on a key Mediterranean species.

MariLIn, a novel index to assess marine litter in a coastal seafloor

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Marine litter represents one of the major anthropogenic pressures affecting marine ecosystems, with evidence of its long-term impacts. Despite the growing availability of monitoring programs, the lack of standardized assessment tools limits the comparison of litter conditions among different areas and the evaluation of ecological impacts. To address this gap, we developed MariLIn (Marine Litter Index), a multimetric index designed to provide an assessment of seafloor marine litter by combining three descriptors: debris typology, abundance, and size. The index was tested along a 7-km coastal sector of the Gulf of Genoa (NW Mediterranean), one of the most anthropized coastlines of the Mediterranean Sea. Marine litter surveys were carried out through 80 standardized visual transects, equally distributed between scuba (5–20 m depth) and Remotely Operated Vehicle (ROV) diving (20–40 m depth). Overall, 146 litter items were recorded and classified according to their origin and characteristics. Plastic debris and fishing-related debris accounted for most of the recorded items, although their spatial distribution differed markedly according to depth and proximity to the Port of Genoa. MariLIn successfully discriminated between contrasting pollution scenarios, highlighting a west-to-east decrease in litter impact in shallow coastal habitats, where land-based sources predominate, while revealing the opposite pattern in deeper areas, where fishing-related debris becomes the dominant component because fishing activities are absent close to the commercial harbour. These results demonstrate the ability of the index to integrate different attributes of marine litter into a single ecological metric while preserving information on the main drivers of contamination. The proposed approach provides a practical, scalable, and transferable tool for seafloor litter assessment, facilitating comparisons among coastal areas and over time, and contributing to ecosystem-based management and the implementation of the Marine Strategy Framework Directive. Future applications across different marine environments will further strengthen its robustness and management potential.

Beyond the catch: trait-based assessment of benthic vulnerability and functional recovery from trawling in Mediterranean shelf benthic ecosystems

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The widespread footprint of demersal fishing, coupled with evolving environmental legislation, necessitates advanced frameworks to assess both the structural and functional dynamics of benthic ecosystems. Modern marine conservation frameworks increasingly demand assessment tools that go beyond structural changes, capturing also the functional degradation caused by bottom fishing. Here we applied a deterministic trait-based modelling framework, the Benthic Fishing Impact Assessment Tool (Bfiat), to quantify how fishing intensity, sediment type, and species life-history traits interact to shape benthic community state and ecosystem functioning.Using macrofaunal data from 143 stations across a gradient of trawling disturbance off the Northern Sicily continental shelf, we estimated the benthic state (post-disturbance density divided by predicted carrying capacity; D/K) and recovery trajectories. We specifically focused on benthic communities, key functional groups (suspension and deposit feeders), and processes (bioturbation and bioirrigation) that play central roles in regulating sediment biogeochemical cycling. The most degraded benthic states (D/K<0.75) occurred in heavily trawled stations (Swept Area Ratio >3yr-1), which were largely dominated by surface-dwelling and shallow-burrowing species.Conversely, an area closed to trawling for over two decades served as a crucial baseline; here, observed densities closely approximated the local carrying capacity, illustrating an environment with minimal fishing pressure. Furthermore, species identified as lower D/K outliers, such as the polychaete *Sternaspis scutata* and the bivalve *Nucula nucleus*, displayed greater variability, suggesting a potentially higher sensitivity when subjected to cumulative environmental stressors. Functional declines in suspension feeding, bioturbation, and bioirrigation closely mirrored the overall structural degradation. Ultimately, this study demonstrates the critical value of integrating functional and structural indicators to provide a more comprehensive, species- and habitat-specific risk assessment of demersal fishing impacts on benthic ecosystems.

Passive acoustic monitoring links anthropogenic sounds to lower bird acoustic activity at alpine climbing sites

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Recreational activities in protected areas can influence wildlife and acoustic environments, yet methods for simultaneously monitoring human activity and biodiversity responses remain limited. We used passive acoustic monitoring to assess whether anthropogenic sounds were associated with reduced bird acoustic detections at Alpine climbing sites located in protected areas in north-western Italy. Ten autonomous recording units were deployed at climbing sites within the Maritime Alps Protected Areas, recording 10-min segments hourly from April to June 2025 and yielding 15,701 recordings. Automated bird detection was performed using BirdNET, with species-specific confidence thresholds derived from manual validation. Anthropogenic sound categories, including engine noise, human voices, and non-vocal human sounds, were fully manually validated. Recordings containing more engine or human noise were associated with significantly lower detected bird species richness. In a within-recording analysis, bird detection rates declined significantly more following the onset of real anthropogenic sound events than around pseudo-breakpoints assigned to undisturbed control recordings, across all three temporal windows tested (30, 60, and 120 s). These results suggest that anthropogenic sound at climbing sites is associated with measurable reductions in bird acoustic detections. Passive acoustic monitoring offers a practical tool for tracking local anthropogenic acoustic activity and biodiversity indicators in protected mountain areas used for outdoor recreation.

Climate affects functional trait dispersion more than trait means in European tree populations

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Understanding forest responses to climate change requires moving beyond mean-based trait–environment relationships and explicitly quantifying how climate affects intraspecific trait variability. Trait dispersion within populations may represent a key component of adaptive capacity, particularly for hydraulic traits linked to drought resistance and tree survival.We analysed five functional traits — P50, Kmax, Huber Value, specific leaf area and wood density — measured on >1,100 individual trees from 111 Gene Conservation Units across 11 European tree species within the FORGENIUS network. We applied hierarchical Bayesian location–scale models to test whether climatic gradients affect trait means and trait dispersion independently. Predictors included interannual variability in water deficit, temperature seasonality, mean annual precipitation, climatic moisture index range and soil water availability. We further tested whether trait dispersion follows Taylor's Power Law and whether climate modulates mean–variance scaling.Climate effects on trait means were generally weak. In contrast, trait dispersion showed an ecologically interpretable climatic responses. P50 dispersion increased with interannual water-deficit variability (β = 0.102, 95% CI [0.035, 0.170]), indicating that climatically unpredictable sites maintain broader hydraulic safety strategies within populations. Conversely, Huber Value dispersion decreased with temperature seasonality (β = −0.094, 95% CI [−0.189, −0.001]), suggesting stronger filtering of allocation strategies under thermally variable climates.Across traits, dispersion scaled positively with trait means, consistent with Taylor's Power Law. Scaling was trait-specific, with SLA showing the steepest relationship (b ≈ 1.45), Kmax a lower slope (b = 0.80, 95% CI [0.62, 0.98]) and P50 a moderate slope (b = 1.05, 95% CI [0.05, 2.06]). Climate modulation of mean–variance scaling was mainly detected for hydraulic traits: climatic moisture index range weakened scaling in Kmax (β = −1.107, 95% CI [−1.690, −0.530], p = 0.004) and Huber Value (β = −0.130, 95% CI [−0.240, −0.020], p = 0.020).These results show that climate may restructure the distribution of functional strategies within tree populations without necessarily shifting their average trait values, highlighting the need to incorporate trait dispersion into assessments of forest vulnerability and adaptive potential.

Effects of boat traffic on community and individual level biophony in protected Mediterranean seagrass meadows

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Recreational boating represents a primary source of underwater noise in coastal regions; its impacts on fish acoustic communities within *Posidonia oceanica* meadows, has a gap in knowledge. In the present study, passive acoustic monitoring (PAM) was used to evaluate how boat traffic influences fish biophony across two Mediterranean Marine Protected Areas (MPAs): Capo Gallo–Isola delle Femmine and Capo Caccia–Isola Piana. Data were collected from 16 sites, during the low and high tourist seasons of 2024. To assess the effects of boat disturbance on community-level biophony, generalized linear mixed models (GLMMs) were employed, using acoustic abundance and richness as response variables, while accounting for spatial and temporal factors (MPA and tourist season). Furthermore, individual-level responses were evaluated by analysing shifts in the acoustic features of *Sciaena umbra* and *Scorpaena* spp. sounds using generalized linear models.Results indicate that the increasing of boat presence, from the low to the high tourist season, significantly reduced biophony in terms of acoustic abundance and richness. Moreover, findings show how boat traffic alters acoustics features of the fish signals: in *S. umbra*, peak frequency, bandwidth, and duration increased; conversely, in *Scorpaena* spp., bandwidth and duration increased while peak frequency decreased. Results highlight that recreational boating is a pervasive disturb that modify seagrass soundscapes by suppressing biophony and inducing, at individual level, plastic changes in acoustic key ecological functions signals. Also, results suggest that MPA zoning alone is insufficient to protect fish communities from boat noise, demonstrating a critical need for temporal vessel restrictions and the integration of passive acoustic monitoring into conservation management strategies.

Plastisphere in freshwater ecosystems and implications for the carbon cycle

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Plastic pollution is widely recognized as a pervasive global issue affecting ecosystems worldwide, including freshwater environments. Its impacts extend across multiple ecological dimensions and can reverberate through key ecosystem functions. One important pathway is the alteration of biogeochemical cycles, particularly the carbon cycle, via effects on aquatic metabolism, which governs the production and consumption of organic matter in aquatic systems. This process is driven by multiple mechanisms, including the formation of biofilms on plastic surfaces (the "plastisphere"), which host diverse communities of autotrophic and heterotrophic organisms capable of influencing this metabolic balance. Despite growing attention, coordinated large-scale studies across environmental gradients remain scarce, limiting our understanding of plastisphere biodiversity and its functional implications. Here, we present the framework of a project designed to address these knowledge gaps, along with preliminary results from a globally coordinated experiment. In this experiment, pristine polypropylene and low-density polyethylene were incubated under semi-natural conditions in the subsurface waters of lakes spanning a range of trophic states and latitudes for 30 days, allowing for natural biofilm development. Biofilms were characterized using chlorophyll-a and ash-free dry mass measurements, while microbial community composition was assessed through 16S, 18S rRNA, and ITS metabarcoding. Additionally, short-term incubations were conducted to estimate net ecosystem productivity associated with plastic-colonized biofilms. This framework will allow us to explore how epiplastic communities vary across different polymer types, while disentangling the relative influence of environmental conditions and substrate properties on biofilm development. It also provides an opportunity to assess whether plastisphere formation can drive shifts in ecosystem metabolism toward net autotrophy or heterotrophy. By synthesizing data across diverse freshwater systems, this study seeks to advance our understanding of plastics as novel ecological substrates and to clarify their role in shaping biogeochemical processes at a global scale.

From taxonomic to functional diversity: linking soil microbial communities to carbon dynamics during forest secondary succession

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Land abandonment across Europe is a widespread phenomenon that promotes secondary succession, reshaping ecosystem structure and functioning. Soil microorganisms play a central role in these processes through their contribution to soil organic matter (SOM) decomposition and nutrient cycling. However, understanding the relationship between microbial diversity and carbon sequestration requires information that extends beyond taxonomic composition alone. We investigated changes in soil carbon dynamics following agricultural land abandonment across a latitudinal gradient in Italy, relating them to microbial taxonomic diversity, activity and inferred functional potential. We specifically asked whether moving beyond taxonomic diversity metrics towards functionally annotated indices could provide new ecological insights into microbial responses to forest recovery and their links with soil carbon dynamics, assessed through CHN analysis, bulk density and basal respiration measurements.Microbial diversity was characterized using eDNA metabarcoding targeting 16S and ITS markers, while extracellular enzymatic activities were used as proxies of microbial functioning. Bacterial functional annotations included biotic interactions, trophic strategies, nitrogen-cycle functions and metabolic traits involved in carbon transformation, including chemoheterotrophy, chitinolysis, ligninolysis, methanogenesis and degradation of aromatic compounds and hydrocarbons. Fungal taxa were annotated according to trophic modes, functional guilds and growth forms, including ectomycorrhizal, arbuscular mycorrhizal, endophytic and saprotrophic fungi. Across the Italian gradient, bacterial function related to carbon and nitrogen cycling increased with afforestation (PERMANOVA, $P < 0.001$), whereas trophic strategies were driven by microclimatic conditions.Variation in enzymatic activity patterns across northern and southern sites underscores the combined effects of land-use change and climate in shaping microbial functioning. Overall, functional diversity captured ecologically meaningful microbial responses to forest succession and carbon dynamics more effectively than taxonomy alone. Our approach provides a promising framework for integrating eDNA- functional information into SOM models, helping to unravel the microbial ”black box” and strengthen the links between microbial community composition, functional potential and soil carbon turnover.

Living on the gradient: phenotypic plasticity of *Littorina brevicula* in a multi-stressor estuarine environment

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Intertidal ectotherms live at their physiological limits, where minor environmental shifts could be instantly reflected in the species physiology, population fitness and community dynamics. In the present study, we quantified the phenotypic plasticity of the periwinkle *Littorina brevicula* across a natural estuarine gradient by applying untargeted LC-MS/MS metabolomics and a combination of traditional and 3D morphometric approaches. Individuals were collected at the Liuqinghe River estuary at two salinity regimes: high salinity in the low intertidal and low salinity in the high intertidal. Traditional morphometric analysis revealed significantly larger aperture height and aperture shape index in the high intertidal group, while overall shell proportions and three-dimensional surface descriptors did not differ significantly between stations, suggesting that aperture shape is the morphological trait most responsive to the estuarine gradient. A combined univariate and multivariate approach identified 765 differentially expressed metabolites and 11 significantly enriched pathways, indicating broad reprogramming of core biosynthetic networks. Methylamines, hypotaurine and taurine accumulated in the low intertidal group, consistent with osmoregulatory adjustment to high-salinity conditions. Malic acid and fumaric acid, biomarkers of anaerobic metabolism in invertebrates, are significantly upregulated in the high intertidal group. The high intertidal snails presented higher concentrations of polyunsaturated fatty acids, consistent with membrane remodelling under chronic environmental stress. Metabolic plasticity exceeded morphological divergence across the estuarine gradient, suggesting that physiological responses may provide the primary mechanism enabling persistence under highly variable intertidal conditions. These results highlight the metabolome's plasticity under the pressure of multiple environmental stressors, forcing periwinkles to prioritise short-term homeostasis over energetically costly functions. By linking salinity-driven metabolic reprogramming to potential shifts in individual performance, these findings suggest that physiological plasticity in intertidal ectotherms may scale up to affect population persistence, consumer-resource interactions and the resilience of estuarine communities under intensifying environmental variability.

Long-term responses of *Posidonia oceanica* to climate and anthropogenic pressures

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The Mediterranean Sea is warming three to four times faster than the global ocean, with a rapid increase in the frequency of extreme temperature events (*e.g.,* marine heatwaves) and evident consequences for coastal ecosystems. Marine heatwaves (MHWs) not only alter the distribution and abundance of species and therefore ecosystem functions but also act synergistically with other local human threats, reshaping coastal habitats, such as *Posidonia oceanica* (L.) Delile seagrass meadows. Although previous studies have documented the effects of warming and thermal stress on the growth, physiology, and biochemical properties of *P. oceanica*, the long-term effects of climatic and local anthropogenic pressures remain poorly understood. Here, we used lepidochronological analysis from 9 Mediterranean locations to assess the effects of MHWs and anthropogenic pressures on production, biochemical properties, stability, and spatial synchrony of *P. oceanica,* accounting for additional production drivers related to water quality, and to evaluate how such metrics change across multiple spatial scales. The results showed three main outcomes: 1) carbon isotopic composition increased with cumulative MHW intensity, 2) leaf production increased under warmer winter conditions and deeper winter mixed layers, and 3) rhizome biomass, as well as leaf production stability, appeared more influenced by local environmental conditions and anthropogenic pressure than by large-scale thermal forcing. Our study highlights the need to integrate physiological responses, growth dynamics, and temporal variability data to monitor the combined effects of climate forcing, local environmental conditions, and anthropogenic pressures on Mediterranean *P. oceanica* meadows.

Mitigation efforts of deep-sea trawling foster resilience of organic C loads but not of benthic ecosystem functioning

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As part of the ARCO project (TED2021-129426B-I00), funded by the Spanish Ministry of Science, Innovation, and Universities, sediment cores were collected on the trawled Palamós (also known as La Fonera) submarine canyon (NW Mediterranean) in four sampling areas: two sites at a depth of ~500 m (one site trawled and the other untrawled), one site at 800 m, and one site at 2000 m. This sampling design replicates that used approximately 10 years ago, which revealed a depletion of the sedimentary organic load and a slowing of remineralization processes along fishing grounds due to chronic bottom trawling. The sediments were analysed for biochemical composition (proteins, carbohydrates, lipids, and phytopigments) and extracellular enzymatic activities. The results were compared with those obtained a decade earlier by estimating the magnitude of trawling effects using an effect size metric. The findings show that, unlike that from 10 years ago, the organic load in trawled sediments does not differ from that in untrawled sediments at the same depth and is higher than that observed at greater depths. Analysis of effect size across the two study periods indicates a significant reversal of the trawling consequences on organic loads, which now appears quantitatively reduced compared to a decade ago. Conversely, carbon degradation rates in trawled sediments remain lower than those in untrawled sediments, regardless of depth. Given that between the two study periods (in late-2017) the trawling gear from the Palamós fishermen guild was modified, changing from demersal to pelagic trawl door models to prevent them from contacting the seabed, these results suggest that while organic carbon accumulation in the sediments shows some resilience, the functioning of the benthic system remains significantly altered. This indicates that, at least at 500 m depth, the effects of chronic trawling persist in the long term despite mitigation efforts.

Moving beyond systematic reviews: what overview of systematic reviews reveals about marine plastic research

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Plastic pollution is widely recognized as a major threat to marine ecosystems and biodiversity. Although systematic reviews (SRs) and meta-analyses (MAs) on plastic pollution have become increasingly common in the last decades, the conveyed evidence remains fragmented and often leads to contrasting conclusions. To obtain a broader perspective, we conducted the first systematic review of systematic reviews and meta-analyses investigating the effects of plastic pollution across diverse marine taxa at multiple levels of the biological organisation.A total of 34 SRs/MAs, published between 2018 and 2024 and synthesizing 1176 primary studies, were analysed. We synthesized the reported ecotoxicological, ecophysiological and functional responses, while simultaneously evaluating the overlap among reviews using the Corrected Covered Area (CCA), and assessing their methodological quality through the AMSTAR 2 framework.Despite the large amount of available evidence, overlap among SRs/MAs was remarkably low (CCA = 1.8%), indicating limited redundancy but strong thematic specialization of research on marine plastic impacts. At the same time, methodological quality was generally poor, with almost three-quarters of the reviews classified as critically low. The overview also highlighted persistent gaps in current synthetized research, including limited ecological realism, scarce attention to higher trophic levels and ecosystem-level processes, and strong methodological heterogeneity mainly due to the predominance of laboratory-based studies focusing on microplastics.Our results demonstrate that this approach provides insight that cannot be obtained from individual evidence syntheses, through the identification not only of what is known, but also where evidence remains weak or fragmented. More broadly, the overview-of-reviews approach may be particularly valuable in rapidly expanding research fields, such as marine plastic pollution, where multiple systematic reviews and meta-analyses are available.

Vertical patterns and environmental drivers of bacterial and archaeal diversity in subsurface sediments of the Gulf of Naples

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Marine sediments host abundant and diverse bacterial and archaeal assemblages that play a key role in global biogeochemical cycles. However, patterns of prokaryotic diversity and the environmental factors shaping microbial assemblage composition in coastal subsurface sediments remain poorly understood, particularly within the first meters below the seafloor. Here, we used 16S rRNA gene metabarcoding to investigate bacterial and archaeal diversity in subsurface sediments collected at 50, 100, and 200 cm below the seafloor from seven stations in the Gulf of Naples. The investigated sediment layers differed in grain size, redox conditions and organic matter content, while contamination levels generally decreased with sediment depth, reflecting temporal changes in industrial inputs from the adjacent coastal area. Bacterial sequences accounted for ca. 70% of total reads, with Dehalococcoidia representing the most abundant bacterial class, whereas archaeal sequences were mainly assigned to Bathyarchaeia. Prokaryotic diversity, expressed as Amplicon Sequence Variants (ASVs), was highest in the deepest sediment layer, where chemical contamination was lowest. More than 1,000 ASVs were exclusively detected in specific sediment layers, suggesting that specific geochemical conditions may contribute to select distinct microbial assemblages. At the same time, the different sediment layers shared several ASVs, accounting for ca. 31% of the total reads. Among these shared taxa, members affiliated with Lokiarchaeia were consistently detected, suggesting the occurrence of prokaryotic lineages with broad ecological tolerance and/or metabolic versatility under changing environmental conditions, even in highly contaminated subsurface sediments. Overall, these findings provide new insights into the vertical distribution of bacterial and archaeal diversity in coastal benthic ecosystems and suggest that subsurface microbial communities may represent sensitive indicators of environmental changes. By linking microbial diversity patterns to sediment geochemistry and contamination history, these results may contribute to improving ecological monitoring strategies and supporting restoration-oriented assessments in impacted coastal ecosystems.

eDNA as a tool to assess ecological disturbance in agricultural landascapes: a case study from Kenya

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Agriculture expansion and intensification are one of the main drivers of biodiversity loss and ecological disturbances in natural habitats. Environmental DNA (eDNA) has emerged as a powerful, non-invasive, cost and time-effective tool for biodiversity assessment across a wide range of ecosystems, enabling the detection of both visible and cryptic taxa.Here, we explore the use of airborne eDNA and surface-derived eDNA to assess how different agricultural practices influence biodiversity patterns and, consequently, ecological disturbance. Specifically, we collected airborne DNA using spider webs and surface eDNA from flower substrates to characterize local communities of metazoan.Sampling was conducted across three regions in southern Kenya, near Lake Victoria and the Kakamega Forest. Natural habitat patches were selected as reference sites representing high expected biodiversity and were compared with agroecological and conventionally managed agricultural fields.We evaluated the ability of eDNA-based approaches to detect disturbance gradients by assessing shifts in community composition across different levels of agricultural landscapes. Both sampling methods provided a well described picture of local biodiversity, with spiderwebs being the tool providing more diversity in terms of taxa.Preliminary results suggest that overall species diversity is comparable between agroecological fields and natural patches, while conventionally managed fields show slightly reduced diversity. In particular, pollinator diversity appears higher in agroecological systems, supporting the hypothesis that intermediate levels of disturbance may promote more complex communities.

Root system architecture as a key biological trait determining PFAS sensitivity in terrestrial plants

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Perfluoroalkyl carboxylic acids (PFCAs) are persistent contaminants increasingly subjected to regulatory restrictions. To date, their effects on terrestrial plants remain poorly investigated. To address these knowledge gaps, a comparative assessment was conducted to identify the most sensitive plant species and the most responsive early-growth endpoints. Five PFCAs were selected according to their carbon-chain length (from 3 to 8 C-atoms). Seven plant species were exposed to a wide range of concentrations (from 0.01 up to 100 µg kg -1). Germination and root elongation were evaluated as developmental endpoints to assess both acute and sublethal effects. Across species, germination exhibited weak responses, whereas root elongation appeared to be the most sensitive screening parameter, displaying divergent species-specific patterns. Notably, *Sinapis alba* and *Cucumis sativus* emerged as the most responsive species, although they exhibited opposite responses. While mustard exhibited low-dose root stimulation, cucumber showed root inhibition. Interestingly, species within the same family (Brassicaceae and Cucurbitaceae) showed contrasting sensitivity, suggesting that PFCA phytotoxicity is species-specific rather than driven by taxonomic relatedness. This divergent pattern may be linked to distinct morpho-physiological traits of the root system architecture . The mechanisms underpinning the two opposite morphological effects remain to be investigated. Disruption of hormonal processes involved in development of RSA may represent a possible explanation underlying the contrasting root responses observed in this study.

Exploring the response of *Ulva lactuca* to short-term tidal emersion

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Intertidal organisms experience rapid and frequent environmental fluctuations that may influence structure and function across all biological scales. We investigated short-term tidal emersion and its effects on physiological and structural ecological traits of the green alga *Ulva lactuca* in the Ria de Aveiro (Portugal). Thalli were sampled during maximum tide level at two nearby microhabitats: site 1 (S1, influenced by aquaculture) and site 2 (S2, lower anthropogenic influence). At each site, we compared fully emersed (E), partially emersed (PE) and submerged (S) thalli to assess how brief desiccation and light/temperature shifts modulate pigment composition, antioxidant metabolites, and morphological traits.Site differences reflected contrasting strategies: S1 thalli exhibited higher photosynthetic pigments, polyphenols, dry weight and leaf dry matter content, indicating greater carbon allocation to compact structural tissue; S2 thalli showed higher fresh weight, water content, thickness and specific leaf area, in accordance with more hydrated tissues, larger size and lower biomass allocation in structure.Partial tidal emersion better preserved tissue hydration and photosynthetic pigments, particularly at S1, suggesting a lower level of physiological stress compared with complete thallus exposure during full emersion. These thalli also exhibited higher polyphenol concentrations across all sites, indicating the activation of biochemical defense mechanisms against desiccation, high irradiance and oxidative stress. Our results demonstrate that *Ulva lactuca* exhibits rapid, coordinated structural and biochemical plasticity in response to short-term tidal fluctuations.Partially emerged thalli were able to maintain photosynthetic performance and water balance, whereas fully exposed activated protective antioxidant responses. Furthermore, differences among microhabitats highlight the importance of local environmental conditions and anthropogenic influence in modulating algal acclimation strategies and stress response.These findings enhance our understanding of adaptive and non-adaptive strategies used by intertidal algae in response to physical disturbances, clarifying the mechanisms underlying their functional resilience and persistence in a changing environment.

Roadkill monitoring in a Mediterranean island: do different methods tell different stories?

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Roadkill is the most prominent direct effect of roads on wildlife which have sparked an interest on roadkill monitoring at a global level. The two most widely used roadkill monitoring methods are systematic recording, and the use of citizen science for data collection. In this research, we aim to compare two datasets derived from these two methods, showcasing their strengths and weaknesses for roadkill recording and mitigation planning on the island of Cyprus. Data were extracted from the Public Works Department (PWD) and the Cyprus Roadkill Observation System (CyROS), a network of volunteers. Data comparison was conducted through visualisation and statistical analysis. The CyROS dataset is comprised of 1322 wildlife records between 2017-2025, while PWD holds 1555 records for the 2013-2022 period. The CyROS records span more than 140 individual roads while the PWD monitors a total of 27 highways and main roads. Yearly distribution varies between the datasets, while monthly records peak during June for both datasets. Datasets exhibit similar species seasonality pattern and similar density of roadkill events. The number of incidents is correlated with traffic volume. Hedgehogs make up the majority for CyROS, while foxes are more than 40% of the PWD database, with significant numbers of birds and snakes in both. Differences of the two schemes influencing the results are discussed. This research provides valuable insights into strengths and limitations of systematic monitoring vs citizen science for roadkill data collection and utilisation. Suggestions of ways to improve both methods, and extracting, assessing and organising data for design of mitigation measures are included, derived from our analyses.

Electrophysiological signatures of drought stress in tomato plants

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Plants have been shown to react to external stimuli by producing variations in the transmembrane electric potential (EP), which propagate through the vascular bundle and influence the physiology of even distant plant tissues.Our objective is to determine whether drought stress can be detected by analysing stem EP recordings and identify the signal features that best discriminate drought stress.We continuously recorded the EP of tomato plants using two electrodes placed at different heights on the stem. Half of the plants were subjected to drought stress, while the other half received adequate watering. The statistical features of the EP signals were then compared between stressed and control plants.Preliminary results show that the power spectral density of the EP signals decay according to a power law. During the day, stressed plants exhibit steeper decay rates (in absolute value), indicating a greater contribution of higher frequency components and a more irregular signal. Moreover, a logistic model based on the statistical features achieved a modest yet significant accuracy of 66% in classifying EP recording from stressed and control model plants.Although still preliminary, our findings demonstrate that drought stress affects the plant electrophysiology and that this stress can be detected by analysing EP recordings. This study provides a step toward developing EP-based early warning systems for drought stress.

Reti trofiche, funzionamento degli ecosistemi ed ecologia di comunità

4

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From primary production to biological responses: an integrated approach to the assessment of marine food-web integrity

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The conservation of marine biodiversity requires tools capable of detecting functional alterations in trophic networks before they result in potentially irreversible structural changes in ecosystems. In this context, the study proposes an integrated index to assess the continuity of the ecological processes that support marine biodiversity, applicable within the framework of the *Marine Strategy Framework Directive*, with particular reference to Descriptor 4 on food-web integrity.The index stems from the need to integrate results from different types of monitoring, providing an overall assessment of the functional status of trophic networks. The model is based on the joint analysis of physico-chemical, biological and ecotoxicological indicators, considering dissolved nutrients, chlorophyll-*a*, phytoplankton community structure, and the responses of organisms belonging to different trophic levels, such as *Aliivibrio fischeri, Phaeodactylum tricornutum* and *Paracentrotus lividus*.The composition and diversity of phytoplankton make it possible to characterize the quality of the ecosystem's food base, while ecotoxicological endpoints allow the identification of sub-lethal effects and biological alterations that may potentially propagate to higher trophic levels. In particular, the sensitivity of Paracentrotus lividus embryos and marine microalgae is useful for the early detection of stress conditions that are not always detectable through traditional environmental indicators alone.The calculation model was developed using public datasets from Tuscany and was subsequently tested in different national geographic areas in order to assess its robustness and applicability across different environmental contexts.The results show that the integrated approach describes the functional status of local trophic networks more reliably than individual indicators considered in isolation. The proposed index therefore provides a synthetic framework of the functional stability of the trophic network and represents a useful tool for defining intervention thresholds in the environmental monitoring of maritime works and dredging activities.

Unraveling the impacts of chronic fishing on community trophic structure and niche through a functional lens

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Bottom trawling is one of the most pervasive forms of fishing disturbance in marine ecosystems, yet its effects on the trophic organisation of benthic-demersal assemblages remain difficult to detect using taxonomic or biomass-based descriptors alone. Here, we integrate stable isotope analysis, Bayesian isotopic niche metrics and functional trait clustering to assess whether chronic trawling acts as a trophic-functional filter on demersal and benthic assemblages of the central Mediterranean shelf (Sicily Malta platform), across gradients of depth and swept area ratio (SAR). Trait-based ordination identified six ecologically interpretable functional clusters, separating seafloor-associated, low-mobility benthic invertebrates from mobile demersal predators along gradients of locomotion, feeding strategy and reproductive investment. Functional clusters showed coherent differences in mean δ^1 N values, whereas their broader differentiation in trait space than in isotope space indicated that traits and isotopes captured complementary dimensions of assemblage organisation. Environmental fitting further showed that isotopic structure was more closely associated with local productivity and near-seafloor physical conditions, particularly chlorophyll, temperature and bottom stress, than with depth. Fishing intensity was associated with a marked non-linear response in isotopic niche structure. Low-SAR assemblages occupied broader isotopic space, whereas assemblages exposed to intermediate-to-high SAR values showed the strongest contraction across multiple niche metrics, consistent with trophic-functional compression. At the highest SAR values, isotopic space partially re-expanded rather than continuing to contract, suggesting trophic reassembly by resistant, opportunistic or trophically flexible taxa rather than ecological recovery. Our findings indicate that combining functional traits and isotopic niche metrics can reveal food-web reorganisation that may remain hidden when trawling impacts are assessed only through taxonomic composition, abundance or biomass. This integrated framework adds a food-web integrity dimension to SAR-based and trait-based assessments, helping to identify candidate zones where chronic trawling coincides with trophic-functional simplification or reassembly. Trait-informed isotopic metrics therefore offer a promising tool for ecosystem-based fisheries management and for monitoring the ecological consequences of reducing or redistributing trawling pressure.

The trophic niche as a determinant of nutrient cycling: a proof of concept from Arctic tundra lakes

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A trophic niche is more than diet: it's the phenotypic route through which organisms acquire energy and redistribute nutrients. Because trophic niches are shaped by selection, resource availability and behavioural trade-offs, they determine the identity of consumed resources, trophic position, the carbon pools that are mobilised, and the nutrients returned to receiving ecosystem compartments through excretion. Thus, variation in the trophic niche of species can alter stoichiometry, microbial activity and ecosystem-level nutrient cycling. Here, Arctic tundra lakes were used as a proof of concept to show how climate-driven niche shifts can propagate from individual foraging decisions to carbon and nitrogen cycles. Sea-ice loss increased the use of goose eggs by polar bears due to reduced predation on seals, modifying the reproductive success and social structure of Barnacle geese (*Branta leucopsis*). In geese, brood status and dominance regulate access to high-quality grass patches versus mosses and aquatic vegetation, producing strong intraspecific dietary differences and changing nitrogen return through faeces, which was higher in grass-rich diets. Goose-derived nitrogen inputs then improved the stoichiometric quality of basal resources in lake food webs, promoting a shift in the omnivorous tadpole shrimp *Lepidurus arcticus* from carnivory to herbivory–detritivory. This accelerated the transfer of carbon from basal storage compartments into consumer pathways. At the ecosystem scale, nitrogen enrichment in lakes, in combination with warming, increased greenhouse-gas emissions, shifting Arctic lakes from carbon sinks to carbon sources. Together, these linked responses describe a "niche cascade" from climate to carbon: trophic decisions propagate through nutrient cycles. Optimal foraging predicted each switch observed in the case study, namely seals to eggs, grass to moss, animal prey to basal resources, suggesting that trophic niches can make nutrient cycles more predictable because they determine which carbon pools are consumed, which nutrients are returned, and how climate-driven changes propagate across food webs.

Emergent biogeochemical properties of multi-species holobionts in seagrass ecosystems

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Marine foundation species such as seagrasses structure coastal ecosystems not only through their physical architecture but through the metabolic activities of their associated microbiomes. The holobiont framework predicts that intimate multi-species associations may give rise to emergent properties: collective functions that exceed the sum of individual contributions and cannot be predicted from the partners in isolation. Seagrass meadows are particularly relevant in this context, as they harbor diverse assemblages of invertebrates — including sponges, bivalves, and other benthic fauna — each carrying their own microbiomes and potentially contributing to ecosystem-scale biogeochemical cycling. Here, I present evidence for emergent biogeochemical function in seagrass-associated multi-species systems in the Mediterranean Sea. Using stable isotope tracer incubations, nutrient flux measurements, and metagenomic profiling, my group characterized key elemental cycling processes — including nitrogen and sulfur transformations — across the individual partners and their associations. In these systems, the association expresses a suite of biogeochemical functions that cannot be predicted from the partners in isolation, and that have measurable consequences for nutrient availability and primary productivity at the holobiont scale. Metagenomic data provide independent genomic support for the functional breadth of these associations. Collectively, these results suggest that seagrass meadows should be understood not merely as monospecific holobionts but as multi-partner biogeochemical units, where emergent functions arising from species co-occurrence contribute to nutrient retention and ecosystem resilience. These findings have implications for how we model elemental cycling in coastal ecosystems and for conservation strategies targeting seagrass meadow integrity under increasing environmental pressure.

Seasonal variability and size structure drive phytoplankton community composition and diversity in a coastal ecosystem

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Marine autotrophic plankton communities are fundamental components of coastal ecosystems, supporting marine food webs and contributing to ecosystem functioning through primary production. Understanding how their taxonomic composition and size structure vary over time is essential for assessing ecosystem responses to environmental changes. In this study, we used a size-fractionated eDNA metabarcoding approach to investigate phytoplankton community dynamics in a temperate coastal area of the northwestern Adriatic Sea over a five-year period (2020–2024). Seawater samples were separated into three size fractions (3–10 μm, 10–50 μm, and 50–100 μm), representing different phytoplankton functional groups, and analyzed by high-throughput sequencing of the 18S rRNA V4 region. Overall, Alveolata and Stramenopiles phyla dominated the communities. Strong seasonal patterns emerged. Winter communities were characterized by higher chlorophyll-*a* concentrations (1.15 ± 0.34 μg L ^{1}), greater diversity under nutrient-rich mixed-water conditions, whereas summer assemblages showed lower biomass (0.22 ± 0.11 μg L ^{1}) and a more homogeneous composition under stratified, nutrient-poor conditions. Stramenopiles dominated winter communities in 2020–2021, while a shift toward higher Alveolata abundance was observed in subsequent years. Community composition was mainly driven by size fraction ($R^2 = 0.337$; $F = 5.51$, $p = 0.001$), with season exerting a secondary influence ($R^2 = 0.092$). Beta diversity analyses revealed that species turnover accounted for most compositional variation (88–92%), indicating that seasonal changes were driven primarily by species replacement rather than nestedness. Despite marked taxonomic and phylogenetic shifts, biomass distribution among size classes remained relatively stable, suggesting that functional organization is more conserved than species composition. These findings highlight the value of size-fractionated eDNA metabarcoding for understanding phytoplankton dynamics and suggest that functional stability may help maintain ecosystem functioning despite substantial taxonomic turnover.

Investigating the diversity of trophic controls through mixed trophic impact breakdown analysis: a case study in a Mediterranean food web

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Understanding the architecture of marine food webs and the diverse patterns of trophic controls is fundamental to assessing ecosystem functioning. Energy pathways are mediated by complex combinations of top-down, bottom-up and wasp-waist controls and quantifying the relative contribution of direct and indirect interactions played by species (or trophic groups) is a critical challenge. This contribution provides a preliminary quantitative assessment of trophic control patterns and direct and indirect impacts played by key species within the food web of the Northern Ionian Sea (NIS, Central Mediterranean Sea).An Ecopath trophodynamic model was developed for the NIS food web, described by 64 functional groups (FGs) for the 2008-2010 period. The model integrated inputs for each FG, including biomass (ton/km^2), production and consumption rates (year^{-1}), diets (W%), gear-specific landing and discard (ton/km^2). For FGs identified by keystoneness indices, a novel breakdown analysis based on the Mixed Trophic Impact matrix was applied with Trophic Level (TL) Decomposition routine across integer TLs.The food web was organized across five integer TLs, with odontocetes occupying the highest trophic position. High-TL predators displayed two distinct top-down cascading patterns: pelagic apex consumers (e.g. striped dolphin) propagated positive indirect effects down to TLII via competitor removal and mesopredator release, whereas demersal top predators, such as anglers, exhibited high negative impacts mostly on TLIV. Squids and mesopelagic fishes functioned as wasp-waist regulators, supporting the benthic-pelagic coupling. Conversely, zooplankton and benthic macroinvertebrates exerted predominant bottom-up control that progressively attenuated starting from TL>3.5. The analysis estimated a 58% contribution of indirect trophic impacts across the food web, mostly represented by the removal of competitors by keystone FGs. By capturing non-linear pathways and identifying key groups, this multi-level decomposition provides quantitative metrics to assess trophic controls patterns, and the methodology could be applied to assess the indirect fishing impacts on the food web.

Long-term changes in functional diversity and redundancy have increased the vulnerability of a temperate rocky reef ecosystem

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Biodiversity encompasses the variety of life at all complexity levels - from genes to ecosystems – and cannot therefore be described by species richness alone; consideration of functional diversity is also required. Marine ecosystems are undergoing biodiversity loss, making it fundamental to study their change over time. In the Mediterranean Sea, coralligenous reefs support biodiversity and complexity, but are affected by multiple stressors. This study investigates long-term changes in the Punta Mesco coralligenous reef (Ligurian Sea) by analysing quantitative cover data, collected since the 1960s at three depths: 20 m, 30 m and 40 m. Functional diversity (i.e., the variety of roles played by the species) and functional redundancy (i.e., the diversity of species playing a given role) were examined. To this purpose Biological Traits Analysis (BTA) was applied to assess whether changes in species composition had affected functionality. Species were characterised according to their biological traits associated with three main functions: trophism, three-dimensionality, and bioconstruction. Species were subsequently grouped into Functional Entities (FEs), defined as groups of species sharing the same combination of traits associated with the three functions considered. Results showed that the Punta Mesco coralligenous reefs underwent an abrupt shift between 1990 and 1996, and a further one between 2008 and 2017. The greatest changes occurred at 20 m depth, with a loss of functional diversity and a reduction in redundancy. At 30 m depth, functional diversity increased, but with FEs represented by a single species, which led to reduced redundancy. Coralligenous reef at 40 m exhibited some stability in functional diversity, but increased sedimentation reduced living cover. The changes over time in community composition and structure of the Punta Mesco coralligenous reef, already documented in previous studies, have therefore implied major alterations also in functional diversity and redundancy, thereby increasing ecosystem vulnerability.

Analysis of the environmental and ontogenetic drivers influencing the diet composition and feeding habits of the small-spotted catshark *Scyliorhinus canicula* (Linnaeus, 1758) in the southern Tyrrhenian Sea

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Understanding trophic interactions of marine mesopredators is essential for evaluating ecosystem functioning and supporting ecosystem-based fisheries management. The small-spotted catshark, *Scyliorhinus canicula*, is one of the most abundant demersal elasmobranchs in the Mediterranean Sea. This study investigated the trophic ecology of *S. canicula* in the southern Tyrrhenian Sea through the analysis of the stomach contents of 244 individuals collected between 2020 and 2024. Diet composition, trophic niche breadth, trophic level, resource partitioning, and trophic overlap were assessed in relation to size class, maturity stage, bathymetric distribution, and sampling year. Multivariate analyses included nMDS, PERMANOVA, SIMPER, null-model approaches based on Pianka and Morisita–Horn overlap indices and Generalized Additive Models (GAMs) to investigate environmental and ontogenetic drivers of prey occurrence. The overall diet was dominated by teleost, crustaceans, and cephalopods, with Osteichthyes (20.53% PSIRI) and Penaeoidea (18.58% PSIRI) representing the most important preys. The species exhibited a high trophic position (TROPH = 4.17 ± 0.55), confirming its role as a mesopredator within Mediterranean Sea food webs. Levins' index indicated a specialist trophic strategy at the population level (B_i = 0.38), although mature individuals displayed a broader trophic niche (B_i = 0.62). Diet composition was significantly influenced by bathymetry, body size and maturity stage, with depth representing the strongest explanatory factor. GAM analyses revealed marked prey-specific responses to environmental and biological drivers, with predictor importance analyses identifying depth as the most influential variable driving prey occurrence patterns. Trophic overlap among ecological groups remained consistently high between Size Classes and Maturity Stages, while was moderate between Depth Classes, suggesting the absence of a complete niche segregation. Overall, data from the present study improve the knowledge base on the resource partitioning dynamics influencing the populations of *S. canicula*, providing important information on the ecology of this essential mesopredator from the Central Mediterranean Sea.

From habitat suitability to species abundance distributions: a mechanistic framework via nonlinear damping and multiplicative noise

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Species abundance distributions (SADs) are a fundamental pattern in ecology, describing the distribution of species abundances within ecological communities. However, their underlying causes remain debated. Classical explanations invoke either stochastic processes, as in neutral theory, or ecological differences among species, as in niche-based approaches. To investigate the processes that can generate SADs, we developed a mechanistic framework that integrates habitat suitability, negative density dependence (e.g., through frequency-dependent predation), and demographic stochasticity within a single analytical model. In this framework, species differ in their habitat suitability, while density-dependent regulation limits the dominance of highly abundant species and demographic stochasticity introduces random fluctuations in population dynamics. This combination yields an explicit analytical expression for the SAD and establishes a direct link between community-level abundance patterns and species-specific habitat suitability. The framework provides a unified interpretation of classical SAD forms. When interspecific variation in habitat suitability dominates, the resulting distributions tend to be lognormal-like, whereas high demographic stochasticity produces patterns that resemble those predicted by neutral models. By bridging niche-based and neutral perspectives, our model can help to identify the ecological mechanisms shaping SADs by generating testable predictions that relate distributional shape to measurable ecological parameters.

Opportunistic but still selective? Feeding preferences of the fireworm *Hermodice carunculata*

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Predation plays a key role in determining marine community structure and dynamics. Due to their dietary flexibility, generalist predators are considered more successful than specialist feeders under ongoing climate change. Nevertheless, dietary specialization is often conceptualised as a fixed attribute derived from the fundamental niche, rather than as an ecological outcome reflecting resource use across spatial and temporal scales. The bearded fireworm *Hermodice carunculata* (Pallas, 1766) is an amphinomid polychaete that has emerged as a native invader in the Mediterranean Sea, rapidly expanding from central-eastern regions towards the western and northern sectors of the basin. Commonly classified as a generalist predator and scavenger, it feeds on fish carrion but also on a variety of living invertebrates, potentially threatening benthic keystone species. Given its ongoing expansion and Mediterranean ecosystems changes, understanding its trophic ecology is crucial.Here, we investigated whether the bearded fireworm exhibits prey preferences under controlled conditions by evaluating its predation towards common Mediterranean prey previously reported in its field diet. After setting the optimal conditions in an experimental arena, ten prey pairings were tested. Predatory behaviour was recorded and analysed both qualitatively and quantitatively using tracking software.The bearded fireworm consumed all prey, confirming its generalist feeding strategy, while showing prey selection, with fish as the most preferred one, followed by mussel (the lab diet), sea anemone and lastly jellyfish. Differences in predatory behaviour (e.g., certain/uncertain) and consumption times further supported this selection pattern, suggesting that, although the bearded fireworm exhibits a broad diet, its feeding behaviour may be influenced by nutritional or ecological requirements based on resource availability.These results improve our understanding of the predatory pressure exerted by this species and highlight the importance of assessing dietary specialisation within generalist consumers to better predict their impacts on Mediterranean communities under the current climate change scenario.

Feeding habits of the lanternfish *Hygophum hygomii* (Lutken, 1982), in the Strait of Messina

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A total of 276 specimens of *Hygophum hygomii* were collected stranded along the Sicilian shoreline of the Strait of Messina between 2010 and 2018 (winter and spring). Their stomach contents were examined to study their diet. The in-depth analysis, at family, genus, and species levels, of the prey ingested by *H. hygomii* enabled us to investigate the trophic ecology of this mesopelagic fish, which has to date been little studied in the Mediterranean Sea. By cross-referencing available data on prey ecology, it was possible to understand the feeding strategy of *H. hygomii*, including its vertical migrations. Within the broad size range of the specimens we examined (14.5–41.1 mm SL), some dietary differences appeared to be linked to predator size, particularly above 25 mm SL. Finally, a comparison was made between *H. hygomii* and other Myctophids in the same study area, highlighting differences and similarities in their feeding strategies. The study of mesopelagic fishes is essential for a better understanding of pelagic food webs. Indeed, due to their large biomass and gregarious behavior, together with the well-known daily vertical migrations, these fish play a crucial role in energy transfer along the water column and across trophic levels. Their diet, based primarily on herbivorous zooplankton, and their role as prey for larger organisms (e.g., tuna, cephalopods, dolphins) are important in this regard. Therefore, deepening our knowledge about mesopelagic fish allows us to gain insights into marine ecosystems and their health, including by studying the presence of contaminants (e.g., microplastics, heavy metals) and their passage through the food web, from plankton to large predators.

Beyond biomass: functional reorganization of north sea plankton

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Plankton plays a fundamental role in marine ecosystems by regulating major elemental cycles and supporting functions and biomass of higher trophic levels. However, under ongoing environmental changes, marine ecosystems are experiencing impacts that can be difficult to detect using conventional bulk indicators such as biomass or primary production. To address this challenge, we applied a combined approach of Mass Balance Models and Ecological Network Analysis to detect changes in plankton trophic web structure and function. We analyzed a 19-year time series from the North Sea Ecosystem Cruise conducted by the Norwegian Institute of Marine Research, comprising 197 samples collected between 2006 and 2024. Our analysis identified a functional reorganization in 2019 detected synchronously by BEAST change point detection algorithm across multiple Ecological Networks Indicators. The shift was consistent across coastal and offshore water masses, while total biomass and primary production exhibited inconsistent patterns. Statistical analysis indicated that the largest differences in trophic organization occurred during the bloom period suggesting a possible phenological changes in the bloom composition. The observed increase in silicate concentrations after 2019 may reflect reduced uptake by diatoms, potentially liked to a shift toward smaller phytoplankton size classes. Overall, the post-2019 system showed an increase in flows organization complexity and in trophic efficiency, changes that were not captured by bulk indicators. These findings suggest that recent changes in the North Sea plankton community reflect a reorganization of trophic interactions and energy pathways rather than a simple change in overall biomass or productivity. This study highlights the importance of integrating long-term monitoring with network-based analysis to detect and understand changes in marine ecosystems.

Prokaryotic diversity and benthic trophic status of two previously uncharacterized Mediterranean solar salterns: a comparative metagenomic study of active and inactive systems

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Solar salterns are extreme environments of high scientific interest, hosting specialized microbial communities shaped by steep physicochemical gradients. Here we present the first comparative metagenomic analysis of two solar salterns in southern Sardinia: Conti Vecchi (active saltern, AS) and Molentargius (inactive saltern, IS), located ~20 km apart and exposed to similar climatic conditions. This setting provides a unique opportunity to assess the impact of saltwork management on microbial diversity along a salinity gradient.Water and sediment samples were collected from ponds with varying salinities in winter and summer, yielding 2786 metagenome-assembled genomes (MAGs; 1537 from AS and 1249 from IS; 1131 from sediments and 1655 from water). Seasonal variation was the primary driver of environmental differences (61% of variance, p-value < 0.001), although site-specific differences in thermal range and pond structure were also observed.Benthic trophic conditions were instead driven mainly by pond identity within each saltern (31% of variance, p-value < 0.001), with no significant effect of saltern or season. In the AS, the medium-low salinity pond was eutrophic, with organic carbon exceeding microbial processing capacity, while the high-salinity pond showed near-complete depletion of biopolymeric carbon, displaying oligotrophic features. Metagenomic results supported these patterns, with Pseudomonadota and Bacteroidota dominating at low salinities, and Halobacteriota prevailing in high-salinity ponds. In the IS, the high salinity pond exhibited a different pattern: despite comparable salinity to the AS hypersaline pond, it had markedly higher carbon degradation rates and faster turnover time in winter, with the opposite trend in summer.This points to a distinct microbial community, confirmed taxonomically by an unexpected dominance of Bacteria - including Cyanobacteria - despite the high salinity. This contrast may reflect differences in saltwork management: the controlled water level in AS produced a solid crust of salt, whereas the less controlled level in the IS produced a gypsum crust with a visible green layer.A large fraction of MAGs could not be assigned to known taxa, pointing to unexpected novelty from species to higher taxonomic levels and positioning southern Sardinia salterns as promising reservoirs of prokaryotic diversity for future investigation of under-characterized Mediterranean extreme environments.

Environmental filtering and functional diversity of meiofaunal communities inhabiting shallow-water hydrothermal vents of the Aeolian archipelago (Tyrrhenian Sea)

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Shallow-water hydrothermal vents are naturally fragmented habitats characterized by steep physicochemical gradients and environmental heterogeneity. These systems function as natural laboratories providing unique environments to investigate the processes that regulate community assembly and ecosystem functioning under extreme conditions. Despite the widespread occurrence of hydrothermal activity in the Aeolian Archipelago (southern Tyrrhenian Sea), the ecology of meiofaunal communities inhabiting these environments remains poorly understood.An investigation was conducted into the abundance, diversity, community composition and functional organization of meiofauna at shallow hydrothermal vents of Vulcano (Porto Levante) and Salina (Pollara Bay), comparing vent-influenced sediments with adjacent non-vent areas. Attention was placed on nematode assemblages, the dominant component of the meiofauna.Meiofaunal abundance and diversity did not exhibit consistent declines near vent emissions, and diversity indices did not differ significantly among stations. In contrast, community composition varied significantly among sites, stations and sediment layers, suggesting that small-scale environmental heterogeneity strongly influences meiofaunal assemblages. Temperature and pH explained from 43 to 58.1% of the variability in meiofaunal community diversity and composition.Nematode assemblages inhabiting vent sediments were largely composed of taxa also occurring in surrounding sediments, suggesting that shallow-vent communities are assembled mainly through differential filtering of taxa from the regional species pool rather than through the establishment of vent-endemic specialists. Nevertheless, marked shifts in trophic structure and life-history strategies were observed along the vent gradient, revealing stronger functional than taxonomic responses along the gradient. Particularly, PSU, pH and temperature could explain up to 56.2% of taxonomic diversity, 70.5% of community composition and 90.9% of functional diversity patterns in nematode assemblages.These findings indicate that shallow hydrothermal vents of the Aeolian Archipelago do not harbour highly specialized meiofaunal assemblages; instead, environmental filtering reorganizes communities primarily at the functional level, generating marked shifts in trophic and life-history strategies despite limited changes in taxonomic diversity.

Community composition and structure of mesophotic rhodolith beds off the Campania coast (Tyrrhenian Sea)

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Rhodolith beds are globally widespread biogenic habitats formed by the accumulation of free-living calcareous red algae. They support high biodiversity and provide important ecosystem services, including carbon sequestration. In the Mediterranean Sea, these habitats mainly occur at mesophotic depths (30-100 m), and their distribution, structural complexity, and biodiversity are still poorly known. This study focuses on four rhodolith beds in the Tyrrhenian Sea (Capri, Sorrento, Ischia, and Cilento), located between 50 and 70 m depth, and investigates their floristic and faunistic composition. In addition to the macrofaunal community, the meiofaunal component was also examined for the first time in Mediterranean rhodolith beds. The results revealed marked variability in rhodolith cover and bed structural complexity among sites. A high diversity of coralline algae was recorded (>10 taxa). The Cilento rhodolith bed, which showed the highest cover and structural complexity, also exhibited the greatest macrofaunal abundance and species richness. Similar dominance patterns of the main taxonomic groups were observed across all beds, with Polychaeta, Mollusca, Crustacea, and Echinodermata being the most represented. Polychaetes were the most abundant group, while molluscs contributed the highest number of species. Among trophic guilds, deposit feeders played a key role in shaping community structure, highlighting the importance of rhodolith beds in detrital food webs. Rhodoliths also hosted a distinctive meiofaunal assemblage, mainly represented by copepods and numerous temporary meiofaunal species (juveniles of macrofauna), confirming the nursery role of these habitats. Overall, these findings confirm the high floristic and faunistic diversity of rhodolith beds and emphasize their crucial role as biodiversity hotspots in the Mediterranean Sea.

Trophic reorganization of forest-floor microarthropods along a vertical resource gradient

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Forest floors are vertically structured systems in which successive stages of leaf-litter decomposition alter both the stable isotope composition and availability of basal resources to consumers.Yet it remains unresolved whether trophic differences along this vertical profile arise from taxonomic turnover or isotopic shifts within taxa shared among forest-floor layers. To address this, we sampled three forest-floor layers (OL: fresh litter; OF: fragmented litter; A: 0-5 cm of soil) in a temperate beech forest and analysed three major microarthropod groups representing different trophic roles. Oribatida and Collembola were identified to species or genus level, whereas Mesostigmata to family level. We quantified vertical variation in basal δ^{13}C and δ^{1} N to account for depth-related shifts in resource isotope composition. We hypothesized that baseline-corrected community isotopic position would differ among layers, that OL–OF changes would arise from group-specific combinations of taxonomic turnover and within-taxon variation, and that isotopic niche breadth would contract toward mineral soil. Basal δ^{13}C and δ^{1} N increased by approximately 3‰ and 4‰, respectively, from OL to A layer. Community mean Δ^{13}C and Δ^{1} N decreased with depth in Oribatida, whereas only Δ^{13}C decreased in Collembola and Mesostigmata. Taxonomic composition differed among layers in all three groups, while trophic-guild structure changed in Oribatida and Collembola. From OL to OF, abundance-weighted community mean Δ^{13}C declined by 0.73‰ in Oribatida, 1.16‰ in Collembola, and 1.30‰ in Mesostigmata; within-taxon components represented approximately 77%, 79%, and 93% of these declines, respectively. In Oribatida and Mesostigmata, opposing turnover and within-taxon effects partly cancelled one another, producing smaller overall changes in community mean Δ^{1} N. Contrary to our prediction, isotopic niche size did not contract toward mineral soil. Vertical stratification therefore reorganized carbon pathways and relative trophic positions through interacting and compensating processes, without consistently narrowing isotopic niche breadth across forest-floor compartments.

Ecosistemi, biodiversità e cambiamento climatico

5

Coordinatori: Antonio Pusceddu, Renato Casagrandi, Diego Fontaneto

Conserving a moving target: marine biodiversity in a rapidly changing ocean

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Climate change and other human pressures are profoundly transforming marine ecosystems, altering species distributions, ecological interactions, and the connectivity patterns that underpin biodiversity, and ecosystem functioning and services' provision. Addressing these challenges requires integrating ecological, oceanographic, climatic, socio-economic, and governance perspectives. Drawing on recent case studies, this presentation will explore how climate-informed ecological modelling, large-scale monitoring, and interdisciplinary research can support the design and management of dynamic and effective marine protected area networks. Particular attention will be also given to connectivity as a fundamental mechanism for maintaining biodiversity, enhancing ecosystem resilience, and supporting adaptive conservation strategies in a rapidly changing climate. Moving beyond static protection approaches, these frameworks provide pathways for adaptive management that can respond to environmental change while safeguarding ecosystem services and supporting local communities.The presentation will conclude with an overview of the newly launched Med4GoC project, *Mediterranean Insights for Baja's coastal future*. Using the Mediterranean Sea as a natural laboratory, the project aims to generate transferable knowledge on climate adaptation, ecosystem restoration, biodiversity conservation, and sustainable fisheries management. By fostering international collaboration, Med4GoC seeks to address shared environmental challenges across two ecologically significant marine regions (the Mediterranean Sea and the Gulf of California) and support evidence-based conservation and management strategies.

Testing species distribution model accuracy against direct evidence of a Last Glacial Maximum breeding-range shift in a wetland bird

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Species distribution models (SDMs) are central to forecasting how species will respond to climate change, yet their accuracy when extrapolated to climate conditions far outside present-day variability is rarely tested directly. Here, we evaluate hindcast SDMs against a rare empirical benchmark: eggshell remains of Mute Swan *Cyngus olor* from an archaeological site in eastern Jordan, identified through palaeoproteomics and directly radiocarbon-dated to the Last Glacial Maximum (LGM) c. 26000 years ago. The Mute Swan's current breeding range lies far to the north of the site, making its presence in glacial-age Jordan strong evidence of a substantial breeding-range shift relative to today. We use this evidence to test whether ensemble SDMs, built from standard bioclimatic predictors alone,

Changes in diversity and structure of sponges: comparison between present and past

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In recent decades, Mediterranean benthic communities have undergone significant changes in composition and distribution, largely attributed to global warming. Porifera represent a key group for detecting environmental change, with some species declining and others expanding their range. This study compares present and past sponge diversity at three Mediterranean areas: one site along the Portofino Promontory (Ligurian Sea), the rocky cliffs of Montecristo Island (Tuscan Archipelago), and a semi-submerged sea cave in “Parco Sommerso di Gaiola” (Naples). The same sampling methods from earlier studies were applied. At the Portofino site, squares (400 cm^2 each) were collected along a vertical transect (0–20 m). At Montecristo, samples were visually selected between 0 and 40 m depth. In the cave, sampling was conducted using quadrats, adapted to cavity morphology and light gradients. At Portofino, 68 species were recorded in 2023 compared to 114 in 1976, with only 43 common species. Species richness declined in all depth intervals except the deeper one. At Montecristo, species richness increased from 27 (1980–1981) to 40 (2019–2020), but only 13 species were shared, indicating a substantial turnover in species composition over four decades. In the cave, species number slightly increased (69 in 1960 to 72 in 2023), yet only 27 species persisted, and sponge cover declined from 55% to 25%. Overall, over a multi-decadal timespan (40–63 years), all sites (Portofino Promontory; Montecristo Island and the Gaiola MPA cave) show a complete shift in sponge diversity, a reduction in overall abundance, and a change in the growth forms, with a decline in massive species and an increase in encrusting forms. These patterns suggest that anthropogenic impacts, together with ongoing climate change, have contributed to the decline and transformation of sponge communities in the Mediterranean Sea.

Rapid plasticity underlies the resilience of *Anemonia viridis* to ocean acidification

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Persistence under ocean acidification is often framed as long-term adaptation, yet on the timescales over which seawater chemistry is changing, organismal persistence may depend on rapid physiological adjustment. Distinguishing such plasticity requires manipulative approaches that natural CO_2 vents make possible. At the Levante Bay vent system (Vulcano Island, Mediterranean Sea), where the symbiotic sea anemone *Anemonia viridis* thrives under chronically low pH, we tested this hypothesis using a reciprocal transplant experiment. Anemones from an ambient pH site (~8.1) and a low pH site (~7.5) were transplanted in both directions, with within-site controls, and assessed before transplantation and after 24 h and 5 d. Net and gross oxygen production and respiration were quantified from O_2 concentration changes in closed benthic chambers, while symbiont photosynthetic efficiency (Fv/Fm) was measured by PAM fluorometry. Performance tracked the pH conditions experienced after transplantation. Anemones moved to low pH increased net and gross oxygen production within 24 h relative to controls ($p = 0.030$), and this pattern persisted after 5 d (among-group Kruskal-Wallis $p = 0.024$), whereas those moved to ambient pH showed reduced net production ($p = 0.029$ at 24 h). Respiration was unaffected, indicating that the response involved production rather than respiration. PAM fluorometry after 5 d corroborated this pattern, with photosynthetic efficiency significantly higher at the low pH site ($p = 0.004$) and, among ambient-origin individuals, in those transplanted to low pH than in their controls ($p = 0.016$), supporting a rapid adjustment of symbiont performance to local pH conditions. These rapid responses indicate that *A. viridis* adjusts its performance to ambient carbonate chemistry through phenotypic plasticity, consistent with relief of carbon limitation in the symbionts at low pH. Rapid adjustment of a key symbiotic function may therefore contribute to the persistence of Mediterranean anemone-zooxanthellae symbioses as the ocean continues to acidify.

Forest plant communities in transition: beyond plant species loss

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Forest plant diversity is threatened by global change and is rapidly shifting due to multiple drivers. Ecologists use different approaches (e.g., long-term studies, space-for-time substitution) and indices (e.g., taxonomic, phylogenetic, and functional; alpha and beta diversity) to monitor forest plant diversity, often yielding contrasting outcomes. Here, we synthesize findings from our research based on several datasets spanning several temporal and spatial scales and different aspects of diversity, in order to unravel overall changes in forest plant communities. In 31 permanent plots of the Italian ICP Forests network, 25 years of monitoring revealed a decline in plant species richness in alpine coniferous and temperate deciduous forests, mainly driven by increased canopy closure and climatic extremes. To overcome limitations related to the low informative value of species richness for assessing species functional roles and interactions, and the reliance on macroclimatic data that may poorly reflect sub-canopy microclimatic conditions, we then provide additional evidence to improve the interpretation of these patterns. In particular, a study based on a 600-year forest chronosequence showed that the progressive decline in species richness over time was partly independent of species interactions. These interactions, quantified through an index called Compositional Diversity, were in fact highest in old-growth forests, despite their relatively low plant species richness. Moreover, by integrating a functional approach with direct measurements of sub-canopy microclimate, we found that understory functional diversity declined with increasing sub-canopy temperature. The complexity of forest ecosystems requires the integration of complementary approaches to better understand ongoing changes. A reduction in species richness is not necessarily a concern per se, particularly when associated with natural forest maturation processes. In contrast, climate change — especially macro- and microclimatic temperature variations — represents a major issue, affecting not only species loss but also plant functioning.

Eukaryotic community succession on autonomous reef monitoring structures (ARMS) in Antarctica: the first three-year 18S rRNA metabarcoding time series from the Ross Sea

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Antarctic coastal ecosystems represent some of the most ecologically unique and vulnerable marine environments on Earth yet remain critically under-characterised due to logistical constraints and the scarcity of long-term benthic time series. Autonomous Reef Monitoring Structures (ARMS), standardised PVC plate assemblies developed to combine recruitment of benthic organisms with molecular characterisation of colonising pioneer communities, represent an effective, purpose-built tool for metabarcoding-based biodiversity assessment of marine sessile assemblages. DNA metabarcoding has emerged as the method of choice for high-throughput, standardised biodiversity assessment of ARMS-associated communities, enabling comprehensive taxonomic characterisation of both macro- and microeukaryotes far beyond the resolution achievable through traditional morphological approaches. Despite their growing global adoption, ARMS deployments in polar regions remain exceptionally rare. In this context, here we present the first 18S rRNA metabarcoding dataset generated from ARMS in the Ross Sea, deployed at Terra Nova Bay (Mario Zucchelli Station, Antarctica). Six ARMS units in Tethys Bay (25 m depth) were analysed across a three-year (2015–2018) colonisation period (two replicates per year), providing the first molecular baseline for Antarctic benthic eukaryotic communities. The 18S rRNA marker was selected to complement the existing COI dataset, capturing protistan diversity systematically underresolved. Results reveal a directional, taxonomically structured successional trajectory: early-stage communities dominated by opportunistic protists were progressively replaced by Bigyra and Bryozoa by Year III, suggesting the onset of a structurally complex, habitat-forming community. Alpha diversity peaked at Year II before declining, while beta diversity confirmed strong compositional turnover across years (PERMANOVA $R^2 = 0.82$, $p = 0.001$). A persistent core of 16% shared OTUs indicates community continuity despite marked successional dynamics. This study fills a critical gap in the molecular characterisation of Southern Ocean benthic communities, establishing a reference framework for future polar ARMS studies, with 18S uniquely resolving early-successional eukaryotic diversity systematically underrepresented in mitochondrial-based surveys.

Fish beneath (changing?) Antarctic fast ice: two case studies reveal emerging vulnerabilies

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Antarctic fast-ice ecosystems are highly exposed to the effects of climate change, as alterations in sea-ice extent, persistence and stability can profoundly influence habitat availability, species distribution and ecosystem functioning. These habitats, however, remain poorly studied because of the logistical challenges associated with sampling under ice-covered conditions. Two studies from Terra Nova Bay (Ross Sea, Antarctica), carried out using remote visual technologies, have improved our understanding of biodiversity patterns and ecosystem responses to changing sea-ice conditions. Surveys conducted using a Remotely Operated Vehicle (ROV) under fast ice revealed the presence of key life-history stages of several notothenioid species within shallow and medium-depth shelf habitats. Different habitat types were associated with distinct life-history stages, including settlement areas for juvenile fish, areas dominated by adults, and sites where reproductively mature individuals were observed. These findings highlight the ecological relevance of coastal ice-covered areas as essential habitats supporting recruitment, adult populations and reproduction in Antarctic fish communities. In a complementary study, multi-year deployments of Baited Remote Underwater Video Systems (BRUVS) investigated the occurrence of Antarctic toothfish (*Dissostichus mawsoni*) in shelf habitats under different fast-ice conditions. Toothfish abundance was significantly higher beneath intact ice and declined markedly in altered ice environments, indicating a close relationship between this high-level predator and sea-ice integrity. As sea-ice anomalies and extreme weather events are expected to increase under future climate scenarios, such changes may affect the spatial distribution of toothfish and potentially alter trophic dynamics in Antarctic coastal ecosystems. These studies identify Antarctic fast-ice habitats as key areas supporting critical life-history stages of notothenioid fishes. Climate-driven changes to fast ice may therefore alter coastal biodiversity and trophic dynamics, highlighting the need to improve our understanding of these ecosystems to support their conservation and management.

From monitoring to mesocosm: data-driven heatwave scenarios for realistic intertidal climate-change experiments

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Marine (MHW) and atmospheric heatwaves (AHW) are extreme thermal events of growing ecological relevance for intertidal communities (Stillman et al., 2025). Using in-situ data from the ISPRA monitoring network across 34 Italian coastal stations (2010 - 2025), we identified 1,577 MHW and 6,826 AHW events (Hobday et al. , 2016 ; Perkins & Alexander , 2013 , respectively). Unsupervised classification id entified t hree recurring event typologies : Dynamic , sh ort a nd moderately intense events; Pulsed , short duration with rapid onset ; and Persistent , long-lasting. The most ecologically relevant finding was the widespread co-occurrence of marine and atmospheric heatwaves: 73.6% of MHW overlapped with at least one AHW at the same station, and the annual number of overlap days increased markedly over the study period (+13.5% yr ^{1}). This increasing concurrence li kely amplifies t hermal stress through air–sea heat exchange processes (Paredes-Fortuny et al., 2025; Ba rkhordarian e t al., 2025). Co-occurrence patterns also va ried s easonally, in dicating t hat organisms experience distinct thermal regimes depending on when compound events occur. These patterns (event typology, co-occurrence dynamics, and seasonal exposure) define the parameter space for realistic laboratory simulations. Based on t his framework , we developed a library of 28 data-driven th ermal trajectories re p resenting r ealistic marine, at mos pheric a nd compound heatwave scenarios . Each trajectory incorporated event characteristics and, for compound scenarios, overlap properties including duration, onset offset, and aerial exposure fraction, stratified by season and event typology. By translating long-term climate observations into a library of data-driven thermal trajectories , this framework bridges climate monitoring and experimental ecology . Capturing the temporal complexity of observed heatwaves, rather than relying on arbitrary warming treatments, provides a mechanistic foundation for predicting how intertidal organisms and communities will respond to increasingly frequent compound climate extremes.

GBIF in italia

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La digitalizzazione dei dati di biodiversità e la produzione di sequenze di barcoding della biodiversità sono due importanti frontiere della ricerca in campo limnologico e oceanografico. La comunicazione evidenzierà come GBIF offra una potente infrastruttura aperta per la condivisione, l'accesso e il riutilizzo dei dati sulla biodiversità, integrando infrastrutture e reti di ricerca come DiSSCo, eLTER, NBFC, ItaBOL e altre, volte ad aggregare dati di occorrenza, collezioni museali, dati molecolari e osservazioni di citizen science in una piattaforma unificata e interoperabile. GBIF offre così strumenti e opportunità senza pari per analisi ecologiche su larga scala, modelli di distribuzione delle specie, valutazioni della conservazione e ricostruzione di trend storici in un quadro di FAIR e Open Science e nel rispetto degli standard internazionali.

Landscape complexity mitigates heatwave impacts on pollination services: evidence from a phytometer experiment

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Extreme climatic events, particularly heatwaves, are expected to disrupt plant–pollinator interactions and compromise crop reproduction. However, it remains unclear whether landscape complexity, through enhanced pollinator communities, can buffer these negative effects. Here, we investigated whether pollination services act as a nature-based solution mitigating the impact of heat stress on plant reproductive success.We conducted a field experiment using *Brassica rapa* L. plants (Wisconsin Fast Plants) as phytometers across eight sites representing contrasting landscape contexts (complex vs simplified). From May to August, plants at the same phenological stage were sequentially exposed to field conditions in ten sampling rounds, capturing seasonal variability and natural heat events. At each site and round, plants were assigned to open pollination or pollinator exclusion treatments to disentangle biotic and abiotic drivers. After a standardized exposure period, plants completed their life cycle under controlled conditions, and reproductive output (fruit set, seed number, seed weight) and biomass were quantified.We expect that heat stress will reduce reproductive performance, but that this effect will be less pronounced in complex landscapes due to higher pollinator activity and functional redundancy. Conversely, pollinator exclusion treatments will reveal the extent to which reproductive failure is driven by direct physiological stress versus pollination limitation.This study provides a mechanistic framework to assess how biodiversity-mediated ecosystem services can enhance agroecosystem resilience under increasing climate extremes, highlighting the role of landscape management in sustaining crop production.

Time matters: explicit integration of climate change in species distribution modelling

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Species Distribution Modelling (SDM), also known as Habitat Distribution Modelling, is a widely used framework for estimating a species' realised ecological niche based on occurrence records and relevant environmental variables. Once the niche has been characterised, SDMs are then used to identify where and when similar environmental conditions occur, allowing projections across geographic regions and time periods. These models are increasingly used to assess the potential impacts of future environmental change, supporting conservation planning, habitat restoration, and biodiversity management.A major limitation of many SDM approaches is how they treat time. Species occurrence data are often collected over decades (e.g., GBIF) or even centuries (e.g., museum collections), yet most available software does not explicitly incorporate the temporal dimension or account for how both land use and climate have changed in the meantime. As a result, estimates of a species' realised niche may be biased, potentially reducing the reliability of model predictions.In this talk, we will present two complementary approaches to address this challenge. The first is *tidysdm*, an R package designed to perform SDMs using time-series data. By explicitly pairing long-term species observations with historical climatic information, *tidysdm* enables more robust reconstruction of realised niches while reducing biases arising from anthropogenic habitat alteration and ongoing climate change, both of which can differently affect species observations over time.The second approach is a workflow we developed to investigate how species' realised niches change through time in response to significant climatic fluctuations. Using case studies spanning tens of thousands of years, we will demonstrate how this framework can be used to reconstruct niche dynamics in the face of substantial climate change. We will then discuss its relevance for understanding species responses to the unprecedented environmental changes occurring today.

A fine-scale approach reveals that local floral resources sustain rich and heterogeneous pollinator communities along an urban riverside grassland corridor

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Urbanisation is a major driver of habitat fragmentation and pollinator decline. Although urban green spaces are increasingly recognized as important refuges for pollinator conservation, most studies have focused on habitat types such as parks, gardens, allotments, and urban meadows. In contrast, grasslands running along rivers remain poorly studied despite being widespread features of European cities and potentially functioning as ecological corridors with less interruption across fragmented urban landscapes. We investigated wild bee and hoverfly communities along an urban riverside grassland corridor of the Arno River (Florence). Pollinators and flowering vegetation were surveyed along eight permanent transects during two consecutive years (2024–2025). We assessed pollinator diversity and community composition in relation to local floral resources, landscape composition, habitat configuration, microclimatic temperatures, and plant–pollinator interactions associated with spontaneous flowering vegetation. The study area supported unexpectedly high pollinator diversity relative to its limited spatial extent, especially for wild bees. Beta-diversity analyses revealed that community differences along the corridor were mainly driven by species turnover rather than nestedness, indicating that the corridor functions as a heterogeneous mosaic of local assemblages of pollinator communities. Consistently, local habitat conditions emerged as the main drivers of pollinator communities. Flowering plant richness and floral cover positively influenced both abundance and richness of wild bees and hoverflies, while warmer local conditions additionally promoted wild bee abundance. In contrast, the percentage of artificial surfaces showed no detectable effects, whereas habitat configuration, calculated as an index of contiguity, positively influenced hoverfly richness. Plant–pollinator interaction analyses highlighted the importance of a limited set of spontaneous flowering species in sustaining pollinator communities. Our results suggest that urban riparian grasslands are overlooked but valuable habitats for pollinator conservation and may enhance ecological connectivity within urban landscapes, emphasizing the potential of local floral management to create more biodiverse and pollinator-friendly cities.

Do biodiversity–geodiversity interactions shape ecosystem carbon fluxes?

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Climate change is reshaping ecosystem structure, functioning and biodiversity worldwide, yet the role of abiotic landscape heterogeneity in mediating ecosystem responses remains poorly understood. Geodiversity has recently emerged as a key factor for ecosystem resilience, potentially influencing biodiversity patterns, ecosystem functioning and the capacity of ecosystems to adapt to environmental changes. However, the extent to which interactions between geological and biological features affect ecosystem processes remains largely unexplored. To address this gap, we quantified CO_2 fluxes across contrasting geo-biological associations in the Folafótur Peninsula (Westfjords, north-western Iceland), including heathlands on volcanic bedrock, wetlands on sedimentary substrates and meadows on marine terraces. Two replicate plots were established within each association to evaluate differences in geodiversity, biodiversity and ecosystem carbon dynamics. We unveil that distinct geo-biological associations exhibited marked differences in gross primary productivity (GPP) and ecosystem respiration (ER), with variation among associations exceeding that observed among environmentally similar replicate plots. Notably, geo-biological associations explained a substantial proportion of carbon-flux variability beyond that accounted for by established environmental drivers such as temperature and irradiance. Although biodiversity and geodiversity metrics did not consistently covary, divergence metrics clearly distinguished the different associations, highlighting the importance of considering both biotic and abiotic dimensions of ecosystem heterogeneity. These findings suggest that geo-biological associations represent an overlooked source of variability in ecosystem carbon dynamics and may contribute to shaping ecosystem responses to climate change. Integrating geodiversity into biodiversity and ecosystem-function research could improve the identification of vulnerability and resilience hotspots, supporting conservation and land-management strategies aimed at enhancing ecosystem adaptation and maintaining climate-regulating ecosystem services under global change.

Who, not how many: functional identity drives benthic community production under ocean acidification

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Ocean acidification is widely expected to suppress marine ecosystem functioning, yet how it reshapes biodiversity-ecosystem functioning (BEF) relationships is poorly understood. Using in situ benthic chambers along a natural CO_2 gradient at Vulcano Island (Mediterranean Sea), we measured community metabolism (community respiration (CR), net (NCP) and gross (GCP) community production) and macrophyte community structure in 19 chambers across ambient (~8.1) and low pH (~7.5) conditions.NCP was significantly higher at the acidified site while CR remained unchanged, revealing a shift of the community trophic balance toward autotrophy consistent with CO_2 fertilisation. Critically, taxonomic diversity (species richness, Shannon, Pielou) did not predict NCP. Functioning was instead predicted by the community-weighted mean (CWM) of species pH tolerance, a trait-based descriptor of functional structure, which was strongly and positively correlated with NCP. Variance partitioning attributed ~23% of the variation in NCP to functional identity and essentially none to species richness, while the acidification-tolerant green alga *Caulerpa prolifera* emerged as the single strongest predictor.These results indicate that ocean acidification does not simply suppress benthic functioning but reorganises it, shifting the predictor of functioning from taxonomic diversity to the functional identity of tolerant species through a selection effect. We argue that trait-based frameworks, rather than taxonomic metrics, are essential to anticipate the functional trajectories of marine ecosystems - including the maintenance or enhancement of ecosystem functioning despite deep compositional turnover - under low pH scenarios.

Climate warming reshapes thermal habitat suitability of the Mediterranean green crab *Carcinus aestuarii* in Mediterranean coastal lagoons

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Global warming is severely threatening Mediterranean coastal lagoons' integrity, with potentially severe consequences for their functioning and ability to provide ecosystem goods and services.The Mediterranean green crab, *Carcinus aestuarii*, is a key component of Mediterranean lagoons trophic webs, also supporting local artisanal fisheries. Thus, assessing future changes in its distribution under progressively warmer lagoon conditions appears urgent.We quantified the thermal performance of *C. aestuarii* by measuring respiration rates (RR) across a temperature gradient ranging from 8 to 38°C. Thermal performance curves (TPCs) were used to estimate its thermal habitat suitability (THS) probability, which was then projected onto seasonal temperature maps of four Sardinian coastal lagoons under reference conditions (2017–2022) and future climate scenarios (RCP 4.5 and RCP 8.5 for 2050).RR increased with temperature up to an optimum temperature of 29.2°C (0.21 $mgO_2\ h^{-1}\ g^{-1}$ WW) and sharply declined thereafter, with complete mortality occurring at 38°C (CT_{max}). Current THS probability projections revealed strong seasonal variability, with low suitability levels during winter and optimal conditions during summer across all lagoons. Under both future warming scenarios, the THS probability increased across all seasons, suggesting expanded thermally favorable conditions for the crab adults.Overall, our results indicate that a moderate warming might enhance habitat suitability for the adult crabs, especially during the winter reproductive season. However, this apparent benefit should be interpreted cautiously. Projected increasing marine heatwaves frequency and reduced thermal heterogeneity caused by warming may expose the crab populations to episodic thermal stress, while the higher thermal sensitivity of early life stages could constrain the species recruitment success, potentially offsetting the habitat suitability gains projected for adults. We conclude that, preserving hydrodynamic connectivity and thermal refugia may be crucial for sustaining the persistence of this species and, considering its ecological importance, the lagoon ecosystem functioning as a whole.

Divergent thirty-year trajectories of two co-occurring Mediterranean Sea urchin species reveal climatic and trophic drivers

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Species population trajectories mostly arise from the combined influence of anthropogenic disturbance, biotic interactions and abiotic factors. However, assessing the relative contribution of these drivers remains challenging, as long-term ecological datasets, essential for robust inference, are scarce. We examined the population dynamics of the co-occurring sea urchins *Paracentrotus lividus* and *Arbacia lixula* using time series spanning up to 33 years from two Western Mediterranean Marine Protected Areas (MPAs): Medes (Spain) and Tavolara Punta Coda Cavallo (Italy). We quantified long-term population trends, assessed the influence of climatic, hydrodynamic and trophic drivers, and identified abrupt shifts in population trajectories. Generalised additive (mixed) models were combined with structural breakpoint analyses i) to investigate both contemporaneous and lagged effects of marine heatwaves (MHWs), storm-driven wave exposure and predatory fish biomass, and ii) to identify abrupt shifts in population trajectories. Our time series analysis showed that while *P. lividus* has declined consistently across the two MPAs, regardless of protection status, *A. lixula* has remained fairly stable at Medes and underwent only a moderate decline at Tavolara Punta Coda Cavallo. Lagged cumulative MHWs intensity, emerged as the strongest predictor of *P. lividus* population decline. Storm-driven wave impact provided an additional source of mortality at highly exposed sites. Breakpoint analyses identified abrupt and persistent reductions in *P. lividus* density at Medes, followed by limited evidence of population recovery. By contrast,

A. lixula exhibited weak and inconsistent responses to MHWs and no detectable response to storm impact, likely reflecting its greater thermal tolerance and morphological adaptations to hydrodynamic stress. These different trajectories are progressively altering rocky-reef sea urchin assemblage composition. Our results highlight the role of extreme climatic events as key drivers of Mediterranean sea urchin dynamics, with potential consequences for herbivory, trophic regulation, rocky-reef community structure and ecosystem functioning as extreme events become increasingly frequent.

Community performance curves predict community stability despite interaction effects

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Predicting the stability of ecological communities in changing environments is challenging. Classical theory posits that community stability cannot be understood without considering interspecific interactions. A contrasting view is that species' environmental responses and their variation (response diversity) influence stability to the extent that effects of interspecific interactions can be ignored. Surprisingly, few studies have evaluated the relative importance of interactions versus species' responses. Moreover, trait-based measures of response diversity often show limited predictability. Here, we introduce community performance curves, the aggregate of species' performance curves, as a powerful mechanistic link between community composition and stability. This approach reveals that species responses predict most of the variation in community stability in simulated communities, even when the strength of interspecific interactions varies. An experiment with ciliate communities corroborates these findings, while a literature review reveals how rarely both mechanisms are assessed jointly. By moving from summary traits to community performance curves, we reconcile the two perspectives: while species interactions undeniably shape community dynamics, community performance curves are sufficient to predict stability. This provides the opportunity to predict community stability, even when information about the multitude and diversity of interspecific interactions is unavailable.

Integrating thermal niches and soil properties to define asparagus optimal production areas in France under climate change

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Climate is a major driver of plant phenology and a key determinant of species geographic distribution. Anticipating the effects of climate change on crops is essential for helping producers make informed decisions and implement adaptation strategies. Here, we propose a process-based phenological model for Asparagus officinalis in temperate production areas and use it to assess cultivation suitability across continental France. Asparagus officinalis is an herbaceous perennial crop grown worldwide and broadly adapted to different climatic regions, whose phenology has received limited attention. We propose two possible models that simulate the annual progression of asparagus phenology: i) a sequential model, where chilling is strictly required for budbreak, and ii) an alternating model, where chilling acts as an accelerator of the subsequent forcing process. Both models include a cooling phase, after the summer solstice, that triggers the onset of dormancy. We calibrated model parameters both from literature data and approximate budbreak dates across several asparagus-growing locations in western France. According to the Akaike information criterion (AIC), we selected the sequential model as the best. We eventually used it to project phenological transitions under different future Shared Socioeconomic Pathways (SSPs) to identify areas that will be suitable for production in the next decades, by considering both climate requirements and soil characteristics. Our results suggest that a chilling period is needed to break dormancy in French cultivars. However, further research is needed to understand the biological mechanisms behind asparagus dormancy. Milder winters may hinder the release of endodormancy in the future, potentially leading to abnormal development and budbreak failure. In addition, the duration of the vegetative phase may shift as a consequence of changes in cold exposure. Suitable production areas are expected to move toward northern regions, where chilling requirements are more likely to be met and conditions for vegetative development may remain more favorable.

Effects of seasonal thermal stress on the functioning of *Eunicella singularis* meadows: an in-situ assessment of ecophysiological responses

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Climate change is rapidly altering Mediterranean benthic ecosystems, with marine heatwaves posing a major threat to long-lived habitat-forming species such as the gorgonian *Eunicella singularis*. This study investigates how seasonal thermal stress affects the eco-physiological performance and ecosystem functioning of *E. singularis* forests in a coralligenous habitat of the central Mediterranean Sea (Capo Gallo and Isola delle Femmine MPA, Sicily, Italy). An integrated in situ approach was used, combining benthic chamber incubations to quantify respiration and photosynthetic oxygen production, pulse-amplitude modulated fluorometry (Fv/Fm) to assess symbiont photophysiology, antioxidant enzyme assays (SOD, CAT, GR) as biomarkers of oxidative stress, and measurements of total and organic suspended matter to evaluate particle dynamics in the water column. Sampling was conducted before and after the summer warming period in forests with contrasting gorgonian density. The results showed a marked seasonal variation in metabolic activity, with a post-summer decrease in respiratory functions. The photosynthetic efficiency of the symbionts (Fv/Fm) was higher after the summer warming period compared to the pre-summer phase. Oxidative stress biomarkers revealed enhanced antioxidant activity after summer warming, with increases in superoxide dismutase (SOD) and glutathione reductase (GR), indicating activation of cellular defense mechanisms against reactive oxygen species. This pattern, together with the observed physiological changes, indicates the activation of cellular stress-response mechanisms under thermal stress conditions. Although no mass tissue mortality was observed, the physiological signal suggests sublethal effects associated with summer warming. Overall, these findings suggest that *Eunicella singularis* forests exhibit physiological resilience to seasonal warming; however, the detected sublethal effects may represent early warning signals of potential vulnerability to recurrent extreme thermal events, with possible implications for the functioning and resilience of Mediterranean coralligenous ecosystems.

Tracking the coral holobiont responses across the 2024 mass bleaching event in the Maldives in two reef-building coral species: *Acropora muricata* and *Porites lutea*

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Coral reefs worldwide confront escalating threats, characterized by increased sea water temperatures due to climate change, resulting in mass coral bleaching events. Endosymbiosis with Symbiodiniaceae algae and bacteria is fundamental for coral survivorship and adaptation to environmental stressors. However, how the spatial-temporal dynamics, inter- and intra-specific difference influence these communities is still not clear.In this study, we present a multi-site, temporally resolved research focused on algal symbiont and microbiome characterisation of two common reef building coral species, *Porites lutea* and *Acropora muricata*, in three different Maldivian islands (Magoodhoo in Faafu Atoll and Thudufushi, and Athuruga in Ari Atoll), across the 2024 mass-bleaching event. Specifically, 80 colonies were tagged and sampled before, during and after the bleaching event, and the different fates of bleaching, recovery, or mortality were identified. In addition, using ITS2 and 16S metabarcoding, we characterized the diversity and composition of both symbiotic microalgae and bacterial communities, aiming to identify community patterns associated with coral survivorship and post-bleaching recovery. We analysed data using custom bioinformatic pipelines, specifically using SymPortal for the taxonomic assignment of Symbiodiniaceae. We evaluated temporal and special patterns in microbial and algal symbiont density, focusing also on functional profiles.Our results showed as the two different species displayed a different bleaching susceptibility and even within the same species, corals from different locations responded differently to the temperature increase. Moreover, community-level analyses revealed contrasting patterns between bacterial and Symbiodiniaceae assemblages, with spatial differences among locations emerging more strongly than temporal variation across bleaching stages.Overall, our findings highlighted as both local condition and coral's endosymbiosis may play a role in coral holobiont tolerance and resilience. This study sheds light on the role of these symbioses in tropical corals and how their reorganisation after extreme thermal stress may impact their health.

Resilience of Mediterranean ecosystems to changing drought regimes and attributes

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Climate models project increasing frequency and intensity of droughts in the Mediterranean Basin, escalating the threat to ecosystems. Exceptionally dry periods can significantly reduce ecosystem productivity and functioning, eventually leading to dieback. Understanding the effect of individual drought attributes on ecosystem resilience is crucial, particularly for the Mediterranean Basin, a biodiversity and climate change hotspot. We employed an event-based approach to drought regime analysis across several ecoregions in the basin over the 2001–2018 period. Droughts were detected using the Standardized Precipitation-Evapotranspiration Index, estimated from CHELSA products, and vegetation response was evaluated using the kernel Normalized Difference Vegetation Index from MODIS data. We measured severity, duration, intensity, time since the last drought, and severity legacy as drought attributes. We evaluated vegetation resilience to droughts by extracting the temporal components of resistance and recovery and analyzing their trends over changing drought regimes and attributes. Classifying droughts by severity quartiles, we observed that most ecoregions maintained their resilience levels across varying drought regimes. Some arid ecoregions displayed reduced resilience under the most severe drought class, associated with a larger response magnitude compared to more humid areas. Drought duration emerged as the strongest driver of the resistance component across different ecosystems, with longer durations associated with reduced resistance, while the recovery component was more influenced by the characteristics of previous droughts, with high variability across ecoregions. These results highlight that the adaptation to water scarcity of arid ecosystems does not necessarily imply their resilience to droughts and support the identification of vulnerable regions under projected drought regime shifts.

Kelp falling in the deep: characterization, mapping and food fall potential of mesophotic *Laminaria ochroleuca* forest on the Madeira Desertas ridge (*NE* Atlantic)

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In contrast to continuous background flux of marine snow, episodic food falls deliver concentrated pulses of carbon that nourish communities in food-limited environments. Macroalgal detachment represents an understudied food-fall pathway. The deep kelp forest of *Laminaria ochroleuca* on the Madeira Desertas Ridge is unique, as it grows at 72-91 m depth under exceptional water clarity. Understanding the extent and potential as a blue carbon source of this forest is important for evaluating the ecosystem value of Madeira waters. This is particularly true since the forest sits directly above bathyal depths exceeding 1000 m, making it a potential source of episodic organic carbon to the deep sea. We combined *in situ* observations from remotely operated vehicles (ROV) and towed cameras, orthomosaic photogrammetry, and physical sampling to quantify the spatial extent, density, and carbon stock of the Madeira kelp forest, and assessed its potential as a carbon source for the bathyal benthos. In total, 1500 living kelp plants were counted along a 12114 m^2 orthomosaic built from 21 video transects over the kelp forest. 54 detached kelp plants were observed below 200 m on six video transects (XOFOS and ROV). No scavenging fauna was observed on the kelp. Using area and kelp food fall calculation as well as carbon content analysis of detached dead kelp specimens we estimate a carbon flux of 0.25 mg C m−2 d−1 from the living forest to the deep slopes. Although this flux suggests a relatively minor role of kelp in vertical carbon transport, it is a direct express pathway of vegetal carbon from the mesophotic zone to the adjacent deep sea. This path is facilitated by the proximity of the forest to bathyal depths and the steep slopes of the Madeiran Archipelago.

Ecologia del suolo: dalla conoscenza alla gestione sostenibile

6

Coordinatori: Flora Angela Rutigliano, Giulia Maisto, Anna De Marco

Breaking plastic, breaking balance: multi-level effects of mulches on terrestrial isopods

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Plastic mulch debris is increasingly accumulating in agricultural soils worldwide, and their ecological role in reshaping soil detritivores functions remain poorly investigated. Here we demonstrated that terrestrial isopods (*Porcellionides pruinosus*) actively fragment and transform both fossil-derived low-density polyethylene (LDPE) and biodegradable (MaterBi®) mulch debris into secondary plastics by shaping ecological traits. Using long-term soil microcosms, we performed a multilevel ecological analysis to assess mulch fate, change in soil physicochemical properties, and trait responses at multiple biological scales, including population-level (gregarious behaviour and trophic activity), individual-level (mass gain, body water content, assimilation efficiency), and biochemical traits (glycogen, protein, and lipid content). Terrestrial isopods generated both micro- and nanoplastic particles from both mulch types and redistributed them through faecal pellets into soil. Plastic exposure disrupted social aggregation networks, reduced coordinated feeding activity, and reshaped energy allocation pathways. Biodegradable mulch promoted higher fragmentation and assimilation efficiency, whereas LDPE lowered glycogen reserves and increased lipid accumulation, indicating metabolic stress. Multivariate trait analyses revealed significant reorganisation of ecological functioning between polymer types and plastic-free microcosms, with behavioural and metabolic traits strongly coupled to environmental changes, and individual performances conformed with the environmental change. This study represents the first integrative assessment of how soil detritivores respond to and potentially mediate the transformation of plastic debris across multiple ecological levels. Our findings identify soil detritivores as active mediators of plastic fragmentation and biogeochemical cycling, highlighting large plastic debris as an overlooked driver of functional reorganisation in terrestrial ecosystems. Furthermore, the multilevel approach suggests that higher-hierarchical ecological responses may be more sensitive and representative indicators of mulch contamination. Project funding from the Ministry of Universities and Research as part of the call to review the final rankings of the PRIN 2022 call for proposals for the project entitled "NANOplastics Toxicity Evaluation and Risk (management) in teRrestrial Agro-Ecosystems (NanoTERRAE)" Protocol number 20229KSJAT/

Biochar-amended vermicompost as a sustainable amendment for improving soil quality and mitigating PFAS uptake by crops

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Per- and polyfluoroalkyl substances (PFAS) are persistent environmental contaminants highly resistant to chemical, physical, and biological degradation. The application of sustainable organic amendments such as biochar has emerged as a promising strategy to reduce PFAS bioavailability and accumulation in crops. The aim of this study was to evaluate the potential of biochar-amended vermicompost (vermichar) to improve the quality of soils exposed to substantial PFAS inputs. To this end, an arid soil collected from abandoned agricultural land in the Canary Islands (Spain) was amended with vermichar at 5%, 10%, and 20% (w/w, dry weight basis) and subsequently spiked with a PFAS mixture (25 ng g ^{1} dry soil each) comprising short-chain (PFPeA), long-chain (PFOS and PFOA), and emerging (6:2 FTSA) compounds. Lettuce (Lactuca sativa) and chickpea (Cicer arietinum) were grown in treated soils for two months. Following harvest, plant growth parameters, soil microbial activity, exoenzyme activities, nutrient availability (NH , NO , and inorganic P), and PFAS concentrations were determined. Vermichar application progressively increased soil enzyme activities, likely due to its high enzymatic and organic matter content. Notably, PFAS-contaminated soils amended with vermichar exhibited significantly greater N- and P-acquiring enzyme activities than non-contaminated soils, consistent with effective PFAS immobilization and limited interference with soil microbial processes. NH concentrations declined across all treatments, whereas NO availability increased substantially following vermichar application, particularly in PFAS-free soils. PFAS analyses further revealed a significant reduction in plant uptake in vermichar-amended treatments. However, the highest application rate (20% w/w) adversely affected chickpea growth, indicating potential phytotoxic effects at excessive doses. Overall, vermichar application at rates of 10% (w/w) or lower simultaneously enhanced soil fertility and reduced PFAS bioavailability and plant uptake, highlighting its potential as a sustainable remediation strategy for PFAS-contaminated agricultural soils.

Wildfire impacts on soil microbial communities in Maiella National Park

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The increasing frequency and severity of wildfires pose a growing threat to soil microbial community, which plays a key role in soil health and functioning of the whole terrestrial ecosystem. The aim of this study was to assess the effects of high-severity wildfires, occurred during 2017 and 2023 summers within the Maiella National Park, on soil microbial communities of a beech forest and a pine forest. Specific goals were to analyse: i) the impact of the 2023 fire in relation to forest type (beech *vs* pine forests), and ii) the effect of fire frequency (1 *vs*. 2 fires in the period 2017- 2024) within the pine forest. On soil samples, collected in November 2024, microbial community performance was analysed in burned sites, compared to unburned controls, measuring microbial biomass, fungal biomass, potential respiration, N-acetyl-β-D-glucosaminidase activity, bacterial and fungal genetic diversity (richness and Shannon index). Significant reductions in microbial and fungal biomass, respiration, and fungal richness were observed in 2023-burned sites, compared to control, with higher negative effect generally observed in beech than in pine forest. However, only in the burned pine forest a negative impact on the bacterial richness was found. Data also showed higher negative effects with increasing fire frequency in the pine site affected by two fires (2017+2023), which exhibited significant decreases in microbial biomass, respiration and bacterial Shannon index, compared to site burned only once. Overall, data showed that 15 months after fire microbial community has not yet returned to its pre-fire state, and that the repeated fires, even six years later, can amplify negative impacts on microbial community.*Funded by the Project "BIOdiversita' Specifica e Funzionale per la Resistenza, Resilienza e Recupero ai disturbi ed al cambiamento climatico [BIOSFeR3a]", within the "National Biodiversity Future Center - NBFC PROJECT" (CUP B83C22002930006), Italian Ministry of University and Research.*

Short-term effects of organic soil amendments on herbaceous plant and arbuscular mycorrhizal fungal communities in a Mediterranean quarry

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Organic soil amendments are increasingly being recognised as effective tools for restoring degraded soils, particularly in Mediterranean regions where climatic conditions accelerate the depletion of organic matter and increase the risk of desertification.Waste-derived materials represent a sustainable option that could be adopted within a circular economy framework. The application of these materials can improve soil properties and facilitate spontaneous plant recolonisation. However, an integrated assessment of the ecological effects on biotic communities is required. Among them, arbuscular mycorrhizal fungi (AMF) play a crucial ecological role by acting as a functional bridge between soil and roots, supporting underground biodiversity and ensuring the recovery of ecosystem functionality.This study, conducted as part of the EMBRACE Project of National Interest (PRIN 2022 PNRR), aims to evaluate the short-term effectiveness of four organic soil amendments in promoting spontaneous renaturalisation of soil in a Mediterranean quarry. The treatments include a vermicompost derived from marine waste and a stabilised sludge-based amendment, as well as variants of these enriched with natural zeolites, compared to an untreated control.Herbaceous plant communities were studied by estimating the three components of biodiversity (species richness, composition and evenness), as well as the relative abundances, based on the number of individuals, dry biomass and cover measured according to the Braun-Blanquet scale. The structure and diversity of AMF communities were also investigated using a high throughput sequencing approach.The results obtained at the nine-month from the amendment provide an overall picture of the effectiveness of the various treatments in guiding renaturalisation processes and modulating the biodiversity of the communities under investigation. The data highlight specific responses that allow the short-term effects of the treatments on the plant component and mycorrhizal community structure to be evaluated and discussed, with a view to the integrated restoration of the soil-vegetation system.

Predicting riparian soil properties using DRIFT spectroscopy: a proof-of-concept approach for ecological applications

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The use of infrared spectroscopy in soil ecology is gaining attention for the low costs and high efficiency in predicting variables strictly related to the right functioning of soil in the existing ecosystem. Predictive models estimate soil properties across large spatial scales, reducing field sampling and laboratory analyses. However, predicting pH, nutrients and biological properties in riparian soils remains difficult due to hydrological fluctuations, sediment deposition and high spatial heterogeneity, making appropriate regression models and spectral preprocessing essential. The intrinsic variability of these soils can worsen predictions; therefore, selecting an appropriate regression model must be coupled with testing accurate spectral preprocessing algorithms. In this framework, this study compared two different prediction regression models, the linear Partial Least Square Regression (PLSR) and the non-linear Supporting Vector Machine Regression (SVMR) using diffuse reflectance infrared Fourier transform (DRIFT) spectra (4000-550 cm^{-1}). Before running the models, the spectra were differently preprocessed: Savitzky-Golay filter (SG), SG with standard normal variate (SNV), and SG+SNV followed by the first derivative. The challenge of this research was to use a limited number of samples (18) from two lakes (Lake Costanza-Germany and Lake Patria-Italy) that differed in salinity, origin and morphology to propose a valid tool for ecological applications. The results highlighted that in calibration PLSR, regardless the preprocessing methods, provided satisfactory results as compared to SVMR. Moreover, in validation, PLSR had greater performance if supported by SG+SNV for predicting N (R^2= 0.80, RPD=2.06), total and organic C (R^2= 0.70, RPD= 1.8 and R^2= 0.70, RPD=1.7 respectively), and by SG+SNV+first derivative for total C (R^2= 0.72, RPD= 1.8). These results support the potential of DRIFT spectroscopy as a rapid and cost-effective approach for predicting riparian soil properties. Despite the limited number of samples, this proof-of-concept study provides encouraging results, highlighting the need for further validation on larger datasets.

Salt stress mitigation of a soil microbiome-rosemary system following applications of different composts

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Soil degradation hampers stability and functioning of soil ecosystems. Among various soil threats, salinization represents a critical abiotic stress, especially in Mediterranean area, which can compromises land quality and limit plant productivity. To address this issue, the implementation of sustainable nature-based solutions represents an important strategy for soil quality restoration. Organic amendments such as composts can be good soil improver and/or fertilizers depending on their composition. In fact, their effectiveness is highly dependent on feedstock origin (e.g. manure, organic fraction of municipal solid waste and yard trimmings) and production process (e.g. from very small to large scale waste management capacity). This study evaluated four decentralized compost capacity of mitigating salinity stress in a soil microbiome-plant system. Moreover, considering a holistic One Health approach, the potential spread of four antibiotic resistance genes (ARGs) and a mobile genetic element was analysed. Various soil pot experiments were performed with *Rosmarinus officinalis* and amended with one of the four composts: 1. community compost (CC, waste ca. 20 t/y), 2. decentralized urban compost (DUC, waste ca. 750 t/y), 3. small-scale agro-compost (SA, waste ca. 30 t/y) and 4. medium-scale agro-compost (MA, waste ca. 500 t/y).Plant biomass, rhizosphere microbial abundance, activity and ARGs were evaluated. Finally, a Soil Quality Index was calculated. Results indicated that salinity stress significantly reduced plant biomass. However, CC and DUC amendments mitigated effectively rosemary biomass decrease, enhancing its growth. Interestingly, the rhizosphere microbial community increased its activity in response to salinity through a pre-existing osmotic defence mechanism, independent from compost presence. Salinity and compost generally increased ARGs in the soil, however the community compost (CC) proved to be the most effective in improving overall soil quality and salt tolerance, confirming that localized processing models (involving a very small number of people) significantly improve compost quality and safety.

Temporal dynamics of above- and belowground biodiversity during quarry substrate restoration with marine-derived lumbricompost

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Soil degradation caused by anthropogenic disturbance compromises essential ecosystem functions, including nutrient cycling, soil biological activity, and plant productivity, making restoration of degraded soils a major ecological challenge. This study, conducted within the EMBRACE project (PRIN PNRR 2022), evaluated the potential of a novel lumbricompost derived from *Posidonia oceanica* residues to promote the ecological restoration of a limestone quarry substrate in Padula (Southern Italy). The experimental field comprised 15 plots in a randomized block design, including treatments with lumbricompost, lumbricompost + zeolite, stabilized sludge, stabilized sludge + zeolite, untreated control. Natural zeolites were added to improve amendment quality and enhance soil restoration efficiency. Over a one-year period, vegetation recovery was monitored seasonally through aerial imaging and phytosociological surveys, while soil samples were analyzed for physicochemical properties, phytotoxicity, enzymatic activities, and community-level physiological profiles (CLPP).Amended plots showed higher revegetation than controls, particularly during summer and autumn. Plots with zeolite exhibited greater plant biomass production six months after treatments, suggesting a positive role of zeolite in improving amendment performance. Soil organic matter increased in all amended plots, while microbial indicators highlighted a rapid activation of edaphic community. Hydrolase and β-glucosidase activities were higher in treated soils, and CLPP analyses revealed enhanced microbial metabolic activity under lumbricompost application, especially for carbohydrate and carboxylic acid utilization. In contrast, control soils maintained low microbial activity and distinct functional profiles.Results indicated that marine lumbricompost rapidly stimulates soil microbial activity and promotes vegetation establishment, supporting a bottom-up recovery process from microbial activation to plant colonization. The results were comparable to that observed with stabilized sludge, an organic amendment commonly used in remediation practices. However, the partial return of microbial indicators toward initial conditions over time suggests mainly

short-term effects, highlighting the need for repeated amendments and long-term monitoring to ensure stable rehabilitation of degraded substrates.

Microbial time in karst soils: successional dynamics of bacterial and fungal communities

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While soil microbial community shifts can widely affect SOM decomposition, nutrient recycle and biogeochemical outputs, the temporal dynamics of the microbial ecological succession in natural soils is far from being understood. This is particularly relevant in karst ecosystems, where shallow lepotsoils, with rapid drainage, meteorological pulses and microclimatic variability can expose microbial communities to abrupt environmental changes. By a nested random sampling design, we collected topsoil samples from three plots at two two temporal scales: a short-term survey, with sampling every two days over a month, and a medium-term survey sampling every two-weeks from beginning of April to mid of October. Bacterial and fungal communities were reconstructed from eDNA extracted from the soil samples through metabarcoding targeting 16S rRNA V3–V4 and ITS1 markers, respectively. Soil chemical-physical properties including texture, pH, organic C and total N percent content, and bulk density, were assessed by standard protocols, while soil water content and temperature were continuously monitored throughout the sampling campaign. Both bacterial and fungal communities showed marked variability in taxonomic diversity and composition and over time, with remarkable changes occurring not only across the seasonal gradient but also over short-time intervals of few days. Alpha diversity varied significantly through time for both marker datasets, clearly indicating that microbial diversity in karst soil is highly dynamic, following shifts in environmental regimes, even within short temporal windows. When exploring the same relationships using the functional annotation of bacteria and fungi datasets as available form public web platforms (i.e. FAPROTAX, FUNGuilds) a clear association of microbial successional dynamics with microclimatic dynamics emerged, with interesting implications for topsoil organic C shifts. These results, highlighting karst soils as dynamic microbial habitats, clarify that soil microbial succession follows a peculiar dynamic, over timescales completely different from those occurring for soil fauna or plant communities. As such, it can also decisively affect our perception of soil biological quality and biodiversity according to the time of sampling.

Functional redundancy and ecological stability of soil microbial community across Mediterranean forest types and management systems.

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Understanding how forest management practices and environmental factors shape belowground community is crucial for preserving soil biodiversity and ecosystem services. Soil microbial community has a key role in soil functioning and its responses to management regime and seasonal dynamics can strongly influence ecosystem processes.This study investigated the influence of forest type (Beech and Turkey oak), forest management (high forest and coppice), and season on the structure and functioning of the soil microbial community in the Matese area (Southern Apennines, Italy). Soil microbial community was characterized through enzymatic activities, Community-Level Physiological Profiling, bacterial and fungal metabarcoding. The integration of multivariate and variation partitioning analyses revealed that forest type was the main factor shaping both soil microbial function and structure. Seasonal variations primarily affected microbial functional responses, whereas community structure was mainly influenced by forest management practices.To better understand these findings, in each forest system we further explored the long-term effects of coppice management by focusing on structural and functional stability of soil microbial community, through betadispersion analysis, Mantel test, co-occurrence network analysis and the associated Network Stability Index (NSI).In soil under beech, our results revealed that long-term coppicing modified the relative abundance of specific bacterial and fungal orders, without impairing microbial metabolism. In soil under turkey oak, coppicing induced a shift in soil microbial community structure and carbon substrates utilization. The application of the multi-metric NSI demonstrated that overall microbial networks did not differ significantly between management regimes.These results showed the high functional redundancy of soil microbial communities, which helped maintain microbial functioning and despite coppice-induced some changes in community structure. Overall, the coppicing regimes adopted in the investigated Mediterranean forest systems did not compromise the stability of soil microbial communities.

Ecologia del paesaggio, dinamiche spazio-temporali e big data ambientali

7

Coordinatori: Laura Carranza, Irene Petrosillo, Emilio Padoa-Schioppa

Integrating long-term monitoring and multi-source environmental data to predict cetacean foraging hotspots: a spatio-temporal machine learning approach

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The integration of *in situ* ecological monitoring with high-resolution, multi-source environmental data is increasingly central to spatially explicit conservation planning, particularly for highly mobile marine species whose critical functional areas are difficult to delineate using static tools. Identifying where a species feeds, rather than simply where it occurs, is essential to functionally define critical habitat, since foraging areas include ecological processes very relevant to conservation and the assessment of anthropogenic interactions. A machine learning-based spatio-temporal modeling framework has been developed to predict feeding habitat suitability for the striped dolphin (*Stenella coeruleoalba*) in the Northern Ionian Sea, Gulf of Taranto (GoT, Central Mediterranean Sea), a biodiversity-rich area subject to multiple human pressures. The model integrates a long-term vessel-based survey dataset (2009–2024; 238 feeding sightings) with daily oceanographic variables derived from Copernicus Marine Service reanalysis products, and geomorphometric descriptors from GEBCO, all interpolated onto a 5×5 km analysis grid. Three machine learning algorithms (Random Forest, XGBoost, and LightGBM) were trained and evaluated under random, spatial, and temporal cross-validation strategies, explicitly testing model robustness to spatial and temporal autocorrelation. Predictions from spatially and temporally validated models were combined into a spatio-temporal ensemble, generating annual feeding suitability maps in 2023 and 2024. Models achieved high and stable discriminative performance (AUC 0.88–0.92) across algorithms and validation schemes, with bathymetric depth, distance from the coastline, and dynamic oceanographic gradients emerging as dominant drivers of feeding suitability. Resulting maps revealed a spatially coherent and temporally persistent feeding hotspot along the westernmost margin of the GoT. This approach opens new possibilities for combining environmental features derived from remote sensing and reanalysis with biological monitoring and machine learning, paving the way for spatially explicit tool to assess the distribution of critical habitats of species of conservation concerns.

Forest landscape fragmentation analysis in the apulia region

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Land-use change is one of the main drivers of landscape transformation, affecting both landscape composition and configuration. Forest fragmentation represents a major ecological concern, resulting from habitat loss and the increasing spatial isolation of forest patches. Land take is a key process accelerating fragmentation. This study aims at analyzing and comparing forest fragmentation patterns, based on 2022 Apulia regional forest cover map, through 1) the assessment of forest composition, also through the forestation index (IF), and configuration using landscape metrics; 2) the assessment of multiscale forest fragmentation; and 3) the assessment of land take effect on forest fragmentation. The results show that forest fragmentation patterns varied considerably among Apulian provinces. Lecce and Brindisi provinces (IF= 4% and IF=3%) emerged as the most fragmented areas, showing high patch density. Bari province (IF= 7%) was classified as moderately fragmented, while Foggia province (IF= 18%) presented the lowest fragmentation levels and Taranto province (IF= 17%) showed intermediate fragmentation. Multiscale analysis revealed a higher degree of fragmentation in Taranto than in Foggia. The complete disappearance of intact forest areas at broader spatial scales in Taranto suggests reduced habitat connectivity, whereas Foggia maintained residual intact cores, reflecting a more compact and ecologically connected forest landscape. Land take results showed that Foggia, followed by Taranto province, are the most affected provinces. In Foggia, land take in forest areas increased from 4535.9 in 2022 to 4556.4 ha in 2024, while in Taranto it rose from 4278.0 ha to 4287.2 ha over the same period. Despite the lower fragmentation observed in Foggia and Taranto provinces, the extent of land take in forest highlights an increasing pressure, compromising the connectivity of forests core. These results underline the need for integrated, connectivity-based forest management strategies to mitigate land-take pressure and enhance landscape resilience.

Ecological reactivity and transient persistence in riverine metapopulations

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Understanding the conditions that favor the persistence of metapopulations inhabiting riverine landscapes, or riverscapes, is essential to guiding conservation and restoration efforts aimed at preserving biodiversity and ecological integrity in freshwater environments. Here, we present a modeling framework to examine the transient persistence of fluvial metapopulations—that is, the temporary occupation of riverscape patches by metapopulations ultimately destined for long-term extinction. Our approach is theoretically grounded in the concept of ecological reactivity, which complements asymptotic stability analysis when studying the short-term response of ecological systems to impulsive perturbations of stable steady states. Our results suggest that under ecohydrological conditions conducive to reactive extinction equilibria, a metapopulation can colonize parts of the riverscape for extended periods. Additionally, we find that in the presence of repeated positive perturbations of the extinction equilibrium, the temporal scales associated with these transient phenomena may allow for reactive pseudo-persistence. This phenomenon involves an arbitrarily long delay in the metapopulation's eventual extinction, which may occur well below the deterministic extinction threshold. Identifying the ecohydrological drivers of reactivity-driven metapopulation persistence and the riverscape patches that contribute most to transient metapopulation dynamics over different temporal scales may provide valuable suggestions for the spatial prioritization of conservation and restoration efforts.

Ecology and landscape ecology in Italy: a longstanding mutual exchange facing new anthropocene challenges

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Ecology and landscape ecology in Italy have long maintained a reciprocal, mutually fertilizing exchange of ideas, each field enriching the other through continuous conceptual and methodological dialogue. Over the past decades, landscape ecology has introduced spatially explicit perspectives, innovative analytical frameworks, and a focus on patterns, processes, and scale that have broadened ecological interpretation of habitat mosaics, connectivity, and fragmentation, while providing a strong theoretical impulse to reflect on the role of disturbances and on the importance of emergent properties in complex ecological systems. At the same time, the field benefited from the solid scientific foundations of ecology, assimilating rigorous experimental approaches, quantitative methods, and theory-driven frameworks that strengthened its analytical robustness. This reciprocal exchange fostered a fertile scientific dialogue, enabling Italian researchers to integrate biophysical processes, landscape patterns, and socio ecological interactions within a coherent interpretative system.Today, however, new challenges require an updated and transdisciplinary perspective. The advent of the Anthropocene forces both ecology and landscape ecology to confront unprecedented magnitudes and velocities of environmental change, encompassing biodiversity loss, disruptions to biogeochemical cycles, and the increasing frequency and intensity of extreme climatic events. Managing Italian landscapes today requires approaches capable of addressing the cascading effects of the environmental crisis while integrating advanced technologies—such as drones, environmental DNA, big data infrastructure, and artificial intelligence—to monitor, model, and interpret complex ecological dynamics. These tools offer transformative opportunities but also require careful methodological (and sometimes ethical) handling.From an applied perspective, the scientific community is increasingly called upon to support the implementation of the National Nature Restoration Plan by translating ecological and landscape ecology knowledge into effective restoration interventions, land management actions, and long-term monitoring strategies. In this context, the synergy between ecology and landscape ecology becomes fundamental to guiding Italy toward resilient, biodiverse, and sustainable landscapes.

Functional networks to assess ecosystem resilience in Mediterranean landscapes

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Plant functional traits provide a robust framework for understanding ecosystem responses to environmental change, as they reflect plant strategies and ecosystem functioning. This study aims to develop Spatial Functional Networks to investigate how the structure of Mediterranean landscapes responds to climate variability and aridity in the Los Pedroches region (Córdoba, Spain).The main research question is whether, and to what extent, the structure of functional networks changes along aridity gradients and across different land uses.To address this, the approach integrates monthly climate interpolations of key environmental variables (mean temperature, precipitation, and relative humidity), high-temporal-resolution remotely sensed plant functional traits, ecosystem productivity, and landscape metrics to characterise spatial functional connectivity and ecosystem resilience. Networks are constructed from significant associations among key ecological variables, including Leaf Area Index (LAI), Fractional Vegetation Cover (FVC), Gross Primary Productivity (GPP), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), canopy water content (Cw), chlorophyll-related traits, and climatic indicators, enabling identification of functional interactions and their spatial organisation across different land-use types. To develop and validate this framework, datasets are integrated and tested on representative landscape units, providing a scalable methodology for assessing ecosystem functioning and resilience at the landscape scale.Based on preliminary results, we hypothesise that increasing aridity alters trait associations and network topology, resulting in higher modularity and greater separation among ecological processes. By assessing network topology and connectivity metrics, the study aims to identify patterns of ecosystem resilience and vulnerability, with particular attention to functional reorganisation processes that may serve as early indicators of ecosystem degradation under increasing climate stress. This framework offers a new approach to assessing the impacts of aridity on Mediterranean landscapes and their ability to maintain ecosystem resilience under changing environmental conditions.

Spider webs reveal urbanization-driven patterns of airborne microplastic occurrence

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Microplastic pollution is an increasingly important component of urban atmospheric contamination, yet its fine-scale spatial patterns remain poorly understood. Spider webs have recently emerged as effective passive samplers of airborne particles and may provide a low-cost tool for biomonitoring atmospheric microplastics. We investigated microplastic occurrence in spider webs along an urbanization gradient in Torino (NW Italy) to assess the influence of landscape and local environmental factors. Spider webs were collected from shrubs across a range of urban intensities. Urbanization was quantified as impervious surface cover at multiple spatial scales, while local variables included shrub area and web type. Microplastic presence was assessed under a stereomicroscope and analysed using generalized linear mixed models (GLMMs). To evaluate whether webs intercept biological and abiotic airborne material through similar mechanisms, we also analysed prey capture patterns. A total of 547 webs were collected, of which 42% contained microplastics. Microplastic occurrence was higher in spring than in autumn and was more frequent in sheet webs. Analyses restricted to adult female webs collected in spring showed that urbanization intensity at the 1000 m scale and shrub area were significant positive predictors of microplastic occurrence at both web and site levels. Sheet webs also had a higher probability of containing microplastics than other web types. Overall, 1,943 prey items were recorded. Prey capture was strongly influenced by web architecture, with sheet webs capturing significantly more prey, whereas urbanization had no significant effect on prey abundance. At the site level, prey density increased with shrub area and artificial light intensity. Spider webs therefore provide a robust, fine-scale tool for monitoring atmospheric microplastic pollution while highlighting differences between the drivers of biological and abiotic particle interception.

Supporting sustainable management of *Posidonia oceanica* banquettes through a multidisciplinary monitoring framework

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Posidonia oceanica meadows and the accumulations of dead leaves along Mediterranean shorelines, known as *banquettes*, are key components of coastal ecosystems, providing multiple ecological functions and ecosystem services. These deposits contribute to shoreline stabilization, mitigate erosion processes, and support biodiversity at the land–sea interface. Despite their ecological importance, *banquettes* are often perceived as a nuisance for tourism and are frequently removed to maintain the aesthetic appeal of recreational beaches, resulting in environmental impacts, including altered beach morphology, biodiversity loss, and increased beach-cleaning costs. To support the sustainable management of *P. oceanica banquettes* as a nature-based solution for coastal protection, it is essential to improve our understanding of their spatial distribution, spatio-temporal dynamics, persistence patterns, and potential role as sinks and vectors of contaminants. Here, we present a multidisciplinary monitoring framework that combines geospatial analysis, remote sensing, and field-based investigations. Specifically, we: (i) developed a GIS-based inventory of *P. oceanica banquette* occurrence across Mediterranean coastlines by integrating spatial information on beach-cast deposits with environmental and management-related geospatial layers, including seagrass meadow distribution, beach-use intensity, and protected areas; (ii) applied remote sensing and geospatial analyses to detect *banquettes*, quantify their spatial extent, and assess their temporal recurrence in selected pilot areas along the Italian coastline; and (iii) conducted field surveys to characterize *banquette* morphology and composition and evaluate their potential role as sinks and vectors of emerging contaminants, including microplastics. The results represent a first step toward the development of a spatially explicit, basin-scale monitoring framework for *P. oceanica banquettes* in the Mediterranean Sea. Such an approach can support evidence-based coastal management, improve ecosystem service assessments, and inform conservation and restoration strategies aimed at enhancing the resilience of Mediterranean coastal socio-ecological systems.

Predicting the spatial recolonization of a wide-ranging carnivore with an adaptive modeling approach

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As large carnivore populations expand across human-dominated landscapes worldwide, there is a growing need to assess their medium- and long-term conservation outlook and their potential consequences for human activities. The wolf (*Canis lupus*) recolonizing the Italian Alps is a good case study. This species of high ecological and societal interest has recently seen its legislative protection status revised, a change driven by its continued expansion and the resulting socio-economic challenges. Its recovery must be assessed against Favourable Conservation Status, an ambitious concept embedded in the Habitats Directive that requires demonstrating a favourable long-term viability of the population. Such predictions are particularly challenging, as wolf recolonization is governed by pack-level social processes, significant habitat selection, and, critically, stochastic long-distance dispersal events that cannot be anticipated. To address this, we developed a spatially explicit individual-based model based on twenty years of population-level data. The model is adaptive, periodically realigning the simulated population to the documented one so that projections remain anchored to the observed trajectory of recolonization and to documented stochastic events. Within a pattern-oriented hybrid framework coupling the model with a neural-network emulator, we calibrated hard-to-observe processes such as dispersal, together with novel processes arising as the population in some areas evolves to high density, such as density dependence. We then validated the model against independent spatial patterns across successive time intervals, projecting pack distribution and population expansion forward in time within known uncertainty bounds. Exploring the projected expansion potential across the Alps, this model can inform the species' progress toward Favourable Conservation Status while also evaluating the evolving overlap between wolf and human activities. By running the model across a range of scenarios, this framework can support management and conservation decisions for a recovering, wide-ranging population.

Agrivoltaic plants: planning renaturalisation strategies to enhance ecosystem services and protect biodiversity

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The transition to renewable energy is crucial to ensuring a sustainable future and ground-mounted Photovoltaic Systems (PV) offer huge potential for reducing net CO_2 emissions. However, ground-mounted solar panels require a significant amount of land, which can lead to conflicts with other land uses, particularly agriculture and biodiversity conservation. The dual-use nature of agrivoltaics (agricultural production between and beneath solar panels) reconciles solar development with biodiversity conservation. In addition, photovoltaic plants should lay the foundations for a more sustainable energy future: an approach we call 'ecovoltaics'. An agrivoltaic system can be defined as "ecovoltaic," as it is based on an approach to renewable energy that integrates ecological understanding and principles into the design and management of solar installations. In this context, the research objectives have been to assess and monitor biodiversity and ecosystem services, as well as to develop environmental mitigation and restoration measures in the area planned for a photovoltaic plant in the province of Foggia. Spectral indices were calculated to analyze many aspects related to the naturalness and ecological functioning of the ecosystem under study; about the flow of ecosystem services, the economic coefficients proposed by Costanza et al. (2014) were used as proxies for their assessment across three different spatial scales. Ecological mitigation and renaturalization strategies were identified based on the area's potential in terms of plant diversity, ecological community complexity, and ecosystem resilience. The restoration project involved introducing plant communities currently found only in the nearby Natura 2000 site "Bosco dell'Incoronata" with plants to be introduced sourced from local ecotypes. The results demonstrated that renaturalization activities will be highly effective in providing ecosystem services on a 2-km scale compared to much larger spatial scales. Furthermore, in the renaturalized areas, vegetation growth will positively influence animal biodiversity, carbon sequestration, soil conservation, and the global water cycle.

Integrating land management units and conceptual maps to assess Mediterranean desertification risk

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Desertification in Mediterranean landscapes results from the interaction of climatic stress, ecological sensitivity, human pressure, and limited adaptive capacity. This study proposes an integrated framework for highlighting desertification risk by combining Land Management Units (LMUs) with conceptual maps of land degradation processes. LMUs, represented by grid cells, pasture plots, or habitat patches, provide a spatial basis for translating conceptual relationships into measurable indicators. The framework starts from conceptual maps linking drought, temperature anomalies, grazing pressure, land-use change, soil erosion, vegetation loss, socio-economic factors, and Agri-Environmental Schemes (AES). These components are associated with spatial layers for each LMU, including NDVI trends, biomass, soil organic carbon, slope, erosion risk, grazing intensity, land cover, plant functional traits such as Specific Leaf Area and Leaf Dry Matter Content, and AES implementation zones. Desertification risk can be assessed through MEDALUS, integrating Climate, Soil, Vegetation, and Management Quality Indices into a Desertification Risk Index, and complemented by time-series analyses of productivity and drought response using NDVI, Rain Use Efficiency, Vegetation Condition Index, and trend-detection methods. A core element is the construction of Spatial Functional Networks, where LMUs act as nodes and links are defined by spatial proximity, trait similarity, NDVI correlation, shared AES membership, or similar degradation trajectories. Network metrics, including node strength, betweenness centrality, modularity, and edge loss, identify resilience hubs, isolated degradation nodes, functional gaps, and fragmented sectors. Embedding conceptual map relationships into network weights quantifies how specific drivers influence connectivity and degradation risk. This integration transforms desertification assessment from static mapping into dynamic decision support. It supports the detection of vulnerable areas, the evaluation of AES effectiveness, and spatial prioritisation of interventions such as grazing regulation, plant regeneration, and soil fertility. Applied to Mediterranean case studies, it can guide adaptive land management and strengthen landscape resilience under future climate and socio-economic scenarios.

Ecologia delle invasioni biologiche: dinamiche, impatti e prospettive di gestione

8

Coordinatori: Antonia Concetta Elia, Paolo Pastorino, Paolo Povero

Is lassa virus knocking on Europe's ports? A One Health data-driven model of introduction and community spillover risk across maritime hubs

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Seaports have long represented - and still represent - critical entry points for rodents into new regions worldwide, through transport via the high volume of ships and vessels. Given their role in the circulation of a wide range of zoonotic pathogens, the current distribution of different viruses reflects rodent dispersal events and their interactions with novel communities. Among rodent-borne diseases, Lassa virus (LASV) is a major global health concern and a WHO Blueprint priority. Recent evidence suggests that LASV transmission may involve multiple potential hosts beyond its primary reservoir *Mastomys natalensis*, including cosmopolitan species like *Mus musculus* and *Rattus rattus*. This increases the likelihood of LASV geographic expansion if infected rodents are introduced into new areas through maritime transport. Here, we innovatively evaluate the risk that rodents potentially carrying LASV, or a LASV-like Disease X, may be inadvertently carried from source countries in West Africa to major non-African (e.g. European) commercial ports, from which they could transmit the pathogen to competent species and establish endemic conditions. To this end, we developed an integrated framework linking shipping importation fluxes with the ecological and anthropogenic conditions surrounding destination ports, allowing us to proxy the likelihood of interaction and spillover from imported infectious rodents to the European mammal communities identified as potential alternative hosts by a recently published phylogenetic association model. Our results, based on fine-scale modelling of habitat suitability and potential human exposure, map the LASV introduction risk around major European arrival ports, identifying the hubs most likely to become the virus' entrance door into Europe. This framework may thus provide decision-makers with a tool to support preparedness, inform preventive bio-surveillance and implement rapid containment policies.

Characterization of biodiversity in Lake Garda harbors through eDNA metabarcoding: patterns and connectivity

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Over the past century, Lake Garda has become a major hotspot for biological invasions, with nearly 50 non-indigenous species recorded to date and new introductions continuously occurring. While traditional monitoring methods typically detect these invaders only after they have successfully established, advanced molecular tools offer the potential for early-stage detection. In this context, lacustrine harbors represent critical entry points, yet they are frequently overlooked in standard biological inventories and dismissed as degraded, anthropogenically impacted areas. Thus, we implemented an environmental DNA metabarcoding approach, sampling water and sediment across eight major harbors around the lake to thoroughly characterize their biodiversity, track alien species presence, and unravel connectivity patterns. Preliminary molecular data, based on COI and 18S rRNA genes, successfully captured a remarkably rich biota encompassing protists, algae, and metazoans. Beyond documenting several alien and undocumented endemic species, this high-throughput sequencing approach unveiled broader catchment-to-lake connectivity. Notably, the detection of terrestrial species' DNA highlights how the lake acts as a sink for runoff and land-water interactions. Ultimately, integrating traditional and molecular approaches bridges the gap from organismal detection to ecosystem-wide monitoring, demonstrating that these heavily impacted artificial habitats actually host high biological diversity and provide key data on watershed-level dynamics.

Tracking an invader: horizonal/vertical movements and temperature gradient of *Silurus glanis* in a small, deep peri-alpine lake

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Understanding the spatial ecology of invasive fish predators is essential for developing effective management strategies. We investigated the horizontal and vertical movements, habitat use, and thermal ecology of the invasive European catfish *Silurus glanis* in Lake Sirio, a small, deep peri-alpine lake in north-western Italy. Fifteen individuals were tagged with acoustic transmitters equipped with depth and temperature sensors and monitored for one year using an acoustic telemetry array. European catfish occupied predominantly shallow waters throughout the year, although they shifted to deeper habitats during autumn and winter. This seasonal pattern was accompanied by marked diel variation in depth use during spring, summer, and autumn, whereas diel differences largely disappeared in winter. Consistently, vertical activity peaked at dawn and dusk and reached its highest levels during summer. Fish body temperature closely tracked ambient water temperature but remained below maximum surface temperatures during summer, indicating active selection of favourable thermal conditions. Seasonal changes were also evident in horizontal behaviour, with individuals expanding their home ranges and increasing exploratory activity during spring and summer. Although core areas shifted over time, home ranges remained comparatively stable, while low overlap among individual core areas but greater overlap among home ranges suggested spatial niche partitioning, with individuals maintaining distinct refuge areas while sharing broader foraging habitats. Habitat use further reflected these seasonal dynamics, with fish concentrating in nearshore habitats during spring and progressively increasing the use of offshore areas in autumn. These findings demonstrate marked behavioural plasticity in *S. glanis* and provide practical guidance for its control. Removal efforts should primarily target shallow littoral habitats around dawn and dusk, particularly during spring, summer, and early autumn, when fish activity is highest. More broadly, this study highlights the value of acoustic telemetry for supporting evidence-based management of invasive freshwater fish predators.

Assessment of long-term population dynamics of *Procambarus clarkii* in Lake Trasimeno

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The red swamp crayfish *Procambarus clarkii* is one of the most successful invasive freshwater species in Mediterranean ecosystems, where its establishment may affect native biota and ecosystem functioning. This study assessed the long-term population dynamics of *P. clarkii* in Lake Trasimeno, a shallow Mediterranean lake characterized by marked environmental variability. Historical and recent datasets spanning more than two decades were integrated to identify temporal trends in population structure, reproductive traits, and biological condition, also considering key environmental variables such as water temperature and hydrological levels. The long-term analysis revealed persistent population establishment and changes in biological traits over time. Temporal shifts were observed in sex ratio, moulting patterns, and reproductive condition, indicating the ability of the species to persist under variable environmental conditions. Sex-related differences in condition indices further suggest differential energy allocation strategies, potentially linked to reproductive investment and seasonal dynamics. Overall, the study highlights the ecological adaptability of *P. clarkii* in Lake Trasimeno and suggests that its population traits may reflect environmental variability in Mediterranean shallow lakes, with implications for biodiversity conservation, ecosystem management, and long-term monitoring strategies. These findings contribute to understanding how non-native crayfish populations persist and interact with changing freshwater ecosystems, with implications for biodiversity conservation, ecosystem management, and long-term monitoring strategies.

River defragmentation promotes the dispersal of non-native species: the case of the Atlantic blue crab *(Callinectes sapidus)*

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The Atlantic blue crab, *Callinectes sapidus*, is among the fastest-expanding invasive species in the Mediterranean Sea, where it has established dense populations in coastal and estuarine habitats. Although its ecological impacts in these environments are documented, its occurrence and role in inland freshwater ecosystems remain poorly understood. A previous study conducted along the Po River (Italy) between 2022 and 2025 demonstrated that this species can migrate more than 160 km upstream. The present study investigated whether the restoration of freshwater connectivity through fish passages may facilitate the dispersal of non-native species such as the blue crab. During spring 2026, three fish passages located along branches of the Po River were monitored: Valle Lepri (14 km from the coastline), Tieni (23.5 km), and Valpagliaro (45 km). A total of 115 blue crabs were captured: 42 individuals were recorded at Valle Lepri and 73 at Tieni, no crabs were detected at Valpagliaro. The population was strongly composed by males, with 95% of captures at Valle Lepri and 98% at Tieni. The mean size of individuals at Valle Lepri was 6.3 cm and 29.4 g, while crabs collected at Tieni had a mean size of 12.9 cm and 38.5 g. These values are considerably lower than those recorded in the Goro Lagoon during the same period (16 cm and 120 g on average), suggesting that intraspecific competition within established populations may promote upstream dispersal. In particular, smaller and younger individuals may be more likely to colonize new available habitats. These findings highlight a potential trade-off in river restoration: although fish passages are essential for restoring connectivity and supporting threatened migratory species, such as the European eel, they may also facilitate the spread of invasive alien species. Further monitoring is needed to assess the ecological consequences of blue crab colonization in freshwater ecosystems.

What can a process-based model tell us about the impact of introduced species on plant-pollinator communities? A case study from the Galapagos islands

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Oceanic islands harbor high levels of endemism, making them conservation priorities, yet their ecosystems are especially vulnerable to anthropogenic disturbance, particularly biological invasions. Assessing the impacts of introduced species is especially challenging when they establish mutualistic interactions with native taxa, as occurs in plant-pollinator systems, creating complex networks shaped by both mutualistic and competitive interactions. In this context, mathematical models represent an invaluable tool to investigate how the introduction (or removal) of an alien species cascades through interaction networks. Here, we propose a process-based mathematical model that captures plant-pollinator dynamics mediated by reward resources. We apply the model to empirical networks, collected over two years on two islands of the Galapagos archipelago, including both native and non-native species. By simulating the removal of plants, pollinators, or both, we quantitatively assess how invasions influence native communities. Our results reveal pronounced heterogeneity in the net effect of introduced species, whose presence can generate both positive and negative outcomes for native taxa. The model further disentangles direct from indirect interactions, showing how cascading effects through the network can substantially alter community responses. Additionally, we highlight the importance of co-invasions, where multiple non-native species reinforce each other's persistence and impact. Although further calibration is required for direct management applications, our quantitative framework underscores that the consequences of biological invasions cannot be understood in isolation but must be evaluated at the community level to capture the full complexity of ecological interactions.

Niche conservatism or niche expansion? Stable isotopes reveal the trophic mechanisms underlying blue crab *Callinectes sapidus* Rathbun, 1896 invasion success

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Biological invasions can modify interactions among species and food web structure. A key question in invasion ecology is whether invasive species succeed by maintaining their trophic niche across geographic ranges (niche conservatism) or by exploiting novel resources and expanding their niche in recipient ecosystems (niche expansion). The blue crab *Callinectes sapidus*, native to the western Atlantic Ocean, has quickly spread in the Mediterranean Sea in recent decades, representing an ecological and socio-economic threat due to its predatory pressure.This study compared the isotopic niche (δ^{13}C, δ^{1} N, δ^{3} S) - as a proxy for the trophic niche - between *C. sapidus* populations in native (three sites along the western Atlantic coast) and invaded areas (two sites in the Mediterranean Sea) to assess whether its invasion success reflects niche conservatism or expansion. Furthermore, since trophic niche dynamics are also shaped by interspecific interactions, the isotopic niche of *C.* sapidus was compared with that of sympatric crab species, to evaluate potential trophic overlap and competition. Sympatric crab species were *Carcinus maenas*, invasive within the native area of *C. sapidus* and *C. aestuarii*, native to the Mediterranean.The blue crab showed a significantly broader isotopic niche in invaded areas, as indicated by higher values of the Bayesian standard ellipse area and Layman's metrics, supporting niche expansion. Also, *C. sapidus* occupied a broader niche than both *Carcinus* spp., reflecting a higher degree of trophic generalism, and showed no significant niche overlap in either area, indicating resource partitioning between the speciesOverall, the observed isotopic niche expansion highlights the high trophic adaptability of *C. sapidus*, which seems to limit direct trophic competition with sympatric *Carcinus* spp. by exploiting different trophic sources. Such high adaptability represents a key factor underlying the invasion success of the blue crab, potentially leading to the restructuring of food webs in recipient ecosystems.

Biological invasions under multiple stressors: linking ecological responses, biomarkers and management perspectives

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Biological invasions are a key driver of global change, affecting biodiversity, community structure and ecosystem functioning in aquatic environments. Their dynamics and impacts may be further shaped by chemical contamination and other anthropogenic pressures, which can influence establishment, persistence, spread and the magnitude of ecological effects. In invaded ecosystems, non-native species often occur under multiple stressors, including habitat alteration, environmental variability, pollution and climate-related changes. Their success may therefore reflect not only biological traits and ecological opportunity, but also physiological plasticity and tolerance to disturbed conditions. This contribution explores aquatic non-native species as informative models for linking invasion ecology, contaminant exposure and ecosystem-health assessment. Selected case studies on invasive crustaceans and non-native bivalves are used to illustrate how biomarker-based responses can provide early-warning information on exposure, tolerance and sublethal biological effects under chemical and environmental stress. Oxidative stress biomarkers and detoxification-related responses are particularly useful for interpreting adaptive capacity, organism performance and ecological responses in impacted aquatic systems. Non-native species are not proposed as substitutes for native taxa, nor as conservation targets or indicators of pristine conditions. Rather, they can provide complementary information within integrated environmental monitoring approaches, especially where invasion success and contaminant pressure coexist. Integrating invasion ecology, biomarkers and environmental context can improve the assessment of invaded aquatic ecosystems and support more effective monitoring and management under global change.

Monitoring fouling non-native species in the Gulf of La Spezia: the outcomes after eight years of assessments and comparison among sampling methods

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The promotion of long-term monitoring in ports is crucial for the early detection of non-native species (NNS). In 2018, we started a continuous NNS monitoring across five marinas in the Gulf of La Spezia, using a standardized protocol developed by the Smithsonian Environmental Research Center (SERC). This method utilizes horizontally oriented 14x14 cm PVC settlement panels attached beneath a brick. Each year, 50 panels were deployed at a depth of 1 meter for a three-month summer immersion period.Over the eight-year monitoring program, 324 panels were recovered and 198 sessile taxa identified (including 16 NNS). Temporal and spatial variability were observed in both the fouling assemblage structure and NNS richness. Notably, this monitoring detected the arrival year of the barnacle *Balanus trigonus* in the study area: it was first observed at two marinas in 2023 and expanded to all investigated marinas by 2024, outcompeting native barnacles.In addition, the effectiveness of the SERC method in detecting NNS was evaluated in 2021 at two sites in the Gulf of La Spezia, by comparing it with three alternative approaches: vertical PVC panels, in-water scraping within a fixed quadrat and off-water scraping using a hand-held rigid net. A total of 75 sessile taxa were identified across all methods, including 13 NNS. Fouling assemblages differed significantly between the four methods, except for the samples taken using the PVC panels at one site. While both the SERC method and vertical panels yielded comparable species richness, the first one was most effective in detecting NNS. Conversely, certain taxa were exclusively observed in scraping samples, suggesting that integrating multiple approaches may optimizes the assessment of fouling community.

Passive acoustic monitoring of *Procambarus clarkii*: a novel non-invasive approach in invasion ecology

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Acoustic behaviour is increasingly recognized as a key component of animal interactions, yet it remains poorly explored in freshwater invertebrates. The red swamp crayfish (*Procambarus clarkii*) is a globally invasive species whose behavioural plasticity, aggressive social dynamics, and high tolerance to pollution and habitat degradation drive its ecological success. While *P. clarkii* is known to produce sounds, the specific behavioural contexts and ecological relevance of these acoustic signals remain unclear.The ”Sound Cray Project” investigates underwater sound production in *P. clarkii* across both controlled and natural conditions to link acoustic activity with social behaviour and detectability. To establish an acoustic baseline, crayfish were monitored in the laboratory using AudioMoth loggers (Open Acoustic Devices) across various social and environmental contexts, including pairs and groups, both with and without access to burrows. Recordings were captured at a sampling frequency of 96 kHz for 5 minutes every 30 minutes over a three-day period per experimental group. Following the isolation of sound emissions from the data, primary temporal, spectral, amplitude, and energy parameters were characterized. The results revealed that sound emissions differ significantly depending on the behavioural context.To validate these findings in the wild, the same AudioMoth loggers were deployed in the natural environments of the Avigliana Lakes Nature Park (Italy). Field recordings were performed continuously at 96 kHz for four days, specifically targeting the hours from dusk to dawn. *P. clarkii* acoustic emissions were successfully detected in these natural contexts, suggesting that bioacoustics could serve as a promising, innovative tool for monitoring this invasive species.By bridging laboratory and field bioacoustics, this research evaluates whether sound production can serve as a behavioural indicator to predict ecological patterns. Beyond advancing fundamental knowledge of invertebrate communication, this work explores scalable, non-invasive strategies to improve the management of freshwater biological invasions.

Sterilising the female pleopods of invasive crayfish to limit their spread

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Biodiversity loss has been caused by global warming and the spread of invasive alien species. A long-term conservation programme has been implemented to enhance the populations of the native crayfish *Austropotamobius pallipes* in Italy. This also includes the control of non-native crayfish species, in order to limit their spread. Since 2022, control measures have been implemented for *Procambarus clarkii* populations, primarily involving volunteers trapping invasive crayfish. The first-year session by massive trapping activities resulted in the capture of over 45,000 crayfish in six ponds, with varying CPUE values per site but consistent trapping trends. Since 2023, trapping has been followed by sterilisation using the pleopod cutting technique, which has been demonstrated to be successful under controlled conditions, both in laboratory and mesocosm settings. After three-year activities by sterilisation, a total of 4,700 crayfish were captured, representing a 89% decline. The most successful outcome was achieved by the ratio of juveniles to adults, showing a 84 % decrease in juveniles and therefore indicating a population that is progressively ageing. Engaging local communities and ensuring their support is the key to achieving long-term success in eradication.Acknowledgement: the study was financially supported by the by the European Funds through Financial Instrument for the Environment, LIFE Nature and Biodiversity (LIFE18 NAT/IT/000806).

Who wins and who lags: functional reorganization of invasive alien plants assemblages under global change scenarios

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Predicting how invasive alien plants (IAPs) will respond to global change is a central challenge for ecology and conservation, yet many forecasts do not consider the functional traits that actually govern invasion success. Here, we investigate whether global change will simply modify IAP ranges uniformly or instead reorganize the functional composition of invasive assemblages. A set of 104 IAPs established across mainland Italy and its islands (hotspots under high invasion pressure) was investigated combining functional classification with hierarchical ecological niche models and explicit dispersal simulations. IAPs were grouped into functional classes whose current invasive ranges are jointly shaped by anthropogenic pressure and climatic filtering. Projections to 2070 under contrasting scenarios reveal consistent but markedly non-uniform range changes, indicating that global change reorganizes dominant strategies rather than uniformly increasing richness. These results argue for moving beyond reactive, species-by-species control toward management that integrates functional syndromes, propagule pressure, and dispersal processes, improving early warning and resource allocation in a rapidly changing Mediterranean.

From invasive alien species to circular resources: the CIRCOLACQUA project for environmental pollution monitoring and sustainable aquaculture

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The increasing spread of invasive alien species (IAS) in freshwater ecosystems poses major ecological challenges while generating large amounts of biomass through mandatory eradication and control programs. The CIRCOLACQUA project funded by the Italian Ministry of Health (IZS PLV 09/22 RC, CUP: J19I22001180001) proposes an integrated circular economy approach aimed at transforming this management issue into an environmental and economic opportunity. Focusing on two widespread freshwater IAS, the European catfish (*Silurus glanis*) and the red swamp crayfish (*Procambarus clarkii*), the project explores their dual role as indicators of aquatic pollution and as alternative raw materials for aquaculture feeds.The first component of the project investigates the suitability of both species for environmental monitoring by assessing the accumulation of multiple contaminant classes, including trace elements, rare earth elements, persistent organic pollutants, pesticides and microplastics. Their widespread distribution, high biomass availability and mandatory removal make these species promising organisms capable of providing information on ecosystem contamination while avoiding impacts on native fauna.The second component evaluates the valorization of IAS biomass as a sustainable protein source for aquaculture. Experimental diets containing 20% *S. glanis* or *P. clarkii* meal were tested in rainbow trout (*Oncorhynchus mykiss*), demonstrating good nutritional quality, absence of antibiotic residues, normal growth and physiological performance, and no evidence of adverse histological or oxidative stress effects. These findings support the feasibility of incorporating IAS-derived ingredients into aquafeeds within a circular economy framework. Overall, CIRCOLACQUA demonstrates how invasive species can simultaneously support environmental pollution monitoring and sustainable biomass valorization, contributing to biodiversity conservation, waste reduction and the development of innovative management strategies aligned with the principles of One Health and the circular economy.

Non-linear responses of soil microarthropod communities across an *Ailanthus altissima* mill. Invasion gradient

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Plant invasions modify habitat structure and resource availability, potentially altering the assembly of belowground fauna communities. Little is known about how soil microarthropod communities respond across different stages of plant invasion. This study investigated whether invasion density and estimated stand age influence soil microarthropod community composition and abundance along an *Ailanthus altissima* invasion gradient.Thirty invaded urban forest stands were selected in Montpellier (France) and classified into three invasion-density classes (low: 0.06–1.69, intermediate: 1.72–4.00 and high: 4.24–9.04 individuals m ²; n = 10 per class) and three invasion-age classes estimated from the maximum stem circumference of *A. altissima* (young <10 cm; intermediate 10–30 cm; old >30 cm; n = 10 per class). Invasion density was quantified as the combined density of mature trees, intermediate individuals and root suckers. At each stand, four soil cores were collected, and soil microarthropods were extracted using the McFadyen method and identified to the lowest possible taxonomic level.Invasion age did not significantly affect either soil microarthropod community composition or the abundance of the main taxonomic groups. In contrast, invasion density was associated with marked quantitative changes. High-density *A.s altissima* stands supported significantly lower abundances ($P < 0.05$) of total Acari, non-oribatid mites, total Collembola, Entomobryomorpha and Poduromorpha groups than both low- and intermediate-density stands, whereas the latter two invasion classes showed comparable abundances. Community composition remained relatively stable across the invasion gradient, although older stands tended to exhibit lower multivariate dispersion, suggesting a reduction in between-site community heterogeneity with increasing stand age.These findings indicate that soil microarthropod communities respond non-linearly to *A. altissima* invasion. Increasing invasion density was associated with taxon-specific quantitative responses, with several dominant groups remaining abundant at low and intermediate invasion densities but declining once *A. altissima* reached high levels of dominance.

Capitale naturale, servizi ecosistemici e contabilità ambientale

9

Coordinatori: Pier Paolo Franzese, Fausto Manes, Chiara Paoli, Paolo Vassallo

The hidden value of marine animal forests: a natural capital assessment through emergy analysis

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The European project OCEAN CITIZEN , funded by the European Commission, aims to develop an innovative and sustainable model for the restoration of coastal and marine ecosystems, with a particular focus on the regeneration of marine algal and animal forests. Within this framework, the present study is part of Work Package 5 (WP5) , which focuses on the assessment of natural capital and the sustainability level of restoration interventions through emergy analysis. The study provides a preliminary estimate of the natural capital associated with Marine Animal Forests (MAFs) at Punta Blanca, Tenerife (Spain), based on data collected through ROV video transects. The surveyed habitats encompass several biocenoses, ranging from shallow-water algal communities to deep MAFs. These latter are defined and characterized by habitat-forming and ecosystem-engineering species, such as *Antipathella wollastoni* (Gray, 1857), *Antipathes furcata* Gray, 1857, *Dendrophyllia ramea* (Linnaeus, 1758), *Stichopathes* sp., and *Axinella* sp. which are among the main target of the OCEAN CITIZEN restoration plan. In addition, the analysis encompassed the entire associated ecosystem, including benthic fauna, flora and demersal fishes, in order to provide a comprehensive picture of the system's complexity. Emergy analysis was applied as a donor-side approach that quantifies, in biophysical terms, the resources invested by the environment to generate and maintain a stock of natural capital. This is expressed in a common unit, the Solar Emergy Joule (sej) , which can subsequently be converted into monetary equivalents (Emergy Euro, eM€) . In this preliminary stage, this allows the estimate of both the generation cost of the natural system and the value of its existence, focused on the biophysical characterization of the observed biocenosis. Overall, this approach provides a quantitative basis for the future assessment of restoration outcomes, supporting the sustainable management of MAF.

Feeding the planet, supporting biodiversity: navigating complexity between challenges and opportunities

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Over the last two decades, a significant conceptual shift has taken place within the EU and the broader scientific community regarding the environmental sustainability of productive systems. The focus has progressively moved beyond the mere assessment of environmental harm towards the active quantification of positive contributions to ecosystem services and nature-based benefits. Current EU legislative frameworks on Agriculture and Environment reflect a clear convergence toward a set of rules and best practices aimed at fostering healthy, resilient, and productive ecosystems, while simultaneously preserving EU competitiveness.Ecosystem health and integrity emerge from the intricate interplay of structural and functional components, where ecosystem services are deeply interconnected within a holistic framework. Among the various criteria that define ecosystem health, biodiversity stands out as both the most fundamental and the most challenging to operationalize. It is inherently complex, multifunctional, and multilayered, defying simple quantification through a single metric. Biodiversity encompasses genetic diversity, species richness, and the variety of ecosystems. It manifests through *composition, structure andfunction*. Each of these dimensions may translate into distinct and sometimes competing operational targets for agricultural management, posing considerable challenges for EU regulations and certification schemes applied to agro-productions, which struggle to establish universally applicable metrics and practices that simultaneously ensure biodiversity protection, agronomic productivity, and cost-benefit sustainability.In this contribution, challenges and opportunities connected to the integration of biodiversity and nature-based benefits into land management strategies are discussed.

Natural capital assessment for the management of MPAs

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The NEPTUNE EVOLUTION project (PatrimoNio natUralE sommerso e gesTione sosTeNibiLe della subacquEa ricreativa — EVOLUTION — IF Marittimo00198) aims to enhance and monitor underwater natural capital, as well as to promote the environmental sustainability of recreational diving in the cross-border area between Italy and France. This project is a follow-up to NEPTUNE, ended in 2022, which involved the assessment of the natural capital associated with each diving site in the Portofino Marine Protected Area (MPA). The assessment was carried out following a protocol developed within the national EAMPA project (Environmental Accounting in Italian Marine Protected Areas), for the ecological assessment of natural capital in Italian MPAs, including Portofino MPA. The protocol is based on the emergy analysis, a donor-side approach that quantifies, in biophysical terms, the resources the environment has invested in to generate and maintain stocks of natural capital. This work included: 1) the update of biomass used to assess natural capital of selected habitats; 2) the revision of coordinates and habitat distribution within diving sites; 3) the update of fish assemblages, associated with each habitat using visual census data collected in 2023 and assessed as number of individuals and biomass. The initial step involved the analysis of marine coastal habitat maps to estimate the surface area of each habitat of the MPA and within a 100-meter buffer around each diving site. Two primary results have been obtained: 1) a new assessment of the entire Portofino MPA natural capital value and the simulation of different management scenarios; 2) the update of natural capital at diving sites using more recent and detailed data. These results provide scientific support for improving management of the Portofino MPA, contributing to the conservation of underwater natural capital while promoting the sustainable development of recreational diving.

Comparing i-tree eco and i-tree canopy tools for urban ecosystem service assessment: a case study in Toruń (Poland)

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Urban green infrastructure (UGI) plays a fundamental role in the provision of ecosystem services (ES), especially in highly urbanised environments. Among these, regulating ecosystem services (RES) are often neglected in ES assessments due to the difficulties associated with their biophysical quantification, despite their critical role. Methodological choices in ES assessment can significantly affect their estimation. This study compares two widely used tools from the i-Tree suite, i-Tree Eco and i-Tree Canopy, both designed to quantify RES provided by UGI. A field-based intensive sampling campaign was conducted in an urban park in the municipality of Toruń (Poland) to create the complete inventory required by i-Tree Eco. This tool relies on detailed tree measurements and provides comprehensive estimates of RES, including key ES such as carbon sequestration and storage, air pollutant removal, avoided runoff, and many others, resulting in very detailed outputs. In contrast, i-Tree Canopy estimates canopy cover and derives RES through manual interpretation of randomly distributed points over high-resolution aerial imagery. It estimates the same major RES of i-Tree Eco through simplified inputs. Requiring no field data, it allows rapid assessments suitable for large-scale applications and temporal comparisons. When applied to the same study area, the two tools showed consistent trends and patterns in RES provisioning, although systematic differences emerged in the absolute magnitude of the results: air filtration in i-Tree Eco was 336.03 kg vs 143.49 kg in i-Tree Canopy, carbon storage 211.2 t vs 174.4 t, and runoff 38.3 kl vs 168.7 kl. In conclusion, the findings indicate that i-Tree Eco and i-Tree Canopy should be regarded as complementary rather than alternative approaches, each being better suited to specific assessment objectives and spatial or temporal scales. These results emphasise the importance of methodological choices in urban ES assessments and provide useful insights for supporting more informed UGI management.

Leaf functional traits and particulate matter removal: implications for air quality regulation in urban areas

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Nature-based Solutions (NbS) are recognized as a strategic approach to improve environmental conditions and human well-being by the provision of multiple ecosystem services. Specifically, urban vegetation can improve air quality by removing atmospheric particulate matter (PM) through adsorption processes. However, not all species are equally effective, as their capacity to capture and retain PM mainly depends on the morpho-functional characteristics of their leaves. Despite the importance of this ecological function in urban areas, the understanding of the role of leaf traits remains challenging.To fill this gap and address species selection for future management of urban areas, this study investigates: i) the performance of different tree functional types (i.e. conifers, evergreen and deciduous broadleaves) in adsorbing PM, and ii) the role of leaf traits involved in the process. To this end, leaf sampling from 10 different tree species were collected in Ferrara (Northern Italy) over two campaigns (winter and summer seasons). The vacuum filtration method was used to estimate the amount of PM_{10} and $PM_{2.5}$ in the samples. The following functional traits were measured for broadleaf species: Length/Width (L/W) ratio, petiole length, wettability, wax content, stomata density and trichome density. Multiple regression with background selection was performed to select statistically significant leaf traits in removing PM. Conifers were found to be more efficient at removing atmospheric PM (mean PM_{10} = 38.5 μg cm ^{2}, $PM_{2.5} = 24.6\mu$g cm ^{2}) than broadleaf trees (PM_{10} = 7.1 μg cm ^{2}, $PM_{2.5}$ = 4 μg cm ^{2}), because of high L/W ratio and wax concentrations. Among leaf traits, L/W ratio, petiole length and stomata density were found to significantly influence PM_{10} adsorption.These results can inform urban green management strategies and reforestation efforts by selecting tree species with morphological characteristics favourable to PM removal, thereby contributing to improve air quality in highly-polluted urban areas.

Abandoned, lost or otherwise discarded fishing gear disvalue assessment on natural capital in Capo Carbonara marine protected area

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The coralligenous reef represents one of the most important coastal marine habitats in the Mediterranean in terms of associated biodiversity and the ecosystem services it provides, being capable of creating an extremely complex and diverse seascape. However, it is highly vulnerable to mechanical damage, particularly from fishing activities. Within a collaboration agreement between the Capo Carbonara Marine Protected Area (MPA) and the University of Genoa, a protocol was developed to assess the biophysical damage (disvalue) caused by Abandoned, Lost or otherwise Discarded Fishing Gear (ALDFG). Starting from the natural capital values of the MPA habitats, estimated through the application of the environmental accounting protocol developed by Vassallo et al. (2017), the ecological loss of natural capital caused by ecosystem degradation due to ALDFG was assessed. For this purpose, the natural capital of coralligenous reef was assessed modeling the food web and accounting for the resources required over space and time for its generation. To quantify disvalue, four samples of ALDFG, removed from the coralligenous reef by MPA staff, were analyzed using the same methodology. Specifically, the biomass of the benthic communities associated with the ALDFG was quantified and the impacted surfaces were estimated as input data for the calculations. The results showed an average disvalue associated with ALDFG of 1.12E+12 sej/m². The analyses revealed considerable variability among the different samples, bryozoans accounted for the largest proportion of the biomass analyzed, consequently, the largest contribution was associated with the heterotrophic component. Finally, a comparison was made between ALDFG disvalue and the values of total coralligenous natural capital in the MPA (6.14E+12 sej/m²): this comparison revealed an 18% loss of natural capital. This confirms the importance of targeted monitoring activities of anthropogenic impacts on this habitat, particularly those related to fishing activities.

Spatial ecosystem accounting for blue carbon ecosystems: evaluating ecosystem condition and carbon sequestration service of *Posidonia oceanica* meadows along the Italian coast

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Posidonia oceanica meadows represent one of the most important coastal habitats in the Mediterranean Sea, providing multiple ecosystem services, among which carbon sequestration plays a crucial role in climate regulation. Nevertheless, these ecosystems are still inadequately represented within National Accounting Systems. This study proposes a spatially explicit approach to quantify the extent, ecological condition, and the carbon sequestration service of *Posidonia oceanica* meadows across the Italian coast, following the principles of the System of Environmental Economic Accounting-Ecosystem Accounting (SEEA-EA) framework. Spatial information on meadow density and rhizome primary productivity was used to quantify structural and functional ecosystem properties and integrated into a composite indicator describing the ecosystem condition. Carbon sequestration was estimated from rhizome production data, converted into carbon content and subsequently expressed as CO_2 equivalents through stoichiometric conversion. Findings indicate that Italian Posidonia meadows sequester nearly 630,000 t CO_2 yr ^{1}, with substantial differences among regions. Economic assessment revealed a significant contribution, ranging from approximately 42 M€ yr ^{1} using market-based carbon values to about 93 M€ yr ^{1} when applying the social cost of carbon. Furthermore, cumulative risk analyses identified critical areas where anthropogenic pressures could coincide with degraded ecosystem conditions, potentially reducing service provision. The resulting losses were monetised through restoration-based replacement costs, estimated as reforestation expenses required to compensate for the diminished service. Overall, the proposed framework establishes a national baseline for integrating blue carbon ecosystems into ecosystem accounting and supports marine spatial planning, environmental monitoring, and climate mitigation strategies.

From leaf to footprint: using isotopic techniques to estimate the water footprint of neglected and underutilised crop species

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The potential of plant biodiversity to support food production and preserve ecosystem services is not fully explored and exploited. Neglected and underutilised species (NUS) for example can represent an extremely interesting economic source in marginal areas of Mediterranean, where degradation, drought and also salinization might impoverish farmer options. NUS might present many environmental advantages, one of the most interesting being their limited water requirements. In the VENUS PRIMA project we investigate the water footprint of these plants to demonstrate their positive aspects compared with most common and diffused crops. However, in order to estimate the water footprint we need to estimate green, blue and grey water. The green water footprint (GWF) of NUS has never been quantified under field conditions, owing to the absence of crop-specific coefficients (Kc) required by the standard FAO-56 framework. To meet our objectives we decided to take advantage of δ^{13}C-based isotopic techniques to calculate the intrinsic water use efficiency (iWUE) and from there the GWF for six Mediterranean halophyte NUS — *Salsola soda*, *Atriplex halimus*, *Crithmum maritimum*, *Beta maritima*, *Salicornia europaea*, and *Suaeda maritima* — cultivated under rainfed conditions on marginal saline soils at two Italian field sites (CONSAE/Veneto and RINCI/Marche) during the 2025 growing season, within the VENUS project. A Kc-independent δ^{13}C-based isotopic pipeline was applied, deriving iWUE from leaf carbon isotope discrimination via the Farquhar model and scaling to GWF through biomass water use efficiency and NASA POWER MERRA-2 climate reanalysis data. A Picarro δ^{13}C analyser was used to estimate the isotopic discrimination of plant samples, while their biomass was used to compute the final GWF. NUS showed iWUE values of 181–262 µmol CO_2 mol ^{1} H_2O for C4 species and 37–83 µmol CO_2 mol ^{1} H_2O for C3 species, corresponding to a GWF of 5.76–7.28 L kg ^{1} and 12.13–40.95 L kg ^{1}, respectively. These values were substantially lower than the 238–384 L kg ^{1} total water footprint of conventional leafy vegetables, while for all NUS species, blue and grey water footprints were zero based on their management requirements, showing the extremely good performance of NUS for the water footprint sustainability indicator. Macronutrient data indicate competitive dietary fibre contents for *Beta maritima* and *Crithmum maritimum* relative to conventional leafy vegetables, with published micronutrient data further supporting the nutritional relevance of several species. All plants present interesting market applications. These results provide the quantitative evidence base needed to support the inclusion of Mediterranean NUS in sustainable agriculture in accordance with EU agricultural directives of sustainability and competitiveness.

Management intensity shapes soil-related ecosystem services and biodiversity in traditional agroforestry systems

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Biodiversity loss and climate change call for re-evaluating traditional agricultural systems as Nature-based Solutions (NbS). The European project TRANSFOrm investigates traditional agroforestry systems (TAS) as models that integrate production and ecological resilience.We present first-year results from cherry orchards in northern Italy, comparing three management regimes: abandoned, extensive, and semi-intensive. We assessed how management intensity shapes biodiversity and soil-related ecosystem services using a multi-taxa approach, including pollinators, carabid beetles, avifauna, and vegetation. Biodiversity was sampled through pitfall and pan traps, netting, acoustic monitoring, and floristic surveys, while soil functioning was evaluated through physicochemical analyses and eDNA-based microbiome characterization.Management strongly influenced biodiversity patterns and ecosystem services. Abandoned sites supported higher pollinator abundance and perennial plant richness, reflecting increased habitat complexity under natural succession. In contrast, carabid functional diversity and bird richness peaked in extensive systems, indicating that low-intensity management maintains suitable habitat structure for multiple taxa. Soil analyses showed differences in organic matter dynamics across systems, suggesting shifts in carbon accumulation and nutrient turnover.Overall, our findings highlight that management intensity regulates biodiversity and soil ecosystem services, with low-intensity systems providing a balance between ecological complexity and functionality. Traditional agroforestry systems emerge as effective NbS to enhance resilience in agricultural landscapes under global change.

Evaluating leaf area and biomass relationship in *Posidonia oceanica* (L.) Delile: a tool for non-destructive assessment

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Posidonia oceanica (L.) Delile is a seagrass endemic to the Mediterranean Sea and a significant contributor to human well-being through a variety of ecosystem functions, such as primary productivity and carbon cycling. Its widespread presence over the coasts of many Mediterranean countries, its role as a biodiversity hotspot and the various ecosystem services it provides have led to the recognition of *P. oceanica* meadows as a Marine Priority Habitat under the EU Habitats Directive. Despite its ecological significance, most methods to assess ecological functions in this seagrass species are either destructive or expensive, especially when estimating leaf biomass and primary productivity. Our work aims at contributing to the development of an effective method to estimate leaf biomass based on morphometric parameters. In this study, 2500 individual leaves from 351 shoots of *Posidonia oceanica* were collected, across 16 sites in the Ligurian Sea, over two time periods (2016–2018 and 2024–2025), and analyzed for total leaf area and dry weight. An allometric equation following a power-law structure was derived using linear mixed-effects models and subsequently validated via 10-fold cross-validation. This equation allows the use of area as a predictor of leaf weight, with an absolute error of ±20.8%. Although some variations in the intercept term were observed, the allometric scaling structure remained consistent across space and time, providing the first robust species-specific allometric tool to estimate *P. oceanica* biomass. This work forms the basis of a non-destructive protocol for meadow-scale biomass estimation. Its application has the potential to bring significant improvements in the collection of data regarding *P. oceanica* carbon fixation capacity and other aspects of its natural capital value.

Towards a bioenergetic currency of ecological function: the carbon functional debt across the animal kingdom

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Current approaches to valuing biodiversity and ecosystem damage rest largely on standing stock or on contingent monetary estimates, neither of which captures the cumulative ecological work an organism performs over its life. Using Dynamic Energy Budget theory and curated parameter sets for the whole Add-my-Pet collection, we reconstructed the complete carbon life history of more than seven thousand animal species, from fertilisation to death, and defined a dimensionless index — the carbon functional debt — as the ratio of total lifetime carbon ingestion to instantaneous standing carbon. The index counts how many times over an organism reprocesses its own standing carbon during life. Three regularities emerge. First, it is essentially invariant with body mass across fourteen orders of magnitude, holding within and across taxa, because lifetime ingestion and standing carbon scale almost identically with size so that their ratio is mass-free. Second, the carbon an organism would still process if it completed its expected life dominates the early life course, crossing the carbon already processed only past the midpoint of life; the functional cost of losing a young individual therefore far exceeds its standing biomass, giving a mechanistic basis for the disproportionate weight of recruitment and juvenile survival. Third, the index is sharply tiered by thermal strategy, endotherms carrying an order-of-magnitude higher debt than ectotherms, whose values match independent estimates from production-to-biomass ratios. We discuss how this individual-level currency can be aggregated from individuals to populations and communities, and applied to conservation, restoration and impact assessment as a common, mechanistic and monetary-independent measure of ecological function gained or lost.

Linking ecosystem structure and human health outcomes in a green prescription programme

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The interest in Nature-based Interventions as ways to improve human wellbeing and health has rapidly increased in recent years. However, there is still limited evidence on which ecosystem properties trigger specific beneficial psycho-physical effects. Here we present the results of a pilot study conducted in a woodland ecosystem in central Italy, where a nine-month "Green Prescription" programme for patients with chronic health conditions was developed and implemented by a medical doctor within an ecological-enactive approach, in which participants actively engaged with the woodland while learning to respect its ecological constraints. To characterize the ecological properties of the woodland, we developed an Ecosystem Structural Complexity Index, which integrates vegetation cover, vertical stratification, and biodiversity metrics as a synthetic measure of the structural complexity of the woodland patches where the intervention took place. Our analysis found significant associations between ecosystem structural complexity and participant responses. In particular, woodland patches characterized by higher structural complexity consistently elicited overall appreciation, greater levels of self-reported relaxation, and physical symptoms relief compared with structurally simpler patches. Moreover, the observed benefits appeared to accumulate over time, with distinct temporal patterns suggesting that dynamics and fluctuations in ecological functions may influence human responses. The results support the hypothesis that ecosystem structure may play an important role in shaping the health-supporting potential of the natural environment, and highlight the importance of integrating ecological assessments, achieved by ecologists and trained professionals, into the planning, design, and evaluation of Nature-based Interventions and Green Prescriptions. We argue that Green Prescriptions, when ecologically designed, may support both human health and ecosystem integrity, in line with the Planetary Health perspective. More broadly, these findings provide futher evidence that conserving ecosystem complexity and ecological integrity is important not only for biodiversity conservation, but also for maintaining the capacity of ecosystems to support human health and wellbeing.

L’ecologia, tra società, educazione e sostenibilità

10

Coordinatori: Giuseppe Barbiero, Stefania Pinna, Paolo Guidetti

Making room for nature: ecological experiments, biodiversity monitoring and citizen engagement in a Milan urban living lab

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Urban green spaces are people's primary contact with biodiversity. Policies such as the Kunming–Montreal Framework (Target:12) and the EU Biodiversity Strategy 2030 call for biodiversity-inclusive urban planning that reconciles public access and use of green spaces with biodiversity conservation and the enhancement of ecological quality and connectivity. Achieving this reconciliation requires sustainability education and citizen engagement, extended to research activities themselves.We present a grassland mowing experiment and two biodiversity monitoring activities, and preliminary outcomes, developed within an urban living lab in a public green space in Milan, Giardino Sorelle Mirabal. Alongside these activities, we gathered citizens' perceptions of restricting human access and adjusting management intensity, aimed at enhancing biodiversity and ecological quality.Co-designed with the municipality and local stakeholders, a higher ecological quality portion of the garden was fenced off from public access, with animal presence monitored via phototraps. In the accessible area, we ran a grassland mowing-intensity experiment, also accounting for initial species richness, to quantify the benefits of low-mowing-intensity management for Milan's urban grasslands. Both areas were also monitored with an AI-powered bioacoustic sensor for automated pollinator detection. Activities were communicated to citizens during their planning and development, via public events and on-site panels in the green space.Preliminary results of this ongoing pilot show that experimental and monitoring activities are feasible in publicly accessible urban green spaces, and are well received by engaged citizens when accompanied by clear communication of their purpose and benefits. Informal exchanges, public events and results of online surveys also suggest growing acceptance of non-human needs in green space management, though this reflects only the views of citizens willing to participate. Municipalities and local stakeholders, when involved, also showed interest in research with direct relevance to local decision-making, suggesting this approach can contribute to reconcile people's and urban nature's needs.

Biophilia in action: the restoration state helps to nurture the affiliation trait.

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Experimental research on biophilia suggests that attention restoration is a state-based process, whereas affiliation is a trait-based one. This finding highlights how differently Nature influences individuals' perceived restoration and affiliation to Nature, depending on contextual characteristics and exposure time. Perceived restoration is a context-dependent process driven by Nature's capacity to evoke fascination. *Fascination* encompasses both content and process, though it is primarily the former; when a stimulus possesses fascinating qualities, the involuntary attentional process (fascination) is triggered. Consequently, the more fascinating the natural environment is, the greater the restoration. *Affiliation* to Nature does not fluctuate with contextual characteristics; instead, it functions as a personality trait that requires time and education to manifest, first as an emotional bond, the so-called connection to Nature, and subsequently as naturalistic intelligence. Studies involving children demonstrate the immediacy of perceived restoration: forests are perceived as significantly more restorative than classrooms and playgrounds. Conversely, affiliation remains stable across different settings, even when the natural environment evokes a sense of awe. Only continuous, high-quality contact – supported by active silence training and biophilic design when direct access to Nature is limited – can foster this trait. In practice, the state nurtures the trait, thereby consolidating a sense of belonging to Gaia.

BEE the change! Citizen science and nature-based solutions for environmental education in urban ecosystems

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Urban ecosystems are increasingly affected by anthropogenic pressures that result in biodiversity loss and ecosystem degradation. Nevertheless, urban biodiversity plays a fundamental role in maintaining ecosystem functions and delivering benefits to human well-being. Enhancing public understanding of urban ecology is therefore essential to foster awareness of the interconnections between biodiversity, ecosystem health, and quality of life. Nature-based Solutions (NbS) have emerged as effective approaches to address environmental and social challenges while simultaneously creating opportunities for citizens to engage with nature and develop pro-environmental attitudes and behaviours. Within this framework, the international citizen science project UrbanBEE employs targeted NbS – specifically designed bee hotels – to support and monitor solitary bees in urban environments. In Turin (Italy), more than 180 volunteers have received and are actively participating in monitoring bee hotels nest occupancy, contributing to data collection while engaging in a hands-on environmental learning experience. Through a dedicated outreach and dissemination programme, participants are encouraged to explore the ecological role of pollinators and the importance of biodiversity in cities. The project investigates patterns of solitary bee occupancy and associated biodiversity indicators across urban neighbourhoods characterized by different socio-economic and environmental conditions. Ongoing analyses, based on citizen science-derived bee occupancy data and integrated with ecological, spatial, and socio-economic information, aim to explore how biodiversity and access to urban nature are distributed across the city, and how this may influence the delivery of ecosystem benefits to different communities. The findings are expected to contribute to biodiversity conservation, environmental equity, and sustainable urban planning. Beyond its scientific outcomes, UrbanBEE highlights the potential of citizen-oriented NbS as tools for environmental education and public engagement. By directly involving citizens in biodiversity monitoring, the project promotes ecological literacy, strengthens human–nature connections, and encourages individual responsibility toward urban ecosystems, contributing to the development of more sustainable and resilient societies.

Breaking barriers for boosting marine conservation theory and practice

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Marine conservation is undergoing a profound transformation driven by the recognition that oceans are socio-ecosystems shaped by tightly interwoven relationships between humans, non-human, and inanimate entities. Marine conservation thus increasingly requires approaches that overcome traditional divides between: nature and culture; natural and social sciences; science and society. Such dualisms are inadequate for addressing current socio-ecological crises—driven by extractive, destructive, and inequitable development models—making conservation inherently interdisciplinary. Global frameworks such as the CBD 30×30 target therefore stress the need to integrate ecological and social effectiveness. Marine Protected Areas exemplify these socio-ecological interactions. However, research often remains disciplinarily constrained and bounded within academia, limiting a full understanding of conservation dynamics. While recent developments and interdisciplinary initiatives (e.g., the establishment of interdisciplinary institutes, new journals, the UN Ocean Decade) promote integration, effective collaboration between natural and social sciences remains limited. Emerging interdisciplinary perspectives and multispecies studies highlight the need to break down ontological divides and adopt relational, holistic frameworks that acknowledge interdependence, shared vulnerability, and the agency of more-than-human actors. Transdisciplinary approaches based on co-produced knowledge and civil society participation are also essential for achieving effective and equitable conservation outcomes. Ocean scientists (bio-ecological, social and economic sciences, and humanities) can contribute to the common good of multispecies societies by integrating diverse knowledge systems and cultivating ethical sensibilities grounded in care, reciprocity, and socio-ecological dynamics. Reframing conservation as a co-constructed, relational process—rather than a human-centred effort to protect passive nature—requires transformative shifts in ontology, epistemology, methodologies, ethics, and policies. This entails challenging entrenched anthropocentric assumptions, rejecting the commodification of biodiversity, and embracing multispecies democracy and eco-justice.

Awareness, ecology, and game: a selection of ludic tools for ecological education and systems thinking

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Understanding ecological processes requires the development of systems thinking, which is essential for grasping the interconnections, feedback, and non-linear relationships that govern ecosystems. However, conveying these abstract concepts within educational and social contexts is often challenging. In this framework, gaming (including board games, role-playing, and simulations) emerges as a powerful pedagogical tool, capable of transforming passive learners into active participants within a dynamic system. This contribution aims to highlight and systematize the role of gamification in ecological education. It emphasizes the importance of providing teachers, educators, and environmental practitioners with effective, engaging, and ready-to-use tools to foster ecological literacy and a deeper understanding of sustainability. The work presents a curated selection and critical review of educational and participatory games showcased during previous editions of the National Congress of the Italian Society of Ecology. The review demonstrates that the ludic medium allows players to internalize core ecological concepts—such as resilience, the tragedy of the commons, and ecosystem services—through direct experience and trial-and-error. This organic collection will be published in the upcoming " Quaderno di Ecologia" (Notebook of Ecology). It is designed to serve as a practical handbook and an operational guide to empower teachers and environmental educators in fostering a conscious, systems-oriented culture of sustainability.

PARTE II

Poster

L'ecotossicologia per la conservazione della biodiversità

1

Coordinatori: Ilaria Corsi, Camilla Della Torre, Andrea Binelli

Neurochemical biomarkers reveal cholinergic and GABAergic alterations in *Eisenia fetida* exposed to individual and mixed PFAS

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Per- and polyfluoroalkyl substances (PFAS) are a diverse group of highly persistent contaminants that accumulate in terrestrial ecosystems and can exert adverse effects on non-target organisms. The earthworm *Eisenia fetida* is widely recognized as a sensitive bioindicator for assessing sub-lethal soil contamination. Previous studies have demonstrated that PFAS exposure induces oxidative stress, metabolic disruption, and reproductive impairment; by contrast, information on their neurotoxic effects remains limited, particularly for emerging PFAS and environmentally relevant mixtures. The present study investigated the effects of five PFAS—perfluorooctanoic acid (PFOA), perfluorobutanoic acid (PFBA), hexafluoropropylene oxide dimer acid (HFPO-DA, GenX), perfluoro(3-methoxybutanoic) acid (PFMOBA), and perfluoro(3-methoxypropanoic) acid (PFMOPRA)—on neurotransmitter systems in *E. fetida*. Earthworms were exposed to each compound individually and to an equimolar five-component mixture at concentrations of 0.06 and 229 μM. Neurochemical alterations were assessed on histological sections using a multiparametric immunohistochemical approach. Acetylcholinesterase (AChE) activity was evaluated using the Karnovsky staining method, whereas γ-aminobutyric acid (GABA) distribution was analysed by immunofluorescence. PFAS exposure significantly modulated neurotransmitter-associated responses within the circular muscle layer. Both AChE activity and GABA immunoreactivity differed from control values, indicating that PFAS engage specific neurochemical pathways beyond a generalized stress response. In particular, AChE staining intensity increased at the highest exposure concentration, especially in peripheral tissue regions, consistent with a localized increase in cholinergic (AChE) enzymatic activity within the muscle wall. GABA fluorescence also varied among treatments and anatomical regions, highlighting differential sensitivity of inhibitory neurotransmission to PFAS exposure. Preliminary observations further indicated detectable neurochemical alterations in organisms exposed to the PFAS mixture, supporting the sensitivity of this histological platform for identifying mixture-induced effects. These findings provide novel evidence of PFAS-mediated neurotoxicity in soil invertebrates and support the integration of neurochemical biomarkers into ecotoxicological assessments of both legacy and emerging PFAS.

Impact of environmental and sub-lethal concentrations of diuron on the soft coral *Coelogorgia palmosa*.

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Coral reefs are among the most biodiverse and economically valuable ecosystems on Earth, providing essential services such as coastal protection, fisheries, and tourism. However, these ecosystems are increasingly threatened by global stressors such as ocean warming and acidification, as well as local anthropogenic pressures including chemical pollution. Among these, herbicides like Diuron, widely used in agriculture and as an antifouling agent, represent a major concern due to their ability to inhibit photosynthesis in the symbiotic algae living within coral tissues. This study investigates the toxicological effects of environmental (0.5 µg/L) and sub-lethal (5 µg/L and 50 µg/L) concentrations of Diuron on the health and physiology of the soft coral *Coelogorgia palmosa* over an 18-day exposure period. *C. palmosa* represents a particularly interesting model species as it is a taxonomically isolated, monotypic species that remains understudied compared to reef-building hard corals. A multidisciplinary approach was applied to evaluate coral health through different biomarkers. Morphological observations were conducted to monitor visible signs of stress including color changes (bleaching), tissue shrinkage, tissue attenuation, and mucus production. Physiological performance was assessed using oxygen respirometry to quantify net photosynthesis and respiration rates. At the cellular level, the density of algal symbionts was measured, and the activity of the antioxidant enzyme Superoxide Dismutase (SOD) was evaluated to quantify oxidative stress responses. In addition, the coral volatilome was investigated through Volatile Organic Compound (VOC) analysis using Headspace Solid-Phase Microextraction (HS-SPME) coupled with Gas Chromatography–Mass Spectrometry (GC–MS) to identify metabolic shifts induced by chemical stress.The results revealed a clear dose-dependent impact of Diuron on *C. palmosa*. Morphological data showed significant tissue shrinkage and attenuation in all treated groups starting from day 6 of exposure. Respirometry measurements indicated a critical shift from a net autotrophic to a net heterotrophic state in all Diuron-exposed corals, as evidenced by negative net respiration values compared with the positive values observed in the control group. Symbiont density showed a marked reduction only at the highest concentration (50 µg/L), whereas the intermediate dose (5 µg/L) triggered a significant increase in SOD activity, suggesting an active but energetically costly antioxidant response. Conversely, at 50 µg/L SOD activity decreased, indicating a potential breakdown of compensatory mechanisms under severe stress. VOC analysis identified 1137 molecules and showed that high Diuron concentrations lead to a simplified volatilome with reduced chemical diversity, potentially reflecting constrained metabolic capacity.These findings highlight that morphological changes and VOC profiles can represent early indicators of chemical stress, detectable within a short timeframe and preceding more severe physiological impairments. However, these indicators should be integrated with additional physiological biomarkers to obtain a comprehensive assessment of coral health.Overall, this study demonstrates that even environmentally relevant concentrations of Diuron can impair the physiological and metabolic integrity of *C. palmosa*.

The combined use of morphological observations, VOC profiling, and enzymatic biomarkers provides a robust and integrative approach that may be applied not only to other coral species but also to the assessment of different chemical contaminants in marine ecosystems.

Active biomonitoring of the environmental quality of Lake Orta using the freshwater mussel *Unio elongatulus*

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Historically, Lake Orta has been severely impacted by industrial pollution, which led to the disruption of its biological communities. Although remediation measures, mostly liming, have driven significant ecological recovery, the ecosystem has not yet been fully restored and remains vulnerable to potential new sources of both industrial and domestic pollution which remain largely overlooked.To address these concerns, the INTEGRARE project aims to assess the presence of anthropogenic contaminants and evaluate their biological effects on benthic communities. To achieve this goal, an active biomonitoring was implemented using the native bivalve *Unio elongatulus*, a species that has recently recolonized the lake. Organisms from a population in Lake Maggiore were translocated and maintained in cages deployed across five sites in the Cusio area characterized by differing gradients of anthropogenic pressure: Imolo, San Maurizio d'Opaglio, Pella, Omegna, and Bagnera.The caged bivalves were sampled after 2 and 6 months of exposure. Heart rate was monitored alongside a suite of biochemical biomarkers, including: energetic metabolism (electron transport system activity), oxidative stress (reactive oxygen species levels, and SOD, CAT, and GST enzymatic activities), oxidative damage (lipid peroxidation), and neurotoxicity (acetylcholinesterase activity). The same biological endpoints were measured in resident populations of Lake Orta located at Gozzano and Bagnera.The results revealed distinct biomarker profiles between the Lake Orta and Lake Maggiore populations, reflecting the different baseline environmental conditions of the two lakes. Notably, no significant differences in the analyzed parameters were observed among the five caging sites within the Cusio area, suggesting the absence of active point sources of contamination in Lake Orta. Overall, the successful translocation procedures and the sensitivity of the biological responses validate the suitability of *U. elongatulus* as a model organism for assessing the ecological quality of lake ecosystems.Acknowledgments: "This research was funded by Cariplo Foundation Bandi Emblematici Provinciali Novara".

Microfiber pollution in Antarctic coastal ecosystems: evidence from benthic species from the Fildes peninsula to the Ross Sea

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Microfiber (MF) and microplastic (MP) pollution is increasingly recognized as a pervasive threat to marine ecosystems, reaching even the most remote regions of the planet, including Antarctica, through both long-range transport and local anthropogenic activities. This study integrates analyses conducted on multiple benthic species, highlighting the role of ecological traits and feeding strategies in the exposure to and accumulation of these contaminants. A harmonized methodological approach was applied, including thermo-oxidative digestion, density separation, and polymer identification by μ-FTIR spectroscopy. In addition, a preliminary assessment of chemical additives associated with MFs was performed in one target species. Three key Antarctic benthic species were investigated: the grazing limpet *Nacella concinna* from the Fildes Peninsula (King George Island), the grazing and scavenging sea urchin *Sterechinus neumayeri*, and the filter-feeding scallop *Adamussium colbecki* from the Ross Sea. MFs and MPs were detected in all species, with occurrence frequencies of 100% in sea urchins and scallops and 25% in the limpets examined. Clear differences emerged in both abundance and fiber size: filter-feeding scallops exhibited the highest contamination levels and significantly longer fibers than grazing organisms, indicating that feeding strategy plays a key role in exposure dynamics. Polymer characterization revealed a predominance of natural and semi-synthetic fibers, together with polyester and PET. Comparison with textile materials associated with nearby research station activities showed strong similarities, suggesting a potential local source of contamination. The detection of plastic additives, including phthalates and organophosphate esters, in both reference textile materials and scallops further supports the role of anthropogenic MF as vectors of chemical contaminants within Antarctic food webs, reflecting the combined influence of local emissions and long-range transport. Overall, these findings demonstrate the widespread occurrence of MFs in Antarctic coastal ecosystems and the close relationship between ecological traits and contamination patterns, confirming the value of benthic invertebrates as bioindicators and emphasizing the need for more effective monitoring and mitigation strategies.

Jellyfish ephyrae as non-conventional models in marine ecotoxicology: *Pelagia noctiluca* responses to organic and particulate contaminants

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Marine ecotoxicological bioassays commonly rely on a number of established model organisms, which may partially represent the complexity of marine biodiversity. Expanding the range to ecologically relevant species is therefore essential to advance environmental risk assessment. Despite their key ecological role, previously overlooked, jellyfish's early life stage (ephyra) has only recently emerged as a sensitive, laboratory-feasible candidate to study pollutants in the marine environment.This study explores the potential of the holopelagic jellyfish *Pelagia noctiluca* (Forsskål, 1775) as a suitable test species in marine ecotoxicology. Following set-up and optimization of bench-scale test conditions, ephyrae were exposed to increasing concentrations of surfactants (0.1-50 mg/L SDS and 0.0001-10% Tween 20) as reference toxicants in an acute toxicity test. After 24 and 48 h, lethal and sublethal endpoints were evaluated, including alterations in swimming activity both as frequency of lappet pulsations and as *ad hoc* stress-related movement categories.LC_{50} values obtained for SDS suggested high sensitivity of *P. noctiluca* ephyrae compared with other marine invertebrate models, supporting the reliability of the proposed test. Moreover, analyses of swimming activity showed that alterations in swimming quality can be used to effectively describe sublethal stress, demonstrating the value of behavioural endpoints for a more comprehensive assessment of contaminant effects on marine organisms.We further assessed the short-term effects of microplastics as emerging contaminants on ephyrae, testing both pristine polystyrene microspheres and environmentally relevant micro-sized fragments of high-density polyethylene. Our results demonstrated the suitability of *P. noctiluca* ephyrae for investigating interactions with particulate contaminants, enabling particle internalisation and tissue localisation through microscopy-based approaches.Overall, our study underlines how *P. noctiluca* ephyrae are a promising ecotoxicological model and establishes a reproducible methodological protocol to assess the effects of anthropogenic stressors on pelagic organisms, promoting the integration of Scyphozoan early life stages into future ecotoxicological investigations.

Antifouling coatings and marine alien species prevention: chemical characterization, toxicity profiling and in-field performance testing.

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Recreational boating in the Mediterranean Sea has shown to be a major vector for the introduction of non-indigenous species (NIS) via biofouling. In order to prevent its development on submerged artificial hard substrates antifouling coatings are commonly applied. Biocidal coatings (BC), typically based on copper and booster biocides, remain the most widely used despite concerns regarding their long-term performance and potential environmental impacts. Alternatively, non-toxic foul-release coatings (FR) are emerging as more sustainable choices. This study investigated how environmental conditions influence metal leaching from antifouling coatings and developed a screening procedure to assess their toxicity using selected marine species relevant to biofouling and biosecurity.Antifouling lixiviates were prepared by incubating coated PVC panels with standardized surfaces under six controlled temperature and salinity scenarios. Metal release was quantified using inductively coupled plasma mass spectrometry (ICP-MS). Toxicity was assessed in the amphipod *Monocorophium insidiosum* and pediveliger larvae of the mussel *Mytilus galloprovincialis*, both common biofouling target species, and the copepod *Acartia tonsa* as a non-target species. Field data was used to complement the findings.Results show diverse metal release across incubation scenarios, indicating a context dependent release of metals to the environment. Regarding the toxicological profiles, FR coating lixiviates did not have an effect on the survival of any of the tested species, while BC coating lixiviate lead to mortality at relatively low concentrations for *A. tonsa*. Higher BC concentrations were needed for the other two tested species, suggesting that the response is species specific and tolerance phenomena across species. These results were further backed up by previous field data. Overall, such findings could have important implications for biofouling management and biosecurity.

A preliminary assessment of the health status of farmed *Helix pomatia* in northwestern Italy

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In 2011, the terrestrial snail *Helix pomatia* was classified as Least Concern by the IUCN Red List of Threatened Species. In Northwestern Italy, this species has been farmed for culinary purposes, with farmers collecting individuals from wild populations in selected areas of the Piedmont region. However, habitat destruction has contributed to a decline in natural populations, limiting this practice and increasing reliance on snails imported from Eastern Europe. This study investigated viral pathogens and chemical contaminants in *H. pomatia* collected from farms located in Northwestern Italy during 2024 and 2025. Ten pooled samples (15 individuals each) were homogenised and analysed for chemical contaminants, while 31 individual snails were screened for viral pathogens using foot muscle tissue and hemolymph samples. Trace metals and rare earth elements were quantified by ICP-MS 7800 (Agilent), while pesticide residues were determined through LC-MS/MS and GC-MS/MS multiresidue methods. Baculoviruses, Herpesviruses, and Poxviruses were screened by PCR on DNA extracts. Aluminum and barium concentrations showed wide variability, ranging from 0.045 to 665 mg/kg and from 27 to 162 mg/kg, respectively. Furthermore, four samples exceeded the maximum permissible levels established for comparable marine species, as no specific regulatory limits are currently available for *H. pomatia*. The synergist piperonyl butoxide was detected in two samples (0.084 mg/kg and 0.072 mg/kg). Since no specific maximum residue level (MRL) has been established for *H. pomatia* , these concentrations exceeded the default MRL of 0.01 mg/kg. Additionally, one sample contained the fungicide azoxystrobin (0.042 mg/kg), exceeding the 0.01 mg/kg limit referenced for terrestrial invertebrates. No viruses were detected in any of the analysed samples. These preliminary findings highlight the importance of systematic monitoring. Further investigations are needed to assess the health status of *H. pomatia* , enhance our understanding of wild populations, and support the development of farming practices.

Blood PFAS concentrations in fledglings of an endemic seabird to the Mediterranean Sea

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Per- and polyfluoroalkyl substances (PFAS) are considered as global contaminants of emerging concern in marine ecosystems because of their persistence, bioaccumulation and toxicity. Seabirs are considered excellent indicators for monitoring marine contaminants because they are long-lived, widely distributed, and feed at relatively high trophic levels, allowing the integration of contaminant exposure across space and time. In the present study, we monitored PFAS contamination in the Mediterranean Sea using the Scopoli's shearwater (*Calonectris diomedea*), an endemic seabird to the Mediterranean basin, as an ecological indicator. Specifically, we measured blood concentrations of 21 PFAS in Scopoli's shearwater fledgings. Blood samples (n = 106) were collected from fledglings grown in six colonies across the Mediterranean basin and then analyzed for the qualitative and quantitative determination of PFAS. PFAS were detected in all blood samples, with eighteen compounds consistently detected across all colonies. PFOS was the predominant molecule, followed by PFUnDA and PFNA, whereas the remaining ones were detected at lower concentrations. PFAS contamination patterns differed significantly among colonies, with fledglings from the Greek islands exhibiting higher concentration levels and dissimilar profile compared with conspecifics from the other colonies. Our results showed that PFAS contamination is widespread throughout the entire Mediterranean basin, suggesting that these emerging contaminants may represent additional anthropogenic pressure to those already acting on this species of conservation concern, including fisheries bycatch, overfishing, disturbance and predation by invasive species at breeding sites.

Microplastics in fibre shapes: multigenerational responses of *Chironomus riparius* to regenerated and fossil PA6

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The global production of anthropogenic fibres has markedly increased over recent decades, rising from 23% in 1965 to approximately 72% of today's textile market. As a result, fibre-shaped microplastics (MPs) represent the most prevalent form detected in environments. In parallel, European policies (e.g., Regulation 2025/40 and Directive 2019/904) are promoting a transition towards recycled plastic materials. However, the ecotoxicological consequences of using recycled instead of virgin MPs remain poorly understood. This study compares the effects of fossil-based polyamide 6 (PA6) and chemically regenerated PA6 (Econyl®) fibres on the benthic freshwater species *Chironomus riparius* across two generations. Econyl® is produced via chemical de-polymerization, monomer purification and re-polymerization.Organisms were exposed to a single environmentally relevant concentration (2 mg per 150 g dry sediment), based on MP levels reported in Italian rivers. Fibres were standardized (200 μm length, 40 μm diameter), and the experimental design followed OECD 233 guideline. In addition, oxidative damage biomarkers such as malondialdehyde (MDA) and protein carbonyl content (PCC) were measured, prior to adult emergence, in both generations. In the first generation, both materials induced comparable responses across emergence rate, fecundity, and fertility, with only slight deviations from controls. Differences in development rate and time were observed for PA6, although these remained consistent with Econyl® patterns. In the second generation, a clearer differentiation emerged: while both polymers affected the same endpoints, PA6 exerted stronger effects, particularly on reproductive parameters, and developmental responses appeared more consistent. Notably, no significant differences were detected for MDA and PCC in either generation, confirming similar oxidative stress responses between the two polymers. Overall, the findings suggest that regenerated fibres may reduce ecological risks, supporting plastic recycling as a strategy to mitigate MP impacts in freshwater ecosystems.

Conservazione, gestione, restauro di specie, habitat ed ecosistemi

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Coordinatori: Mariachiara Chiantore, Gianluca Sarà, Valentina Asnaghi, Paolo Biel-
la

Preliminary assessment of bycatch of vulnerable marine species in the GSA 16 (Strait of Sicily)

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. Bycatch is defined as “the accidental capture of non-targeted species or individuals of undesirable size ranges of the target species by non-selective fishing gear”. It is widely recognized as one of the main threats to marine biodiversity, potentially affecting vulnerable species and altering ecosystem structure and functioning. Consequently, increasing attention has been given in recent years to improving bycatch monitoring and mitigation strategies. Within the framework of the scientific cooperation agreement between CNR-IRBIM and ISPRA, supporting the implementation of the Marine Strategy Framework Directive (2008/56/EC; Legislative Decree 190/2010) . The activities will support Descriptors 1 and 3 and the D03-03 monitoring programme (MWEIT-D03-03) in the Strait of Sicily (GSA 16). Fishery-dependent data were collected to assess the bycatch of vulnerable marine species, including elasmobranchs, sea turtles, marine mammals, and seabirds. The study involved four commercial fishing vessels from the ports of Mazara del Vallo, Sciacca, and Licata, including three bottom trawlers and one longliner. Data was collected through two complementary approaches: self-reporting by fishers and on-board observations by scientific observers. Preliminary results showed that the accidental captures of 482 individuals were composed almost exclusively of Batoidea and Selachii, with just one individual of *Caretta caretta* (Linnaeus, 1758). The most frequently reported species were *Scyliorhinus canicula* (Linnaeus, 1758) (36%), *Squalus blainvillei* (Risso, 1827) (41%), and *Raja clavata* (Linnaeus, 1758) (13%). These bycatch events were mainly recorded by the trawling fleet of Licata and Mazara del Vallo. These findings provide an initial overview of the species most affected by accidental catches of vulnerable species and their spatial distribution in the Strait of Sicily. The gathered data help fill knowledge gaps for endangered, threatened, and species currently listed as Data Deficient on the IUCN Red List, thereby supporting ecosystem-based fisheries management and conservation measures in the Strait of Sicily.

Responses of ulvan production to simulated tidal exposure in Mediterranean Ulva strain selected for aquaculture

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Ulva is a green seaweed genus (Chlorophyta) widely distributed in intertidal and shallow subtidal environments and has gained attention for its aquaculture potential as a source of food and high-value bioproducts. In particular, ulvan, a sulfated polysaccharide of the Ulvophyceae cell wall, has been extensively investigated for its biochemical properties and applications in biotechnology and pharmaceuticals. Although several studies have examined how abiotic factors modulate ulvan production, little is known about the effects of tidal exposure on its content. This study aims to investigate differences in ulvan content in Ulva exposed to different degrees of simulated tidal exposure. Given the high plasticity of Ulva morphology and chemical composition under varying environmental conditions and the role of ulvan in maintaining thallus moisture during low tide, we hypothesize that desiccation stress promotes resource allocation to ulvan production rather than growth, resulting in increased ulvan content with longer aerial exposure. Thalli of a high-performing Ulva strain selected for regenerative aquaculture applications will be cultivated in 2-L aquaria (2.5 g L ^{1}; n = 3) containing enriched filtered seawater (36 PSU; 0.5 mL L ^{1} Guillard solution), under constant aeration, an irradiance of 150 μmol photons m ^{2} s ^{1}, and a 14-h photoperiod. Thalli will be exposed daily to simulated low tides of 0.5, 1, and 1.5 h, and a control (0 h), for 15 days. Seawater pH will be monitored daily, while photosynthetic performance and rapid light curves will be assessed every three days using a Diving-PAM II. Every seven days, fresh biomass and ulvan content will be determined. This study will provide new insights into the effects of tidal exposure on ulvan production and contribute to optimizing Ulva cultivation and its sustainable exploitation.

Analysis of fungal communities in loggerhead sea turtle (*Caretta caretta*) nests using metabarcoding: implications for hatching failure

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The loggerhead sea turtle (*Caretta caretta*) is the most widespread sea turtle species in the Mediterranean Sea and the only one regularly nesting along the Italian coasts. Understanding factors affecting hatching success is essential for conservation, particularly in nesting areas increasingly exposed to environmental and human pressures. While abiotic drivers such as temperature and humidity have been extensively studied, the role of microbial communities remains poorly understood. Fungal colonization, in particular, has been recognized as a major cause of egg infection and embryonic mortality, yet its diversity and temporal dynamics during incubation are still largely unexplored. This study investigated fungal and bacterial communities associated with three loggerhead nests monitored along the Ionian coast of Reggio Calabria, one of Italy's most important nesting areas, during the 2025 nesting season. Environmental samples, including nest sand, eggshell fragments, and egg surface swabs, were collected after egg deposition and during nest excavation after hatching. Environmental DNA (eDNA) was analysed using high-throughput metabarcoding targeting the fungal ITS1 region and the bacterial 16S rRNA gene. Diversity analyses, community comparisons, and functional predictions were performed to explore microbial dynamics and their relationship with hatching success. Hatching success varied markedly among nests: two showed high success rates (84.1% and 85.9%), whereas one experienced severe failure (13.3%) with uniform pre-embryonic arrest. Temperature (~31 °C) and moisture (1–3%) remained within suitable ranges, suggesting that abiotic conditions alone did not explain the failure. Fungal metabarcoding revealed highly diverse communities in nest sand, likely acting as a microbial reservoir, while eggshells hosted less diverse assemblages dominated by opportunistic fungi. *Fusarium solani* was the most recurrent and abundant species in unhatched eggs, consistent with its known pathogenic role in sea turtle nests. Other opportunistic taxa, including *Aspergillus alabamensis* and *Purpureocillium lilacinum*, were also frequently detected. Results suggest that early fungal colonization, particularly by F. solani, may impair embryonic development, while nest-specific environmental conditions influence microbial succession and community structure. Integrating molecular and environmental approaches can support more effective conservation and nest management strategies.

Appropriate assessment of the significant impacts deriving from the use of water of Campolattaro artificial lake

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Lake Campolattaro, located in the province of Benevento (Campania), is an artificial reservoir created in the 1970s by damming the Tammaro River. Originally built for water management purposes, it has evolved into a site of ecological significance, designated as both a Special Protection Area (SPA) IT8020015 and Special Area of Conservation (SAC) IT8020001, within the Natura 2000 network, due to its vital role as a refuge for birdlife. Indeed, as a vast wetland ecosystem located along major migratory routes, it provides an essential resting and feeding site for more than 170 migratory bird species, and it also serves as an important breeding and nesting area. The recent approval of the final design for the project concerning the "Use of water from the Campolattaro reservoir for drinking purposes and the enhancement of the drinking water supply for the Benevento area" —included among the ten Italian strategic projects of the National Recovery and Resilience Plan due to its national strategic importance— will enable, upon completion, the use of the reservoir's water for drinking water supply, irrigation, and hydropower generation, making Lake Campolattaro one of the most important operational artificial reservoirs in Southern Italy. However, the deep and significant impacts resulting from the use of the lake's water, and the consequent fluctuations in the reservoir's water level, on habitats and species of this artificial ecosystem, protected under the Habitats Directive (92/43/EEC), required an appropriate assessment of the project's significant effects on the conservation objectives of the Natura 2000 sites IT8020015 and IT8020001.A scientific study and a thorough analysis of the quantitative/qualitative environmental changes resulting from the project's operational phase (conducted based on various future climate and usage scenarios) have enabled the development of a comprehensive environmental restoration plan, involving compensation and mitigation measures designed to preserve ecosystem functionality.

Multi-species management of sea urchin fisheries: a three-threshold review linking sustainable fishing and conservation

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Sea urchins are key components of rocky reef ecosystems and valuable fishery resource in many coastal regions. Their management is challenging because they can act both as ecological drivers, influencing algal cover and habitat state, and as harvested resources whose overexploitation may compromise population viability and fishery sustainability. Conservation and fishery objectives are often addressed separately, although both depend on maintaining sea urchin populations within ecological, demographic and socio-economic limits. Here, we present a review of sea urchin management worldwide, integrating evidence from fisheries, habitat conservation and population dynamics within a three-threshold framework. We screened 562 studies, of which 137 addressed management actions across 23 Exclusive Economic Zones. The reviewed evidence was strongly dominated by fishery-oriented studies, which accounted for >80% of the total, whereas culling, restocking and combined actions were much less represented. We further assessed the knowledge base across 29 marine biogeographic regions to evaluate how evidence is distributed among three key dimensions: fishing sustainability, habitat condition and population viability. Our results identify only a few reference systems providing useful models of integrated management, while the strongest combined evidence of scientific knowledge across the three thresholds emerged from the Western Mediterranean, California Coast and Northwest Atlantic. Many marine regions remain poorly represented, and in general management approaches rarely integrate ecological thresholds, demographic limits and socio-economic constraints within a common framework. This review highlights the need to move beyond single-objective management of sea urchins as either ecosystem stressors or fishery resources. A three-threshold approach can support adaptive and ecosystem-based management by identifying the safe operating space within which sea urchin populations, fisheries and rocky reef habitats can persist. Such an integrated framework is particularly relevant for Mediterranean systems, where commercial harvesting,

habitat conservation and population resilience increasingly interact under cumulative anthropogenic and climatic pressures.

Ulva spp. as a biofilter for restorative aquaculture: supporting *Pinna nobilis* hatchery in IMTA systems

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Nowadays, aquaculture has undergone significant transformations, increasingly adopting more sustainable practices. Low-trophic organisms, particularly seaweeds, are now recognized as strategic components for regenerative aquaculture. Among them, *Ulva* spp. has emerged as one of the most promising seaweeds for integrated multi-trophic aquaculture (IMTA) systems due to its high nutrient uptake capacity, fast growth rates in tank-based production, and wide spectrum of industrial applications.Beyond regeneration, aquaculture can also play a restorative role in the context of environmental crisis and biodiversity loss. In this study, we explored the potential of *Ulva* sp. as a biofilter to enhance water quality in the hatchery of the fan mussel *Pinna nobilis*, a critically endangered Mediterranean species. Semi-closed experimental systems were designed to evaluate whether *Ulva* sp. could efficiently remove dissolved nitrogen (N) and phosphorus (P) remaining compatible with *P. nobilis* rearing.During entire experimental period the ammonia values were under safe limits for mussels in hatchery, up to 0.22 mg.L^{-1}. Nutrient concentrations were reduced in 35% and 32% daily for N and P, respectively. The daily growth rate (DGR) of *Ulva* sp. averaged 2.75 ± 0.79 %·day ^{1} in IMTA and 3.55 ± 0.79 %·day ^{1} in the control, without significant differences ($T = -1.24$; $p = 0.28$).Despite relatively low growth performance, *Ulva* sp. proved efficient in nutrient removal, maintaining water quality within suitable ranges for *P. nobilis* hatchery conditions. Importantly, the IMTA approach was safe for *P. nobilis*, with no evidence of negative interactions.These findings highlight the dual role of *Ulva* sp. in regenerative and restorative aquaculture, supporting its use as a biofilter in conservation-oriented systems and as a tool to integrate sustainable production with biodiversity restoration, amplifying the ecological and practical applications of *Ulva* sp. in Mediterranean aquaculture.

Supporting restoration through *ex-situ* cultivation and outplanting of *Cystoseira compressa*: insights on growth and establishment success

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Brown macroalgal forests of the complex *Cystoseira sensu lato* have undergone a severe decline along Mediterranean coastlines, making active restoration strategies, based on the *ex-situ* cultivation of juveniles from fertile apices, increasingly necessary.Under the Nature Restoration Regulation, the recovery of *Cystoseira s.l.* species, including *Cystoseira compressa,* is a priority action for achieving restoration targets, given their role in shaping macroalgal forests and supporting biodiversity.This study aims to support restoration efforts by assessing the reproductive performance of wild *C. compressa* individuals and comparing them with individuals subjected to higher temperature and extended photoperiod (Treatment), as well as with individuals maintained under laboratory conditions that mimic those found in the field (Control).*Ex-situ* outplanting was carried out for all the conditions by cultivating the fertile apices on clay tiles and ropes. After three weeks of laboratory cultivation, the density of juveniles (individuals cm ²) and their length were measured. Juvenile density was used as a direct indicator of establishment success, defined as their ability to settle and persist on the cultivation substrate.Cultures that achieved suitable growth were subsequently transferred to the sea and deployed at the Aqua De Mâ finfish aquaculture facility (Lavagna, Liguria, Italy). Juvenile density and length were since then monitored monthly.The experimental design allows the implementation of *C. compressaex-situ* outplanting protocols, while determining how rearing conditions and substrate type influence juvenile establishment and persistence under natural environmental conditions. Comparisons among treated, control, and wild populations are conducted in both laboratory and field settings.The findings will provide insights into factors influencing both laboratory growth and post-transplanting performance, contributing to the optimization of active restoration and aquaculture techniques for *Cystoseira s.l.* forests in the north-western Mediterranean Sea.

Fishers interviews as a citizen science approach for monitoring by-catch of protected, endangered and threatened (PET) species in the Ligurian Sea

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Incidental by-catch represents a major conservation concern for Protected, Endangered, and Threatened (PET) marine species in the Mediterranean Sea. Within the framework of the TALASSA project, interactions between professional fishery and PET species were investigated along the Ligurian coast, encompassing four Special Areas of Conservation (SACs). The study focused on elasmobranchs, cetaceans, seabirds, and marine turtles, aiming to assess the frequency, distribution, and characteristics of incidental bycatch events while integrating scientific data with fishers' local ecological knowledge (LEK). Data was collected through interviews with professional fishers operating in the Ligurian Sea. The study examined from an historical perspective, fishing areas and gear types, fishers' responses to incidental captures, perceptions of vulnerable species protection, and practices related to the reporting and recording of bycatch events. Results indicated that small-scale fisheries dominated the area, with gillnets and bottom longlines most associated with by-catch. Elasmobranchs (mainly *Prionace glauca*, *Hexanchus griseus*, *Mobula mobular*, and *Alopias* spp.) were the most frequently reported by-catch group, followed by seabirds (*Larus michahellis*, *Gulosus aristotelis*, and *Phalacrocorax carbo*) and marine turtles (*Caretta caretta*). Bycatch events were generally perceived as stable over time. Despite not being involved in by-catch events, cetaceans, particularly *Tursiops truncatus*, were reported to have increased over the last 15 years and to interact frequently with fishing gears, causing depredation of catches and structural damage. Fishers declared the importance of protecting by-catch species and an interest in sharing their observations, although the majority showed no interest in participating in training events on this subject. Although fishers' knowledge proved to be a valuable source of information, limitations emerged regarding spatial precision and species identification. Despite these constraints, the study highlights the importance of integrating local knowledge with scientific monitoring to improve understanding of by-catch dynamics and support more effective conservation and management strategies in the Ligurian Sea.

Fish fauna as a tool for assessing the conservation status and ecological quality of transitional wetlands

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Transitional environments in deltaic areas comprise a mosaic of aquatic ecosystem resources, characterized by distinct biological communities and ecological functions that contribute significantly to human well-being. In the context of ecological quality, identifying reliable biotic indicators for assessing the conservation status and ecosystem services in these systems remains a challenge due to their high spatial heterogeneity and temporal variability.This study explores the application of fish communities to describe the biotic characteristics of eight transitional wetlands in the Po Delta (Italy), as indicators for assessing their conservation status and ecosystem services (i.e., fisheries and habitat provision for species). Fish communities were used to characterize the compositional, structural, and functional status of ecosystem resources, based on both presence/absence survey data and local fish market records. The indicators were developed by calculating the Fish Habitat Biological Index (HFBI), taxonomic diversity metrics, and functional indices based on key life-history traits, namely habitat use and feeding mode.The results indicate that fish-based indicators effectively discriminate between wetlands with different ecological conditions and service provision capabilities, capturing significant variations in both ecosystem structure and function. Overall, the study demonstrates that fish communities provide operational and policy-relevant indicators that can be directly integrated into ecosystem condition and ecological quality accounts of these environments, supporting the implementation of ecosystem accounting in transitional deltaic wetlands.

Assessing the photosynthetic performance of restored *Posidonia oceanica* meadows on Giglio island (Italy)

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Seagrass meadow restoration has become a key strategy to counteract the decline of the Mediterranean endemic *Posidonia oceanica* (L.) Delile, and transplant monitoring represents a fundamental tool for evaluating the success of interventions. In this context, monitoring plans are increasingly integrating basic plants functional traits with traditional structural descriptors, yet photosynthetic assessments remain largely overlooked (Bacci et al., 2024; Calvo et al., 2021; Pansini et al., 2025). This gap in our understanding of plant physiological response to transplantation constrains our ability to predict medium and long-term establishment and resilience, especially under climate change scenarios (Mancuso et al., 2024). Integrating photo-physiological responses into restoration monitoring may provide valuable insights into the capacity of transplanted cuttings to recover and maintain photosynthetic functionality under changing environmental conditions.The present study aims to address this gap by evaluating the photosynthetic performance of *P. oceanica* transplants over seven years on Giglio Island (Italy), where a long-term restoration program was implemented following the impact caused to native meadows by the Costa Concordia shipwreck (Mancini et al., 2021). In 2023 photosynthetic and fluorimetric measurements were carried out using a Junior-PAM fluorometer (Madonia et al., 2021), in combination with morphometric descriptors, to compare the photosynthetic response of *P. oceanica* meadows transplanted in 2016, 2019, and 2022 with that of an adjacent natural meadow.This study provides a baseline dataset for understanding the physiological response of transplanted *P. oceanica* and highlights the value of integrating traditional structural and phenological metrics with photosynthetic functions within restoration monitoring plans. This multidisciplinary approach may enhance the assessment of restoration outcomes, supporting more effective, evidence-based management strategies.

Shift in spawning time of the red shrimp *Aristaeomorpha foliacea* in the Strait of Sicily

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The deep-water benthopelagic red shrimp *Aristaeomorpha foliacea* (Risso, 1827) represents one of the main target species of the trawl fishery in the Strait of Sicily (Fiorentino *et al*., 2024). Its distribution is typically associated with deep muddy bottoms, which are considered oligotrophic, homeothermic and environmentally stable habitats. These conditions, which promote stable life cycles over time, could, however, be altered by the ongoing climate change and increasing anthropogenic pressures on marine environment. The aim of this study is to compare recent information on *A. foliacea* spawning period in the Strait of Sicily, with the results of the classical study by Ragonese *et al*. (1995), based on specimens collected during seasonal trawl surveys, in the second half of 1980s. New data were collected between January 2024 and 2026 through monthly sampling, conducted in the waters off Licata (Strait of Sicily) within the *Offshore Ibleo* Project. Samples, collected from a total of 219 hauls (276 - 598 m depth), were processed in laboratory and data on carapace length (mm), sex and maturity stage were recorded according to *MEDITS* maturity scale (MEDITS-Handbook No. 9, 2017). Increasing percentages of mature females were observed for both years between spring and summer, although with a marked interannual variability. In addition, a secondary peak of mature females was observed in autumn 2025. Comparison with 1980s data, when a single reproductive peak in summer occurred, suggests a deep change in the phenology of life cycle of *A. foliacea* with an extension of the reproductive period from spring to autumn.

Functional rarity and conservation prioritization of Italian flora: do red list assessments and conservation legislation match functionally rare and evolutionarily distinct taxa?

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Conservation prioritization typically relies on the IUCN Red List, yet these frameworks may not adequately capture the diversity of functional traits in assessed taxa. Calculations of functional, phylogenetic and evolutionary uniqueness have been applied at large geographical scales, although at the national scale they may have practical applications to increase efficiency of targeted conservation. Using trait data from the TRY Plant Trait Database, we quantified functional distinctiveness for 2,359 spermatophytes, 50 pteridophytes and 661 bryophytes in Italy, using Gower's distance and we identified functionally rare taxa as those falling at the extremes of the mean dissimilarity distribution. A novel approach involved calculating functional distinctiveness for growth-related and reproductive traits, rather than combining all traits into a single metric as done conventionally. We tested whether inclusion in IUCN assessments and conservation status categories, scopes (assessed nationally only vs assessed in other lists) and policy coverage (Habitats Directive, Bern Convention, CITES) is predicted by functional rarity using phylogenetically-informed logistic models accounting for geographic range size and endemism status. Finally, we tested a novel binary rarity index - defined as the count of traits for which each species falls at distributional extremes - and compared its predictive power to that of functional distinctiveness. Preliminary results showed that functional rarity calculated with growth and reproductive traits predicts likelihood of assessment and policy inclusion better than overall functional distinctiveness. Furthermore, the rarity index based on extremes of trait values predicted IUCN assessment inclusion and category more accurately than functional distinctiveness.At its completion, this research will provide a detailed account of trait and phylogeny-based rarity for each Italian plant species and serve as case study to advocate for the integration of functional traits into red-listing and policy-design processes.

Harbouring more life: 3D-printed biodiversity support units (BSUs) boost benthic richness in the port of Genoa

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The expansion of coastal infrastructures is increasingly recognised as a major driver of marine biodiversity loss. Urban and industrial ports are particularly human-impacted marine environments, where submerged artificial surfaces are often structurally less complex and colonised by non-indigenous species. Eco-engineering approaches that increase habitat complexity are emerging as Nature-based Solutions (NbS) to enhance biodiversity. This study aims to assess the effects of *ad hoc* Biodiversity Support Units (BSUs) for enhancing biodiversity associated with submerged quay walls in the Port of Genoa. To achieve this goal, large BSUs (L-BSUs; 3D printed in concrete with two alveolation types; dimensions: 100x100x20 cm) were deployed at two sites, at depths of 0.5 m, 3 m, and 5.5 m, and compared to the flat walls. L-BSUs were monitored every three months over 15 months using ROV-based imagery to assess the temporal dynamics of benthic assemblage composition, taxon richness, and percent cover across sites, depths and substrate types. Small 3D printed BSUs (S-BSUs), deployed at 0.5 m depth, were also periodically retrieved to allow a finer *in vivo* taxonomic identification of small-sized organisms. Multivariate analyses and GLMMs showed a clear temporal trajectory: early-stage assemblages were dominated by turf and colonial ascidians, progressively replaced by serpulid polychaetes (mostly *Hydroides* spp), and bryozoans, and later by filamentous and encrusting algae. At 0.5 m depth, both alveolation types supported about 50% more taxa than adjacent flat wall, while the effects on total cover were less pronounced. Overall, L-BSUs consistently enhanced benthic biodiversity and promoted more complex assemblages over time, indicating their potential as NbS in the ecological rehabilitation of urban marine environments.

Long-term changes in reef fish trophic structure across protection levels: a Mediterranean application of the normalized reef status index

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The Mediterranean Sea is undergoing ecological degradation driven by overfishing and other anthropogenic stressors, which, together with climate change, lead to the loss of upper-trophic-level biodiversity and affect ecosystem functioning. Marine Protected Areas (MPAs) are widely used to mitigate the direct impacts and support marine biodiversity conservation. However, total fish biomass, one of the most commonly used metrics, does not explicitly quantify how biomass is distributed across trophic levels. Understanding how fish trophic structure changes over time, therefore, remains key to evaluating the effectiveness of protection measures. In this study, we applied the Normalized Reef Status Index (NRSI) to the Mediterranean context for the first time to assess how the trophic structure of rocky reef fish assemblages varied over time across different protection levels. We compared fish biomass across low, intermediate, and high trophic levels among fully protected, partially protected, and unprotected areas over the long-term period (2007–2025) in the Tavolara – Punta Coda Cavallo MPA (Sardinia, Italy). A clear gradient among protection levels was detected since the beginning of the study period, that persisted through years. The fully protected area showed positive NRSI values, indicating a greater contribution of upper trophic-level species to total biomass. In contrast, the partially protected areas remained close to zero, while the unprotected area showed mostly negative values. Beta regression confirmed a strong positive effect of protection on the NRSI, with both fully and partially protected areas showing significantly higher values than the unprotected area. The model also revealed a small but significant negative effect of year, reflecting a mild overall decline shared across all protection levels. Despite this slight common decline, the NRSI did not follow a consistent directional trend but fluctuated over time within each protection level. In the fully protected area, an initial decline was followed by stabilization at positive values, indicating the persistence of a predator-oriented structure. Importantly, differences among protection levels persisted throughout the study period. Overall, our findings indicate that protection exerted a consistent positive effect on reef fish trophic structure over time, and

that the NRSI provides a standardized and scalable framework for detecting and tracking differences in trophic structure across protection levels.

From persistent structures to biodegradable modules: gypsum and lime mixtures for *Posidonia oceanica* restoration

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Posidonia oceanica meadows are fundamental ecosystems for Mediterranean marine biodiversity. In recent decades, a drastic decline of this habitat has been observed, mainly as a consequence of increasing anthropogenic pressures. Therefore, several restoration projects have been launched using different techniques and materials. Although many restoration interventions resulted successful in ensuring the stability of transplanted cuttings, only a limited number of current techniques rely on eco-compatible and non-persistent materials. For example, one widely used technique involves concrete frames and metal nets, which can persist in the marine environment for many years without degrading. To reduce the environmental impact of anchoring techniques, this study tested alternative materials capable of degrading within 1–2 years after deployment at sea. These materials should provide the stability needed during the initial anchoring phase, without persisting beyond the required time. The behaviour of gypsum and hydrated lime putty mixtures in seawater was therefore evaluated to identify the ideal compositions in terms of dissolution. Cubic modules of 5 cm^3 were produced using four different compositions: A, 100% gypsum; B, 50% gypsum and 50% hydrated lime putty; C, 67% gypsum and 33% hydrated lime putty; and D, 33% gypsum and 67% hydrated lime putty. Mass variation and dissolution rate were monitored both under controlled conditions and in the field. In both contexts, mixture B, followed by mixture C, showed more stability over time, while mixture A was the least resistant. Mixture D showed a peculiar pattern, with an increase in mass, under controlled conditions. Based on these results, mixtures B and D were selected to produce transplantation modules that will be tested at sea to verify their real effectiveness. Although this study represents a preliminary experimental phase, further tests on these materials could support the development of lower-impact and lower-cost modules for *P. oceanica* restoration.

Rolling stones live in Tavolara-Punta Coda Cavallo MPA: rhodolith beds as biodiversity hotspots and ecosystem engineers in the Mediterranean Sea

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Rhodolith beds (RBs) are globally distributed, biodiversity-rich habitats formed by free-living coralline algae that function as ecosystem engineers and important carbonate reservoirs. Despite their ecological and biogeochemical significance and their increasing vulnerability to climate change and ocean acidification, RBs remain understudied. This preliminary study integrates morphological, taxonomic and genetic approaches to characterise RBs in the Tavolara-Punta Coda Cavallo Marine Protected Area (Sardinia, Italy) and assess their role in promoting biodiversity. RBs were investigated through remotely operated vehicle (ROV) observations and grab samples, following the Marine Strategy Framework Directive monitoring protocol. RBs were identified as a continuous area covering at least 500 m² and based on the spatial distribution of 15 ROV video transects, six distinct RBs were mapped between 46.6 m and 77 m depth. Genetic analyses were performed on rhodoliths representing different morphotypes to capture species diversity and morphological variability within the sampled beds. Morpho-molecular analyses conducted on three of the six investigated beds revealed that: i) one bed (RB1) was primarily composed of Ramicrusta sp., a genus previously unreported in the investigated area; ii) a second bed (RB2) was characterised by a relatively high abundance of branches morphology; iii) a third bed (RB3) was dominated by pralines morphology. Species belonging to Lithophyllum, Lithothamnion, Phymatolithon and Spongites were also identified within the collected material. The associated benthic and necto-benthic assemblages were investigated by annotating video footage with BIIGLE, a web-based annotation platform, yielding 2193 observations. Organisms were assigned to major taxonomic groups, including Algae, Demospongiae, Cnidaria, Polychaeta, Mollusca, Ophiuroidea, Echinodermata, Tunicata and Teleostea enabling the characterisation of assemblage structure and variability among RBs. Demospongiae, Ophiuroidea and Teleostea were the most abundant groups, highlighting the importance of RBs as biodiversity hotspots supporting diverse benthic and necto-benthic assemblages.

Survival outcomes of translocated *Pinna nobilis* across Mediterranean pilot sites

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Since 2016, populations of the Mediterranean fan mussel, *Pinna nobilis* Linnaeus, 1758, have undergone a dramatic decline throughout the Mediterranean Sea due to recurrent mass mortality events associated with a multifactorial disease. As a result, several conservation initiatives have been launched to support the recovery of this critically endangered species. Among these, the European LIFE PINNA project (LIFE20 NAT/IT/001122) implemented active restoration actions based on the translocation of juvenile individuals collected from larval settlement devices and mussel-farm longlines, together with adult specimens previously maintained for ex situ reproduction.This study presents the results of a two-year post-translocation monitoring, conducted in the frame of the project action D2, at three pilot sites: the Capo Mortola Marine Protected Area (western Ligurian Sea), the Miramare Marine Protected Area, and the Slovenian coast (northern Adriatic Sea). Between December 2023 and August 2025, 13 translocations were carried out, involving a total of 58 juveniles and 27 adults.At Capo Mortola, all translocated adults eventually died despite being relocated to a deeper and more sheltered site, although the longest survival exceeded eight months. In contrast, juveniles achieved higher survival rates in the Adriatic Sea. At Miramare, individuals survived in lantern nets for up to six months, while along the Slovenian coast one juvenile survived for 15 months, including one year after transplantation onto the seabed.Overall, the results highlight marked differences in survival between life stages and study areas. Adult *P. nobilis* individuals exhibited greater persistence in the Ligurian Sea, whereas juveniles performed better in the Adriatic Sea. The environmental and biological factors underlying these contrasting survival patterns will be investigated within the LIFE PINNA After-LIFE Conservation Plan to support future restoration and conservation strategies for *Pinna nobilis*.

Rewilding grasslands using feral horses: a preliminary study

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Large mammalian herbivores have a disproportionately high impact on terrestrial ecosystems compared to other species and play unique ecological roles as environmental engineers. The (re)introduction of large herbivores is gaining momentum as an effective way to rewild and restore grassland habitats. Large herbivores, like horses (*Equus ferus*), are excellent candidates for rewilding activities, as they can contribute to reducing the loss of open landscapes. The rewilding based on horses relies on domestic individuals. Understanding the ecology and behaviors of such populations may become crucial to restore self-sustaining wild (feral) populations. This contribution presents preliminary results of a study conducted on the population of feral horses inhabiting a mountainous range in Central Italy (La Calvana) recognized as SIC (IT5150001) of Natura2000 network. This feral horse population can be considered as a sort of unintentional rewilding process, as it originated from a small group of free-ranging horses abandoned in the '70. The aim of the study is to assess the structure of the population, to provide a description of its behaviors, and to quantify their potential impact on grassland habitats. Firstly, we analyzed population structure and collected samples for genetic analysis. Secondly, we sampled plant communities in two different areas of animal range, characterized by different levels of grazing intensity (90% vs 50%). Moreover, exclusion cages were installed in the two areas to quantify animal intake along the season. The results showed that the population is divided in 9 separate herds (each composed by a dominant male, several mares and a few foals or juveniles), plus some groups of bachelors composed by mature but non-reproducing males. Vegetation data highlights that horse grazing leads to a selection of plant communities in terms of biomass and species composition which could promote the conservation of grassland habitats threatened by shrub and tree encroachment. These preliminary data will be used to model the population dynamics and provide preliminary estimates on its long-term effect on the environment.

A comprehensive assessment of genetic variation in the endangered *Austropotamobius pallipes* species complex using genotyping-by-sequencing and mtDNA analysis.

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The white-clawed crayfish *Austropotamobius pallipes* species complex is widely distributed across the European area. This species has a narrow ecological niche and inhabits small streams with clean and cold waters. Due to anthropogenic activities, its population size and distribution have declined dramatically over the last fifty years. Moreover, pathogens carried by non-native invasive crayfish species caused the extinction of *Austropotamobius* populations in several areas of Italy. Residual isolated populations are now confined to high altitudes and pristine habitats, where the non-native crayfish have not yet reached. The Italian Peninsula has been identified as a repository of genetic diversity of *Austropotamobius* spp. So far, only *A. pallipes* has been included in the IUCN Red List of Threatened Species, which hinders conservation initiatives for other Italian species and subspecies that have not yet been formally recognised. The identification of management units is fundamental for conservation activities which can be achieved using genomic tools. To this end, a total of 1,650 samples of *Austropotamobius* spp. were collected from 75 populations distributed across Italy and Croatia and characterised with both Genotyping-By-Sequencing and COI mtDNA sequencing approaches. Here, we report the use of genome wide SNPs markers that clearly identified three distinct genetic clusters corresponding to *A. pallipes*, *Austropotamobius fulcisianus fulcisianus* and *A. fulcisianus meridionalis*. This provides genome wide evidence of the presence of two species (*A. pallipes* and *A. fulcisianus fulcisianus*) and suggests that *A. fulcisianus meridionalis* may warrant recognition as a distinct species. These findings, are corroborated by COI mtDNA results. We also show that there is extensive genetic differ-

entiation between local population groups that roughly correspond to different water basins, which lays the foundations for targeted reintroductions of *Austropotamobius* spp. populations guided by the distribution of genomic diversity.

Integrating hydrodynamic modeling to optimize the ecological restoration of *Posidonia oceanica*: the Sanremo case study

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Posidonia oceanica is a seagrass endemic to the Mediterranean Sea, where it forms extensive meadows of high ecological value, providing key ecosystem services such as biodiversity maintenance, coastal protection and carbon sequestration. In recent decades these meadows have undergone a marked regression due to cumulative anthropogenic pressures and environmental changes, making effective conservation and restoration strategies increasingly urgent. Among active restoration actions, the transplantation of *P. oceanica* cuttings has been tested using different anchoring techniques. However, restoration interventions based on similar techniques have often produced very different outcomes depending on the transplantation site, in terms of shoot density, anchoring stability and survival. These differences suggest that restoration success does not depend only on the adopted technique, but also on the environmental suitability of the selected site, intended as the combination of ecological and physical conditions that allow transplanted cuttings to remain stable, develop new roots and expand. Besides parameters that can be directly assessed, such as depth, substrate type or protection level, less readily observable hydrodynamic and physical factors, including bottom currents, storm-induced stress and seabed stability, may represent important mechanical constraints, especially during the early post-transplant phase. This study proposes a preliminary hydrodynamic modelling approach aimed at supporting site selection for *P. oceanica* restoration. Using GIS tools, bathymetric and spatial data were processed to build input grids in Delft3D. Sanremo site was selected as the first case study due to the availability of data from previous restoration actions and monitoring activities. The proposed workflow aims to include quantitative hydrodynamic descriptors in restoration planning, helping to distinguish between ecological habitat suitability and the physical stability required for transplant persistence. This approach may support the selection of sites and anchoring techniques more consistent with local physical conditions, improving the use of resources and the effectiveness of restoration actions.

Underwater structure-from-motion photogrammetry for the ecological characterization and biomonitoring of northern Adriatic bio-geogenic outcrops

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Bio-geogenic rocky outcrops in the northern Adriatic Sea, locally known as ”tegnùe” or ”trezze”, are highly valuable habitats and biodiversity hotspots. This study presents the application of underwater Structure-from-Motion (SfM) photogrammetry for the mapping and characterization of these habitats. The investigated areas include three biogenic outcrops located near Caorle (Venice), including the Natura 2000 site “Tegnùe di Porto Falconera”. These sites are situated at various distances from the coast, at depths ranging between 6 and 20 meters, and are characterized by different size, morphology, and ecological conditions. Surveys were conducted between 2022 and 2026 by CNR scuba divers using a multi-camera rig and specific protocols tailored for the low-visibility conditions typical of these environments. High-resolution (submillimeter) orthomosaics and Digital Elevation Models were produced and analyzed through digital image segmentation and taxonomic identification at the highest possible resolution. Morphometric analyses and ecological metrics based on megabenthic cover were computed. This approach enabled a high-resolution, spatially explicit biological and ecological characterization of the outcrops. Furthermore, the generated datasets were analyzed using indicators and indices for ecosystem status assessment, calibrated against traditional photo-quadrat methods. This step aimed to validate the SfM approach for bioindication and biomonitoring, establishing it as an effective tool for the conservation and management of these vulnerable habitats. Moreover, this framework provides a methodological basis for long-term monitoring and restoration initiatives of these habitats and their associated biodiversity.

PosiFarm project: a Posidonia oceanica nursery for the restoration habitat of the Posillipo seabed (Naples, Italy)

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This project aims to restore *Posidonia oceanica* meadows along the Posillipo coast in Naples (Italy) by experimenting with new methodologies based on transplanting seedlings grown under controlled conditions.The seeds were collected in spring 2025 along the coasts of southern Italy thanks to a citizen science initiative. Four main areas were selected: two in Campania (Ischia and Cilento) and two in Sicily (Vindicari and Marsala). The visually viable seeds, selected after sorting, were germinated in dedicated tanks using different types of substrate: rock wool, coarse organogenic sand, and biodegradable peat pots filled with rock wool or organogenic substrate. Some seeds were also germinated in the dark to evaluate the effect of light on germination.Once germinated, 1071 seedlings were transplanted, from July to November 2025, into previously identified dead matte areas within the Marine Protected Area of the Gaiola Underwater Park, using two different techniques. The first method involved anchoring the seedlings to the seabed using steel and coconut fiber biomats as support, supporting up to 21 seedlings at a time. The second technique consisted of individual square iron frames designed to independently anchor the seedlings to the substrate. Additionally, some replanting stations were covered with wire mesh cages to protect the seedlings from herbivores, such as *Salpa sarpa*, while others were left unprotected to assess differences in growth patterns under varying grazing pressure.The different replanting stations were then periodically monitored to collect data on survival rates in relation to the different transplanting techniques, cultivation, and provenance.The project's primary objective was to test methods for restoring *Posidonia oceanica* habitats that would avoid impacting existing meadows while simultaneously allowing the transformation of stranded seeds destined for drying into new meadows. A secondary goal was to implement these activities with low-cost equipment, making the method reproducible and exportable.

Do the North Ionian Gyre reversals alone affect the spatial-temporal distribution of deep-sea resources? A case study of juvenile *Aristaeomorpha foliacea* in the central Mediterranean.

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Identifying the environmental factors that influence the distribution of fisheries' target species is essential for ecological modelling, an useful tool for the sustainable management of fisheries and the protection of essential fish habitats. The giant red shrimp *Aristaeomorpha foliacea,* is one of the most valuable fishery resources in the Mediterranean, particularly in the Ionian Sea, where significant changes in the abundance with time have been detected. Previous studies highlighted the role of environmental variables (sea-bottom temperature and fishing effort) in shaping the distribution of this species. Moreover, due to its feeding habits and its planktonic and epipelagic larval and post-larval phases, juveniles may be also exposed to the complex hydrological dynamics.The Adriatic-Ionian Bimodal Oscillating System (BiOS) strongly influences the oceanographic circulation and variability in the central Mediterranean, and the reversals of the North Ionian Gyre (NIG) circulation, between cyclonic and anticyclonic, modify upwelling and downwelling rates, nutrient fluxes, and phytoplankton phenology. To test the effect of NIG reversals on the *A. foliacea* juveniles' distribution, the North Ionian Gyre Index (NIGI) was computed analysing Multivariate Empirical Orthogonal Functions (M-EOF) of monthly historical time series (1987–2025) of environmental variables, derived from Copernicus Marine Service products. Moreover, considering the satellite-derived Chlorophyll-a concentrations (1999-2024) as a proxy for primary productivity, its interaction with the NIGI was tested using generalized additive models. The abundance of juveniles (carapace length ≤27 mm) was derived from the historical time series (1999–2024) collected during the Mediterranean International Trawl Surveys (MEDITS) in the North-Western Ionian Sea (Geographical Sub-Area 19).The preliminary results showed a significant effect on juveniles' abundances of the interaction term, acting as a modulating factor that provides a more comprehensive description of *A. foliacea* juveniles' dynamics compared to the effect of single environmental variables. Further investigations are required to better understand these complex mechanisms.

Risposta degli ecosistemi al disturbo: impatti, adattamenti e strategie di mitigazione

3

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Marine biodiversity in life cycle assessment: a systematic review of current gaps, research coverage and future challenges

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Marine biodiversity is increasingly recognized as a critical indicator of environmental health and sustainability, yet its integration into Life Cycle Assessment (LCA) remains underdeveloped. This systematic review synthesizes 30 studies that evaluate and contribute to the development of marine biodiversity impact assessment within LCA, including studies that propose preliminary impact pathways or alternative biodiversity loss metrics, develop and operationalize new pathways or refine already established LCA indicators. The review examines their geographical and temporal coverage, impact pathways and sectoral and taxonomic representation. Results reveal fragmented research efforts, with greater attention devoted to fisheries and offshore wind farms sectors and their related impacts and indicators, while other major marine sectors (e.g. shipping) remain unexplored. Similarly, when it comes to impact pathways and indicators, marine eutrophication is already fully operational and integrated as an LCA indicator with a consolidated modelling framework, whereas other key pressures responsible for marine biodiversity loss (e.g. invasive species) remain underdeveloped and marginally addressed, as they often lack comprehensive ecological datasets and LCA inventories. Taxonomic coverage is centered on commercially important or easily monitored groups, while some foundational taxa, primary producers and microorganisms remain underrepresented. The functional dimension of organisms and ecosystems is not yet accounted for and cumulative impacts are not yet operationalized due to inconsistent units and mismatched scales. In addition, the scarcity of long-term assessments limits our understanding of the delayed responses of marine organisms to chronic exposures to impacts. Overall, current LCA approaches risk to misrepresent marine biodiversity loss due to incomplete taxonomic, spatial and ecological information, highlighting the need for more ecologically comprehensive biodiversity impact assessments frameworks.

Beyond tissue loss: microbiome dysbiosis in *Paramuricea clavata* during a mass mortality event in Sicily

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Mass mortality events are increasingly affecting benthic communities of Mediterranean coastal ecosystems, with the red gorgonian, *Paramuricea clavata*, being among the most visibly impacted. Over the past twenty years, studies focusing on the microbial communities of this species have revealed a link between its die-off and the dysbiosis of its bacterial community (i.e., changes of microbial community composition negatively impacting the host). Specifically, while the core microbiome of healthy colonies is stable and dominated by members of the *Endozoicomonadaceae* family, populations subjected to environmental stress and anthropogenic impacts are characterized by a higher microbial diversity with rare and opportunistic pathogens, such as members of the *Vibrionaceae* family. Despite these observations, current knowledge remains insufficient to identify common causative agents underlying disease onset and mortality events in this gorgonian. In this study, we aimed to identify the origin and causative agent of a mass mortality event affecting P. clavata in Sicily, South Italy, following a severe thermal anomaly occurred during summer 2024. Specifically, we sought to determine whether the event resulted from a stress-induced physiological impairment of the host that facilitated colonization by opportunistic bacteria, or whether it was triggered by a pathogen that compromised the host's immune system, thereby increasing its vulnerability to environmental stress. To this aim, we compared the microbiomes of healthy and diseased *P. clavata* colonies from two different sites. We also characterized the microbial community of apparently healthy gorgonians within a diseased population that may have been delayed in exhibiting the phenotypic signs of disease. We considered as diseased those colonies presenting more than 10% of tissue loss and as healthy the ones with no tissue loss. Our results shed light on the mechanisms underlying the development and spread of mass mortality events affecting one of the most vulnerable ecosystem-engineering species of the Mediterranean Sea.

Integrative approaches to monitor biodiversity changes for the conservation of urbanized areas along the south-central coast of Vietnam

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Coral reefs of Vietnam host high biodiversity and hold significant ecological and economic values for the country. However, in recent years, increasing anthropogenic and climate pressures have caused drastic degradation of these ecosystems. Effective conservation requires reliable monitoring programs that integrate innovative approaches with traditional survey methods. Here we will present the preliminary results from the VIBRANT project (https://site.unibo.it/vibrant/en) developed under the 8th Executive Program for Scientific and Technological Cooperation between Vietnam and Italy, through collaboration between the University of Bologna (UNIBO) and the Vietnam Institute of Oceanography (IO). VIBRANT aims to assess the health of coral reefs along the south-central coast of Vietnam by combining established monitoring protocols with advanced techniques, including digital imaging and environmental DNA (eDNA) metabarcoding. Field surveys were conducted during summer 2025 in the shallow coral reefs of Nha Trang Bay and Nui Chua National Park, encompassing sites characterized by different levels of protection and anthropogenic pressures such as urbanization and tourism. Acoustic habitat mapping was performed using side-scan sonar, while reef condition was assessed through underwater visual censuses following the Reef Check protocol. Coral bleaching was evaluated using the CoralWatch method. Furthermore, the effectiveness of different eDNA sampling methods (e.g., eDNA metaprobes, water samples, and sponges as natural samplers) in capturing benthic metazoan diversity will be evaluated through COI and MiFish metabarcoding analyses. These biological data will be integrated with environmental parameters to provide a comprehensive assessment of reef ecosystem health. The results will support evidence-based conservation policies and contribute to the design of effective management, conservation, and restoration strategies for coral reefs along the south-central coast of Vietnam.

Ports, marinas and protected areas: a mosaic of fish biodiversity along the Sicilian coast

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The Mediterranean Sea is a biodiversity hotspot but faces a range of direct and indirect anthropogenic pressures threatening its ecosystems, including intensive coastal urbanization. Growing "marine urbanization", such as the construction of commercial and touristic ports and marinas, has led to extensive coastal armoring, with evidence of marine ecosystems' disruption. However, recent studies have found that these areas can host unexpected biodiversity levels, act as nurseries and offer heterogeneous microhabitats.This preliminary study investigates how coastal infrastructures and different anthropogenic pressure levels may affect the composition and structure of fish assemblages along the NW coast of Sicily, including port areas, small marinas and areas under different levels of protection within an MPA.Sampling was carried out using Baited Remote Underwater Video systems (BRUVs). Univariate and multivariate analyses, community indices (S, MaxN, LCBD, IndVal) and a habitat quality index, which takes into account habitat heterogeneity and complexity, were performed.Results on a single sampling season reveal an unexpected relationship between anthropogenic pressure and fish assemblages in these coastal environments, with the port of Palermo city showing fish assemblages that are quite diversified and structured, suggesting that heterogeneity and complexity of artificial habitats might favor some fish species. Along the anthropogenic gradient, areas at moderate human press and with less-complex and heterogeneous habitats, exerts low diversity but unique species. Less-disturbed and highly protected areas hosted assemblages of high ecological value, with a balanced presence of species belonging to different trophic levels and associated with natural substrates. These results show that fish assemblages do not follow the gradient of anthropogenic pressure in a linear way but exhibit more complex responses. Both protected and heavily modified by humans environments can contribute to the mosaic of biodiversity at a meso-scale (100 m-10 km), suggesting the need for integrated management and perhaps consideration into spatial planning.

From fertilization to microbiome shifts: effects of *Ostreopsis ovata* blooms on sea urchin early development under thermal stress

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Ostreopsis cf. *ovata* is a benthic marine microalga recorded along the Italian coasts since the 1990s, being responsible for recurrent bloom events in the Ligurian Sea. Under specific environmental conditions, such as shallow waters, low hydrodynamics and high temperatures, it can form Harmful Algal Blooms (HABs), causing mass mortality of benthic organisms, including sea urchins. However, its effects on early developmental stages remain poorly understood. Within the framework of the Under-Pressure project (PRIN 2022), we investigated the combined effects of thermal stress and *O. ovata* blooms on the early developmental stages of *Paracentrotus lividus*. Sea urchin gametes (eggs, sperms) were exposed for up to 72 hours to three *O.* cf. *ovata* abundances (4, 40 and 400 cells/ml) under moderate and extreme temperature conditions (21 and 24°C). The effects of HAB exposure on fertilization success (0.2 hours post-fertilization - hpf), embryonic (24 hpf) and larval development (72 hpf) were evaluated. Fertilization occurred in all treatments but was significantly reduced at the highest *Ostreopsis* abundance (400 cell/ml). Embryonic and larval development were impaired from 40 and 4 cell/ml onward, respectively. A significant interactive effect between temperature and *Ostreopsis* abundance was observed after 24 hours at 40 and 400 cell/ml, while after 72 hours this interaction was significant across all treatments. In addition, changes in the larvae-assocwasd microbiome induced by *O. ovata* exposure were investigated through 16S rRNA gene metabarcoding. Overall, the prokaryotic community associated with sea urchin larvae remained stable following combined exposure to *Ostreopsis* and elevated temperature. However, increasing *Ostreopsis* abundances resulted in a greater prokaryotic taxonomic richness, altering sea urchin microbiome in the larval stage. In conclusion, our findings demonstrate that high *O.* cf. *ovata* abundances negatively affect fertilization success and early developmental stages of *P. lividus*, while also inducing significant shifts in the associated microbiome.

Early detection of harmful phytoplankton shifts in disturbed coastal ecosystems: supporting adaptive management and mitigation strategies

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Coastal ecosystems are increasingly affected by human activities and climate change. These factors can alter the structure and functioning of phytoplankton assemblages, potentially favouring the development of Harmful Algal Blooms (HABs). Rising temperatures, changing nutrient regimes, and altered hydrodynamic conditions can modify species composition and promote the proliferation of bloom-forming, potentially toxic taxa. This has consequences for biodiversity, the trophic network, and the ecosystem services on which human activities, including shellfish farming, rely. In order to understand how phytoplankton respond to environmental disturbance, approaches are needed that can detect changes in community composition at an early stage of bloom development. In this context, integrating a recent, innovative molecular approach such as droplet digital PCR (ddPCR) into ecological monitoring programmes could provide a sensitive method of quantifying target phytoplankton species and detecting early changes in community composition. Direct estimates of rDNA copy number per cell, obtained without the use of internal standard curves, revealed significant variability among ecologically relevant taxa. This ranged from 4.65 copies cell ^{1} in the bloom-forming diatom *Skeletonema* spp., to 5.58 copies cell ^{1} in *Chaetoceros socialis*, and from 23 copies cell ^{1} in the potentially toxic diatom *Pseudo-nitzschia* spp., to 7,845 copies cell ^{1} in the toxic dinoflagellate *Alexandrium minutum*. These taxon-specific differences greatly improve the interpretation of molecular abundance estimates and facilitate the identification of ecologically meaningful changes in phytoplankton community structure in response to environmental disturbance. Furthermore, the timely detection and quantification of harmful taxa provide a basis for early warning systems and adaptive management strategies aimed at mitigating the ecological and socio-economic impacts of HABs. Integrating molecular indicators with ecological monitoring can support risk assessment and decision-making in mussel farming areas, thereby contributing to the preservation of the functioning of coastal ecosystems that are increasingly exposed to global change and the sustainable management of these ecosystems.

Macrofaunal communities associated with beach wrack: a pilot study on northwestern Mediterranean beaches

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The macrophytes stranded on the beach, also known as wrack can provide habitat and food to beach-dwelling macrofauna and seabirds, contribute to carbon and nutrient cycling and protect from coastal erosion, when accumulations are large and compact. In the Mediterranean Sea, beach wrack is largely composed of endemic seagrass *Posidonia oceanica* leaves and rhizome fragments, often mixed with woody debris. The aim of this study is to investigate how macrofauna varies in relation to wrack accumulation on northwestern Mediterranean beaches . We expect that greater wrack cover may be associated with higher macrofaunal abundance and diversity. D uring spring 2026, a sampling campaign was carried out on twelve beaches within three locations (Tuscany, eastern and western Liguria) to encompass a range of environmental conditions. On each beach we sampled along three transects high and low on the shore. Macrofauna was collected using five replicated pit traps per transect and height on the beach, deployed overnight. W rack cover was quantified visually (%) using five 50 × 50 cm quadrats around each pit trap. The study is part of the Interreg MARITIMO project AMMIRARE, which aims to enhance the resilience of Mediterranean beach ecosystems to climate change through the management of *P. oceanica* accumulation as a nature-based solution. We will present the preliminary results of this study and discuss new insights into the ecological role of wrack and its relevance for sustainable coastal management.

Lampenflora as functional indicator of anthropogenic disturbance in show caves

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Show caves are natural cavities equipped with infrastructure that facilitates access and typically requires an entrance fee. Nowadays, cave tourism generates approximately 3 billion/year of U.S. $ (value 2028), representing an important cultural and economic resource. However, the presence of visitors introduces multiple disturbances, with consequent impacts on cave ecosystems. Among these, artificial lighting plays a central role by promoting the growth of photosynthetic biofilms known as lampenflora, mainly composed of cyanobacteria, diatoms, and green algae. Lampenflora proliferation leads to physical, chemical, and aesthetic alterations of cave surfaces. Moreover, the introduction of external microorganisms by visitors can modify the composition and functionality of the native subterranean microbiome. For these reasons, lampenflora represents a direct proxy of anthropogenic disturbance, being strictly dependent on artificial lighting and human activity. In this context, lampenflora can be more appropriately defined as a functional indicator of tourism-driven ecosystem alteration in show caves. We measured lampenflora concentration in fourteen Italian show caves, alongside environmental variables such as light intensity, moisture and tourism intensity. Monitoring of lampenflora allowed us to assess the current level of disturbance across different cave systems. These results provide a first comparative baseline for evaluating anthropogenic pressure in Italian show caves, highlighting the key role of artificial lighting and tourism intensity in shaping biofilm development. This approach represents a practical tool for long-term monitoring and offers valuable support for the development of sustainable management strategies aimed at balancing conservation needs with touristic use.

Characterization of *Posidonia oceanica* banquettes for supporting sustainable management practices.

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The accumulation of dead leaves of *Posidonia oceanica* (*banquettes*) is a natural process along Mediterranean coasts, providing important ecosystem services such as beach nourishment and protection against coastal erosion. Despite their ecological relevance, *banquettes* remain poorly investigated, particularly regarding their geomorphological characteristics and composition, which are essential for supporting sustainable management practices. In many tourist areas, banquettes are routinely removed as waste, to improve the aesthetic appeal of recreational beaches, leading to significant environmental impacts. *In situ* surveys of *banquettes* are crucial to evaluate the effects of the different management options, and to assess their effectiveness in the protection from coastal erosion, particularly during extreme storms, in climate change scenarios.To this aim, in spring 2026, the geomorphological, sedimentological, and chromatic characteristics of *banquettes* and associated sediments were investigated at two coastal sites, showing different hydrodynamic conditions and human impact levels, along the Cilento coast (Agropoli, Italy): Lido Azzurro and Baia di Trentova. Standardised protocols were used for sample collection (both sediments and *banquettes*) and analyses of the *banquette* composition (leaf/sediment ratio) and sediment granulometry. The following parameters were also recorded: beach and deposit geometric extent, deposit slope (%), morphosedimentary features and colour characteristics with CIE-LAB colour space coordinates.Here, we present the methodological approach and preliminary results of *in situ* surveys of *banquettes* along the Cilento coast which provide important insights of the beaching dynamics of these deposits and their interaction with coastal. The geomorphological characterization, *banquette* composition and sediment analysis, integrated with information on local anthropogenic pressures, highlighted distinct accumulation dynamics. These findings support site-specific beach management strategies, promoting *in situ* preservation of *banquettes* where they contribute to sediment balance and coastal resilience, while guiding selective clean-up actions in areas subject to higher anthropogenic impacts.

Volatilome signatures of long-term adaptation to ocean acidification in the epiphytic diatom *Mastogloia fimbriata*

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Diatoms are among the main primary producers in marine benthic ecosystems, where they colonize a variety of substrates. Their complex interactions with co-occurring microorganisms and macroorganisms are possibly mediated by infochemicals, including volatile organic compounds (VOCs). However, the overall VOC emission profile (volatilome) of epiphytic diatoms remains largely understudied. We performed a comprehensive volatilome profiling of two strains of *Mastogloia fimbriata,* originating from a naturally acidified site and a non-acidified site, respectively, under low irradiance (5 µmol photons m ^{2} s ^{1}) and high irradiance (100 µmol photons m ^{2} s ^{1}) conditions. Our aim was to understand whether diatoms undergoing long-term adaptation to ocean acidification also exhibit changes in their volatilome. VOCs were analyzed using Proton Transfer Reaction–Time-of-Flight Mass Spectrometry (PTR-ToF-MS), a highly sensitive, real-time analytical technique. The resulting mass spectral fingerprints were evaluated using Principal Component Analysis (PCA), heatmaps and analysis of variance (ANOVA) with post-hoc tests. Distinct volatilome signatures were observed for each strain, indicating that strains selection in acidified sites is associated with significant metabolic reprogramming. Light availability also influenced VOC emissions. This investigation provides the first comprehensive analysis of the volatilome of *M. fimbriata* and forms a basis for using VOCs as non-invasive diagnostic biomarkers for monitoring benthic ecosystem health and cellular responses to global environmental changes.

Anthropogenic substrates and their role in benthic community dynamics and habitat formation (ATTACH)

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Plastic pollution is widely recognized as a major threat to marine ecosystems due to its persistence and ubiquity across coastal and deep-sea environments. While the presence and distribution of marine litter have been extensively documented, a critical gap persists in understanding its ecological consequences at the population and community levels, particularly for macrozoobenthic assemblages. In particular, the role of plastic debris as an artificial substrate shaping biodiversity patterns, species interactions, and community structure remains poorly understood. ATTACH PhD project aims to address these knowledge gaps by investigating the colonization of plastic litter by macrozoobenthic communities across Mediterranean coastal and deep-sea ecosystems. The research is articulated into three case studies. The first examines communities associated with benthic plastic debris in the Capo Peloro coastal lagoon (Central Mediterranean Sea), comparing them with those colonizing natural substrates to assess differences in taxonomic composition, abundance, and structural complexity. The second adopts an experimental approach, involving the *in situ* installation of artificial substrates made of different polymers, to evaluate colonization dynamics over time and to unravel the influence of material properties on settlement patterns and community development. The third focuses on deep-sea muddy habitats, analyzing macrozoobenthic assemblages associated with plastic litter collected during MEDITS trawl surveys in the southern Tyrrhenian Sea (GSA 10), evaluating the role of plastic as potential available substrates for benthic organisms in deep marine habitats. By integrating observational and experimental approaches, the project seeks to answer key questions: 1) do plastic substrates support distinct benthic communities compared to natural ones? 2) how do colonization processes develop over time? 3) does polymer type influence community assembly? ATTACH will provide novel insights into whether plastic litter acts as a surrogate habitat or a novel ecological niche, contributing to a deeper understanding of its role in benthic ecology and informing future marine conservation strategies.

Impacts of abandoned, lost, or otherwise discarded fishing gears on biodiversity, with post-removal recovery data, from Mediterranean coastal ecosystems of the Valencian coastline (Spain)

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Abandoned, lost, or otherwise discarded fishing gears (ALDFG), represent a major source of marine pollution worldwide, posing significant threats to biodiversity. This study assesses the influence of ALDFG on marine ecosystems along 300 km of the Valencian coastline (Spain), analysing the biodiversity responses following their removal in one (Benidorm) of the fifteen explored sites. Between 2022 and 2025, ten ghost nets and one discarded longline were detected and removed. During removal operations, benthic habitats and associated faunal communities were assessed through standardized underwater visual census conducted immediately after gear removal, followed by a survey based on horizontal and vertical transects. Recovered gears were transported to the Fundación Oceanogràfic facilities, where associated organisms were identified and classified according to their interaction with ALDFG as: (i) entangled, (ii) associated, or (iii) exhibiting both interaction types. At the Benidorm site, a six-month post-removal monitoring survey was conducted to assess changes in benthic biodiversity following gear removal. Statistical analyses evaluated the randomic species distribution among ecological categories, the taxonomic patterns across phyla and the taxa contributing most to the observed differences. Concerning ghost nets, a total of 131 species belonging to eight phyla (Annelida, Arthropoda, Bryozoa, Chordata, Cnidaria, Echinodermata, Mollusca, Porifera) were recorded. Overall, 57.3% of species were entangled, 26.7% associated and 16% showed both interaction type. Mollusca were predominantly represented among entangled fauna (34.4%) and associated fauna (82.1%). The discarded longline hosted more than 2.700 egg capsules of *Scyliorhinus canicula*, highlighting artificial materials as potential oviposition substrates. At the Benidorm site, six months post-removal monitoring revealed an increase in Shannon diversity index (from 1.69 to 1.80), suggesting an early shift in community structure. Overall, this study provides new evidence on the taxon-specific ecological impacts of ALDFG, supporting the integration of biodiversity assessments into removal programmes to improve conservation and management strategies.

Qualitative and quantitative characterization between BOTTOM TRAWL and SET NETS

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Discards represent the portion of the total fishery catch rejected at sea, for different reasons; their management has become increasingly important within the framework of the Common Fisheries Policy (CFP), representing a major challenge for commercial fisheries, with significant implications for the sustainable management of fishery resources and marine ecosystems in the Mediterranean Sea. This study aimed to provide a qualitative and quantitative characterization of discards generated by bottom trawl fisheries (OTB) and set nets used in small-scale fisheries (SSF), including trammel nets (GTR) and gillnets (GNS).Monitoring conducted in the Ligurian Sea during 2025 included 47 observations: 19 from OTB fisheries, divided into three métiers (OTB_DES, OTB_DWS, and OTB_MIX), and 28 from GNS and GTR fisheries, classified according to target species. Results showed that OTB_DES exhibited the highest discard rates, reaching 25% in abundance and 21% in biomass. Among set nets, the highest discard rates were recorded in GTR in terms of abundance (55%) and in GNS in biomass (17%). Shannon and Pielou indices indicated greater multispecificity in trawl fisheries (75 species) compared with set nets. The comparative analysis of length distributions for two target species, *Merluccius merluccius* (HKE) and *Mullus barbatus* (MUT), highlighted a marked difference between gear types. OTB_DES captures a significant proportion of juvenile HKE, with a median length (L_{MED}) of 18 cm, below both the minimum conservation reference size (MCRS) and the length at first maturity (L_{50}); whereas GNS catches are more concentrated on larger specimens (L_{MED} 32 cm). For MUT, median sizes are above both the MCRS and L_{50} in both gears, with an L_{MED} of 14 cm in OTB_DES and 19 cm in GTR. These findings highlight substantial differences in discard production among fishing gears and provide useful information for developing measures to reduce their impact on fishery resources and environment.

Reti trofiche, funzionamento degli ecosistemi ed ecologia di comunità

4

Coordinatori: Salvatrice Vizzini, Edoardo Calizza, Cristina Misic

Modelling macroinvertebrate hydraulic preferences across broad geographic and environmental gradients using a limiting factor approach

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Rivers host high biodiversity and provide key ecosystem services but are increasingly affected by hydrological alterations. Aquatic communities are shaped by hierarchical environmental filters acting from regional to microhabitat scales, with hydraulics representing a pivotal driver at the finest scale. Over recent decades, several studies have assessed taxon-specific hydraulic preferences allowing the inference of rules to mitigate flow alterations that modify in-stream hydraulic conditions. These studies demonstrated that hydraulic conditions filter similar taxa across distinct rivers, supporting the transferability of hydraulic-based models beyond different contexts. However, previous research has mainly focused on individual taxa or traits, typically evaluating average responses among reaches within a restricted geographical context. Here, we tested hydraulic influences at both taxon and community levels, evaluating responses along the entire hydraulic gradient and across environmentally contrasting regions. We compiled a database of 1,430 macroinvertebrate samples from 89 rivers across 15 regions spread in North Africa (Morocco) and Europe and developed quantile regression models relating 16 dominant macroinvertebrate families and 9 community-level metrics to water velocity, depth, and substrate size. Half of the modelled taxa and 66% of the community metrics responded significantly to hydraulic conditions, with velocity emerging as the main microhabitat filter, with stronger effects toward high values. Baetidae, Elmidae, and Simuliidae, together with Ephemeroptera, Plecoptera and Trichoptera proportion (%EPT), Lotic-invertebrate Index for Flow Evaluation (LIFE), and Shannon diversity, exhibited consistent hydraulic preferences across regions. This univariate pattern suggests that these community metrics can be used to assess ecological status at both reach and microhabitat scales across broad geographic and environmental gradients, extending flow-ecology generality and offering robust, transferable tools for river management.

Digging into camera trap data elucidates the activity patterns of mammals across trophic groups in two regional natural reserves in Abruzzo

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Camera trapping is a standard practice in animal ecology to investigate the composition of communities, the relative abundance of species and their occupancy dynamics. Camera trap data can also provide valuable information about the factors affecting the overlap or segregation between species in space and time.The Regional Natural Reserves WWF Oases "Lago di Serranella" and "Cascate del Verde" are protected areas located in the Abruzzo region (Central Italy). The Serranella Reserve hosts a mosaic of habitats (hygrophilous woodlands, scrublands, olive groves, and vineyards) and a large wetland originating in 1981, when a dam was built at the confluence of the Sangro and Aventino Rivers. Differently, the "Cascate del Verde" reserve is primarily covered by forests, fragmented by the Verde River and its gorge.In the context of a project for updating the faunistic checklists of these reserves, we deployed camera traps between July 2024 and November 2025 to monitor their mammal communities. We analysed the obtained data in R environment to explore the activity patterns of the observed species, across three trophic groups: apex predator (*Canis lupus italicus*), mesopredators (e.g., *Vulpes vulpes*, *Meles meles*), and herbivores (e.g., *Sus scrofa*, *Capreolus capreolus*).Observation frequency and daily activity patterns of some species (e.g., roe deer), as well as the temporal overlap between the Apennine wolf and its main preys - wild boar and roe deer - notably differed between the two reserves, probably due to the different amount of agriculture-driven habitat fragmentation. Less pronounced discrepancies emerged for the mesopredators and the crested porcupine *Histryx cristata*, which might be linked to a lower predation pressure on these species by the Apennine wolf in both reserves.Our results reinforce previous evidence about camera traps representing a crucial tool for investigating the spatio-temporal dynamics of mammals' activity and assessing their drivers.

Menu à la carte: spatial and temporal variability of *Merluccius Merluccius* (Linnaeus, 1758) diet in the central Mediterranean Sea.

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The European hake *Merluccius merluccius* (Linnaeus, 1758) is one of the main fishery resources in the Mediterranean Sea and plays a key ecological role as a mid- to high-trophic-level predator linking demersal and mesopelagic food webs. As a species capable of feeding throughout the water column, European hake interacts with multiple trophic compartments, serving as a major predator of commercially and ecologically important fish and crustaceans, while also constituting prey for larger predators. The present study investigates the dietary preferences of the species and their interannual and spatial variability in the central Mediterranean Sea (Strait of Sicily, GSA 16). Diet composition was assessed through stomach content analysis of specimens collected annually between 2018 and 2024 within the Italian Data Collection Framework (DCF), through scientific trawl surveys (MEDITS) and monitoring of commercial catch (CAMPBIOL). To account for ontogenetic dietary shifts, specimens were grouped into three size classes: young-of-the-year (YOY, ≤15 cm TL), juveniles (15–28 cm TL), and adults (>28 cm TL). Diet composition was analysed using the percentage Prey-Specific Index of Relative Importance (PSIRI; Brown et al., 2012), considering size class, spatial distribution, and year of sampling as explanatory variables. Results confirmed the known preference of YOY for Mysida and Euphausiacea, with a progressive shift in larger individuals toward a diet dominated by Decapoda and Osteichthyes. Prey composition also varied among years, with Osteichthyes and Decapoda alternating as the dominant prey groups. Spatial analyses revealed greater dietary heterogeneity in the western sector of GSA 16. These findings provide evidence of trophic plasticity in *M. merluccius*, suggesting that its feeding strategy responds to spatial and temporal variations in prey availability. Such dietary flexibility highlights the species' adaptive role within marine food webs and should be considered when evaluating the productive potential of fishery resources under an ecosystem-based fisheries management approach.

Winter distribution of Euphausiids in an area of the Strait of Sicily (pelagian archipelago).

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In March 2006, the oceanographic cruise "Fin Whale Sicily Strait" (FWSS) was conducted around Lampedusa Island (Pelagian Archipelago, Italy) in the Strait of Sicily. Due to its unique morphological, hydrological, and hydrodynamic features, this area significantly influences the distribution and composition of the plankton community; furthermore, it plays a critical role in understanding the hydrodynamic and biological exchanges between the Western and Eastern Mediterranean basins. Data collected during this study revealed high sea surface temperatures and an increase in salinity below a depth of 200 meters, enabling the identification of two distinct water masses: Atlantic Water and Levantine Intermediate Water. Regarding the euphausiid assemblage, seven species belonging to five genera were identified: *Thysanopoda aequalis*, *Meganyctiphanes norvegica*, *Euphausia krohnii*, *Euphausia hemigibba*, *Nematoscelis megalops*, *Stylocheiron abbreviatum*, and *Stylocheiron longicorne*. This study provides a preliminary baseline on the distribution and abundance of Euphausiacea in the Strait of Sicily.

Taxonomic and functional diversity of macrobenthos communities in water streams of the Po Plain

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Is water quality or the presence of aquatic macrophytes more important for supporting taxonomic and functional macrozoobenthic diversity in lowland running waters?To address this question, we sampled for a year 12 water streams in the Po Plain. At each site and sampling station, three samples were collected across four seasons: spring (May), summer (July), autumn (October), and winter (January). We also recorded abiotic parameters (water temperature, pH, conductivity, dissolved oxygen percentage, and stream speed), presence or absence of aquatic macrophytes, and landscape attributes (riparian naturalness and surrounding land use). Physicochemical parameters were measured in situ using appropriate instruments, while chlorophyll was estimated in the laboratory from water samples collected on site. Macrozoobenthos was collected using a Surber sampler and subsequently identified in the laboratory, both taxonomically and according to trophic/functional traits.The highest mean abundance of individuals per m^2 was recorded at sites with high water quality and macrophytes, followed by sites with high water quality but no plants. Interestingly, however, the highest values of both taxonomic and functional diversity were observed at sites without macrophytes, suggesting that their presence may increase competition among functional groups.Multidimensional scaling (MDS) clearly highlights a differentiation between the 10 natural rivers and the 2 artificial channels, as well as a longitudinal gradient across the Po Plain (upper, intermediate, and lower sections), indicating a general deterioration of the studied systems approaching the Adriatic Sea.

Relationship between environmental factors and the cladoceran community in the Malta Channel during late summer

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This study analyzes the relationship between the main environmental factors and the structure of the cladoceran community in the Malta Channel during late summer. Zooplankton samples were collected at 32 stations during the OUROBS2025 campaign, between August 31 and September 6, using a Bongo40 net (200 μm) and a CTD profiler to characterize the environmental factors.The results indicate typical late-summer conditions. The water column was highly stratified, well oxygenated and characterized by low phytoplankton biomass. A clear hydrological gradient was recognizable: warmer, less saline and relatively less productive Atlantic waters on the western side of the study area and cooler, more saline and more productive Ionian waters on the eastern side.Cladocerans occurred at 93.75% of the stations and showed a strong heterogeneous spatial distribution. The community was dominated by *Evadne spinifera*, followed by *Pseudoevadne tergestina* and *Podon intermedius*. Multivariate analyses (NMDS + envfit) and Spearman correlation identified water-column stratification (Brunt–Väisälä frequency squared, N^2) as the only environmental factor significantly associated with the community structure, influencing both total and species-specific abundances and species richness. Salinity also showed positive relationships with most of the abundances and richness, suggesting a complementary, but not decisive, role in shaping the community.The highest abundances were mainly observed in a few highly stratified coastal stations, influenced by river inflows. Some offshore stations also showed relatively high abundances, related to a higher salinity.The distributions of individual species agreed with previous reports from the Mediterranean: *P. intermedius* was mostly associated with coastal and continental shelf waters, *P. tergestina* preferred more saline offshore waters, whereas *E. spinifera* was found throughout almost the entire study area, confirming its oceanic affinity and its typical summer abundance peak.

Short-term responses of natural phytoplankton communities to nutrient supply and experimental unit size

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Scientific evidence emphasises the importance of phytoplankton cell size in competition and coexistence dynamics, although these mechanisms are not yet fully clarified. Theoretical frameworks predict that, under low nutrient availability, smaller cells are favoured because of their higher surface-to-volume ratio, whereas larger cells dominate under nutrient-rich conditions. The size and shape of phytoplankton cells influence their movement within the water column, thereby enhancing their efficiency in acquiring nutrients.This study investigated the combined effects of volume and nutrient supply on phytoplankton community composition and size structure. Water samples from the Acquatina lagoon were used to fill microcosms of 0.5 L, 0.8 L and 15 L, enriched with different nutrient concentrations, control, 1.6 µM and 16.1 µM, with three replicates maintained for seven days. Total and size-fractionated chlorophyll a (pico-, nano-, and micro- phytoplankton), biomass, cell density, taxonomic composition and diversity were analysed at the beginning and end of the experiment to evaluate the effects of the treatments.Results show that total and size-fractionated chlorophyll a increased with nutrient enrichment and larger experimental volumes, also in the control. Maximum values occurred at 16.1 µM and in the 15 L microcosms. Larger volumes also promoted micro phytoplankton dominance without increasing taxonomic richness. These findings suggest that larger species exploit spatial resources more efficiently, likely due to the relationship between cell size and sedimentation rate. Overall, the study highlights the effect of volume and nutrient on phytoplankton community structure. The experiment therefore confirms that size is a key trait that shapes ecological response patterns.

Linking per-capita feeding to population-scale grazing in exploited and unexploited *Paracentrotus lividus* populations: the role of size structure and density

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Intensive harvesting of the sea urchin *Paracentrotus lividus*, a crucial grazer in Mediterranean rocky reefs, selectively removes commercial-sized individuals and produces size-truncated populations dominated mainly by medium-size individuals. Whether this demographic reorganization alters grazing pressure on macroalgal communities remains poorly understood. Grazing at the population scale emerges jointly from per-capita consumption, size structure and density of the population. We quantified individual algal consumption of medium (i.e. under commercial, 35-45 mm test diameter) and large (i.e. commercial, >50 mm) sizes of sea urchins under standardized laboratory conditions, using individuals from two contrasting Sardinian populations outside marine protected areas: a truncated population (exploited condition) and a well-conserved population (unexploited condition). Trials were run in the cold and warm seasons to capture different physiological states of the gonadal cycle. We analysed size-normalized per-capita consumption, through a fully crossed three-way ANOVA (population x size x sampling period). Also, grazing at the population-scale was estimated by scaling absolute consumption to the respective population demographic structure under i) the same density (controlled conditions) and ii) the densities observed in the field. Results indicate that population-level grazing pressure cannot be inferred from per-capita consumption alone, but rather emerges from the combined effects of individual consumption rates, population size structure, and density. This highlights that fishing-induced size truncation may reshape macroalgal grazing through demographic reorganization, with effects that can differ or even reverse between controlled and field-density scenarios.

Microplastic occurrence in Antarctic copepods from the western Ross Sea: first insights

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Microplastics (MPs), defined as particles <5 mm, are widespread throughout the global ocean; however, their ecological interactions in the Southern Ocean remain poorly constrained, raising concerns about their incorporation into marine food webs. In this context, copepods may represent a potential pathway for MP transfer across trophic levels. To explore this interaction, zooplankton samples collected during the 2014 Ross Sea Mesoscale Experiment (RoME) expedition were analyzed, providing a preliminary assessment of microplastic occurrence in copepod assemblages from three stations in the Western Ross Sea: Cape Hallett (A), Terra Nova Bay (B), and the Franklin–Beaufort sector (C). For each station, copepod samples were divided into two size fractions (<2 mm and >2 mm), each further split into taxonomic and analytical aliquots. Taxonomic analysis provided ecological context for the investigated size classes, revealing distinct community compositions, with *Ctenocalanus* sp. dominating the smaller fraction and *Metridia* sp. predominating in the larger one. The corresponding analytical aliquots (400 individuals from the <2 mm fraction and 200 individuals from the >2 mm fraction) were used to investigate potential size-dependent contamination patterns. Suspected microplastic particles recovered after digestion of copepod aliquots were morphologically characterized and mainly classified as fragments, with occasional fibres also detected. Fragment areas ranged from 0.0004 to 0.016 mm², consistent with those reported for zooplankton-associated microplastics, and their abundances were comparable between copepod size fractions (<2 mm: 0.033; >2 mm: 0.035 particles ind. ^{1}). The highest occurrence was observed at Station A (n = 9), followed by Station C (n = 8), whereas fewer fragments were detected at Station B (n = 3). Finally, FTIR analysis of selected fragments suggested compatibility with polyethylene, polypropylene and polyamide. These findings therefore highlight the importance of integrating historical and contemporary observations to better understand temporal patterns in MP occurrence and their ecological implications in the Southern Ocean.

Population structure, dynamics and stable isotope-based trophic ecology of *Ocypode ceratophthalmus* (Pallas, 1772) in the Maldivian archipelago.

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Ghost crabs are key components of tropical sandy shores, linking marine and terrestrial ecosystems through sediment dynamics and nutrient recycling. Despite their ecological relevance, information on Maldives' populations of the ghost crab *Ocypode ceratophthalmus* is currently lacking, particularly regarding population structure and trophic ecology. In this context, stable isotope analysis of carbon (δ^{13}C) and nitrogen (δ^{1} N) is a useful tool for investigating trophic position and dynamics. The present study aims to provide the first assessment of the population structure of *O. ceratophthalmus* from the Maldivian archipelago, integrating morphometric, isotopic and growth analyses to investigate population traits and trophic niche on Magoodhoo Island (Faafu Atoll), an area increasingly exposed to human impact. Between 2024 and 2025, 221 individuals were collected, weighted, sexed and measured. Allometric relationships and growth parameters were analyzed through log-log regressions and FiSAT II/ELEFAN I, respectively. Stable carbon and nitrogen isotope ratios were analyzed in three different tissues using isotope ratio mass spectrometry. Morphometric analyses highlighted sexual dimorphism, with males exhibiting larger major chelae characterized by positive allometric growth, and female wider abdominal structure. Growth analysis estimated an asymptotic carapace width of 50.40 mm and a growth coefficient of 0.680 year ^{1}, suggesting continuous recruitment with a probable peak between May and July. Isotopic analyses revealed depleted δ^{13}C values (-20.41 ± 2.64‰) and high δ^{1} N values (9.79 ± 0.98‰), suggesting a relatively high trophic position that may reflect an opportunistic feeding strategy. Muscle tissue may reflect a stable assimilated dietary signal, while stomach variability could indicate heterogeneous recent feeding, with no sex-related trophic differentiation. Overall, this study established the first baseline for *O. ceratophthalmus* populations assessment in the Maldives, providing essential data for future ecological, and conservation-oriented research on tropical sandy intertidal ecosystems. This acquires an utmost importance considering the vulnerability of these sensitive environments to growing anthropogenic impacts.

Composition and distribution of the zooplanktonic community of the Malta Channel (Strait of Sicily, central Mediterranean Sea): a new baseline for zooplankton monitoring

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The Strait of Sicily is an hydrodynamically active stretch of sea in the centre of the Mediterranean Sea, crucial for its circulation, as waters masses from the western basin meet water masses of the eastern one. In this context, zooplankton represents an excellent indicator of the ecology of pelagic environment of the area. The aim of this study is to describe the general composition and distribution of the zooplanktonic community sampled during summer 2025 with the "OurOBS 2025" scientific survey.The samples were collected in 32 stations located between Malta and the southern coast of Sicily (GSAs 15 and 16) using a Bongo 40 equipped with 200 µm mesh sized net. In each sampling station, environmental factors were recorded with a CTD probe. In the laboratory, sorting of larger organisms and taxonomical analysis were carried out, as well as the counting of the smaller organisms (e. g. copepods, cladocerans, gastropods larvae), and then density of individuals/m^3 was calculated. A total of 133 organisms were identified to the lowest taxonomical level possible. Multivariate analyses reveals that the community composition is coherent with the summer circulation models in the area, as the species composition of each sampling point resulted in a clustering driven by the water column stability (Brunt–Väisälä frequency) with statistical significance. SIMPER analysis revealed that cluster dissimilarity is tied almost totally to the abundance of copepods, appendicularians and teleost eggs.These preliminary results help to improve the understanding of the structure of zooplankton communities in the central Mediterranean Sea and provides a basis for future studies focusing on ecological monitoring, on the introduction of alien species and the assessment of plankton responses to climate change.

Long-term changes in fish community structure and trophic ecology in a Mediterranean coastal lagoon

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Monitoring the spatio-temporal evolution of fish communities is essential to comprehend their resilience under climate change in coastal-marine ecosystems. This is particularly relevant in transitional ecosystems, where strong environmental fluctuations can lead to pronounced changes over time, making them sentinel environments for detecting and monitoring early signs of climate impacts. The aim of this study was to assess changes in the composition and trophic structure of fish communities inhabiting two sites of a Mediterranean coastal lagoon (Stagnone di Marsala, Italy) subjected to different degree of confinement over a 24-year period.We used abundance and stable isotope (δ^{13}C, δ^{15}N) data from fish communities collected in 1996-1999 and 2023, to estimate respectively spatio-temporal changes in: (i) community structure; (ii) trophic position (TP) and isotopic niche width as estimated by the Bayesian Standard Ellipse Area.Preliminary results revealed temporal changes in fish community composition and abundance at both sites, with a decrease in fish density for most resident species, particularly *Atherina boyeri*. Isotopic data showed that, while community isotopic niche decreased from 1999 to 2023 at both sites, TP partially shifted towards higher values for most species.Changes observed in the fish communities throughout the considered years suggest high structural and trophic plasticity of the species composing such communities, enabling them to adapt to the strong variability in the environmental conditions and resource availability typical of transitional ecosystems. Further steps will link the observed changes to quantitative descriptors of environmental conditions in the study area, including temperature, salinity and vegetation coverage, to support predictions of fish community trajectories under climate change.

Long-term seasonal dynamics of the mesozooplankton food web at the promontory of Portofino LTER site (NW Mediterranean)

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Coastal marine ecosystems in the Mediterranean are increasingly exposed to multiple pressures, including climate change and local anthropogenic impacts, with consequences for biodiversity and ecosystem functioning. In the Ligurian Sea, previous studies have shown marked changes in water-column temperature dynamics, including longer warm seasons and warmer cold seasons (Vassallo et al, 2022). As zooplankton play a key role in pelagic food webs and biogeochemical cycling, understanding changes in mesozooplankton community structure and functions is essential to assess ecosystem responses to ongoing environmental change.This study investigates seasonal and long-term dynamics of mesozooplankton communities at the Long-Term Ecological Research (LTER) site Promontory of Portofino (eLTER-IT15-001-M), using a 20-year time series collected between 2003 and 2022. The dataset includes 345 samples collected approximately every 15 days under favourable sea conditions. We applied a food-web modelling approach and Ecological Network Analysis (ENA) to characterise community structure and function, identify key functional nodes, and detect potential trophic reorganisation over time. Mesozooplankton abundance data were converted into biomass estimates using the normalized biomass size spectrum (NBSS), derived from ZooScan imaging and EcoTaxa workflow.Our results first revealed a marked seasonal pattern in individual size, accompanied by seasonal variation in several ecological network indicators. These observed dynamics highlight higher values of Average Mutual Information and Finn's Cycling Index in warms seasons while Total System Throughput shown a peak only during spring. We also identified temporal discontinuities in mesozooplankton food-web, particularly around 2009, 2014, and 2018, coinciding with changes in environmental parameters such as temperature, salinity, and nutrient concentrations. These results show how long-term ecological observations, when coupled with food-web modelling, can help interpret plankton dynamics not only as changes in community composition or size structure, but also in terms of ecosystem structure and functions under environmental change.

Diet composition and marine litter ingestion of the small-spotted catshark *Scyliorhinus canicula* (Linnaeus, 1758) in the central Mediterranean

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The analysis of stomach contents is a pivotal tool for understanding the trophic ecology of marine predators, predator-prey interactions, and the indirect occurrence of marine litter within food webs. This study investigates the diet of the small-spotted catshark *Scyliorhinus canicula*, sampled in the northern Ionian Sea during the 2025 MEDITS International Bottom Trawl Survey.A total of 63 stomachs were examined ranging from 130 to 540 mm in total length (TL). Specimens were categorized into two size-classes based on maturity: juveniles (400 mm TL, n=36) and adults (400 mm TL, n=27). For each individual, biometric data, sex, and maturity stage were recorded. Prey items were identified to the lowest taxonomic level, and their dietary contribution was evaluated using the Prey-Specific Index of Relative Importance (%PSIRI). Ontogenetic dietary shifts were tested via the Morisita Index, while the Trophic Level was estimated combining %PSIRI with FishBase baseline values.No empty stomachs were recorded, showing mostly medium-high fullness. The trophic spectrum was highly diversified, comprising benthic and benthopelagic prey. Overall, the diet was dominated by Mollusca (31.85%), Teleostea (25.45%), and Decapoda (16.62%), followed by Annelida (8.92%), unidentified Crustacea (6.89%), and Euphausiacea (5.21%). A high Morisita index (0.746) indicated significant dietary overlap between life stages, confirming substantial homogeneity in the trophic niche. The estimated trophic level (4.05 ± 0.40) characterizes *S. canicula* as a specialized secondary predator. Interestingly, plastic items were found in four juvenile stomachs, accounting for 2.43% PSIRI in immature specimens and 1.39% overall.Although litter contribution remains low, its exclusive ingestion by juveniles could be related to the spatial overlap with high-litter accumulation zones or to an opportunistic feeding habit, but it needs to be better explored. These findings enhance our understanding of *S. canicula's* trophic role in the Ionian Sea and highlight the importance of marine litter monitoring across the marine food web.

Ecosistemi, biodiversità e cambiamento climatico

5

Coordinatori: Antonio Pusceddu, Renato Casagrandi, Diego Fontaneto

Linking leaf structure and photosynthesis to adaptive capacity in Mediterranean maquis species under environmental change

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Mediterranean ecosystems are among the most vulnerable to climate change, which is expected to increase the frequency and intensity of heat waves and prolonged drought events. These environmental stressors impose strong constraints on plant growth by limiting photosynthetic performance. In this study, we compared leaf functional traits and photosynthetic performance of species widely distributed in the Mediterranean maquis of southern Italy, to assess how the coordination between structure and function supports their ecological resilience during summer. Sclerophyllous *Pistacia lentiscus*, *Phillyrea angustifolia*, *Quercus ilex* and the semi-deciduous species *Cistus i*ncanus show contrasting drought-response strategies in Mediterranean summer conditions. Sclerophylls maintain higher photosynthetic rates and water-use efficiency (WUE), supported by stronger stomatal control and more conservative, structurally robust leaves with higher leaf mass and tissue density and lower water content. In contrast, *Cistus incanus* displays lower photosynthesis, WUE and C:N ratio, reflecting a more resource-acquisitive strategy.These structural differences reflect distinct patterns of photosynthetic energy allocation. Sclerophyllous species directed a greater proportion of absorbed light toward photochemical processes (higher photosystem activity), thereby maximizing carbon gain under summer drought. In contrast, semi-deciduous species relied more strongly on photoprotective mechanisms, dissipating excess excitation energy through non-photochemical quenching avoiding photoinhibition. This flexible balance between energy utilization and energy dissipation represents two contrasting but equally successful strategies of photosynthetic regulation. Overall, the coordinated adjustments in leaf structure and function explain the ecological success of Mediterranean species and their potential resilience across Mediterranean region.

Valve-gaping monitoring of the grooved carpet shell *Ruditapes decussatus* to salinity and thermal stressors using hall sensors

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Mediterranean lagoon ecosystems are particularly sensitive to Climate Change (CC) events that include rapid reductions in salinity (e.g., flash flood) and increase of seawater temperature represent major stressors for bivalve populations. Continuous monitoring of behavioral responses can provide a sensitive indicator of physiological stress. This study used Hall sensor valvometry to investigate the valve-gaping behavior of the clam *Ruditapes decussatus* exposed to two environmental stresses, the first simulating a drastic reduction of salinity (35, 20, 10 and 5 PSU) and the second an anomalous increase of temperature (22, 24, 26, 28 and 30 °C). The entire experimental setup was housed in independent aquaria units called Technological Aquarium Racks system (TARs) to minimize external disturbances to valve opening behavior, allowing for the independent manipulation of multiple environmental stressors under controlled laboratory conditions. Four behavioral descriptors were calculated from normalized valve-opening data: Average Valve Opening (AVO), Proportion of High Opening (PHO), Probability of Near Closure (PNC) and Number of Closure Events (NCE). Behavioral responses were analysed using linear mixed-effects models and beta-binomial generalized linear mixed models. Progressive salinity reductions decreased AVO and PHO while increasing PNC and NCE, indicating suppression of filtration activity and activation of defensive valve-closing responses. A marked threshold was identified between 20 and 10 PSU below which valve activity rapidly declined. At 5 PSU salinity the PHO disappeared completely, suggesting an almost complete interruption of filtration. Rapid behavioral responses to osmotic stress were observed with no significant effect of exposure time.Increasing temperature led to an increase of AVO and PHO between 26 and 30 °C whereas NCE progressively decreased, indicating longer and more stable valve opening periods. Temperature × time interactions demonstrated that behavioral responses progressively changed throughout exposure, whereas PNC remained unaffected, indicating that the tested temperatures did not trigger defensive valve closure.These findings demonstrate that Hall sensor valvometry provides a sensitive, high-resolution approach for detecting early behavioral responses of *R. decussatus* to climate-related environmental stressors, supporting its application for ecological monitoring and aquaculture management in Mediterranean coastal ecosystems.

New findings and biological notes of *Ommastrephes bartramii* (Cephalopoda: Ommastrephidae) in the Strait of Sicily (central Mediterranean Sea)

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In April 2026, as part of the "Offshore – Ibleo Gas Fields Argo and Cassiopea" project, two females of *Ommastrephes bartramii* (Lesueur, 1821) (neon flying squid) were collected. The individuals measured 60.0 cm and 50.5 cm mantle length (ML) and weighed 7.5 kg and 4.7 kg, respectively. They were caught in two hauls conducted during a fishing campaign using a high-opening trawl net off Licata (Strait of Sicily, GSA16). The specimens were provisionally identified based on the morphological characters described by Jereb & Roper (2010). Since recent advances in molecular biology and genomics have questioned the validity of identifications based exclusively on morphological characters, genetic analyses are currently underway to confirm the taxonomic identity of the specimens. Information on the biology, ecology, and distribution of the genus *Ommastrephes* in the Mediterranean remains fragmentary. Although sightings of *O. bartramii* and *O. caroli* have been reported in recent years, available records are still scarce and often derive from bycatch during vertical jigging or from stranding events. In this context, morphology, sexual maturity, diet, and age information of these new records is given to improve knowledge of their distribution in the Mediterranean Sea, particularly in the Strait of Sicily, where reports are extremely rare to date.

Impact of ross ice shelf meltwater on phytoplankton community structure in Antarctic coastal waters (Ross Sea, Antarctica)

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The Ross Sea is one of the most productive regions of Antarctica and a key hotspot for Southern Ocean biogeochemical cycling. In this area, the Ross Ice Shelf (RIS) exerts a major influence on the physical and biogeochemical properties of the water column, releasing large amounts of freshwater during summer. However, the consequences of these meltwater inputs on primary production processes remain poorly understood. Phytoplankton communities respond rapidly to environmental stressors through shifts in biomass and functional traits, with cascading effects on trophic transfer efficiency, carbon export, and ecosystem functioning.This study investigates how meltwater-driven gradients shape phytoplankton community structure along a west–east transect between Ross Island and Cape Colbeck during the Austral Summer 2025, within the framework of the GLOB project (40th Italian Antarctic Expedition).Preliminary results reveal a pronounced west-to-east gradient associated with increasing freshwater influence. Although microphytoplankton dominated total biomass across the transect, stations affected by meltwater showed a progressive shift toward smaller size classes, with rising contributions of nano- and picophytoplankton. Pigment analyses indicated elevated chlorophyll-b concentrations along the freshwater gradient, pointing to an increasing presence of chlorophyll-b-containing taxa. Molecular data supported these patterns, confirming a diatom-dominated assemblage throughout the transect but with a growing relative contribution of Chlorophyta and other non-diatom groups in the eastern, meltwater-influenced stations.These findings suggest that meltwater inputs linked to RIS dynamics act as key ecological drivers structuring phytoplankton communities. Even subtle shifts toward smaller size classes may alter trophic pathways, reducing energy transfer efficiency to higher consumers and modifying carbon export dynamics. Under future scenarios of intensified ice-shelf melting, such changes could significantly reshape biodiversity patterns and ecosystem functioning in Antarctic coastal environments.

Characterizing the thermal preferences of the demersal species in the Ionian Sea

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Seawater increasing temperature significantly affect marine ecosystems, threatening biodiversity and essential ecosystem functions. Therefore, the identification of thermal preferences of the species is of paramount importance to determine the response of the marine community to climate change.This work aims to establish a rigorous methodological approach to characterize the thermal preference of the demersal species collected in the North-Western Ionian Sea, identifying the thermal optimum associated with the maximum probability of presence for each taxon.The core value of this analysis lies in the use of a thirty-year standardized time series data, integrating demersal species distribution with seabed temperature. Specifically, data were gathered annually from 1995 to 2025 within the EU Data Collection Framework, during the MEDITS (Mediterranean International Trawl Survey) experimental bottom trawl surveys, conducted in the North-Western Ionian Sea (Geographical Sub-Area 19), covering a bathymetric range between 10 and 800 meters in depth.The preferential temperature of over one hundred species of different faunistic categories (Cephalopods, Crustaceans, Cartilaginous and Teleosts fishes) was obtained through the development of Generalized Additive Models (GAMs). Indeed, sea-bottom temperature data, connected to the presence/absence of the demersal species along the historical data series, were projected onto a high-resolution continuous space to estimate the thermal preference values (*optima*). The application of strict diagnostic protocols ensured the statistical robustness of the applied model.The availability of thermal *optima* of the demersal species, can allow future analysis to detect the marine ecosystem responses to local warming and to predict the evolution of the demersal community under the pressure of future climate scenarios.

Harmful algal blooms in the Mediterranean Sea: advances and challenges

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Harmful algal blooms (HABs) represents a major environmental concern in coastal marine ecosystems due to their impacts on human health, fisheries, aquaculture, tourism, and ecosystem functioning. In the Mediterranean Sea, blooms of toxin-producing microalgae, including species belonging to *Ostreopsis* sp., *Alexandrium* sp., and *Dinophysis* sp., highlighted the need for effective monitoring strategies that can support risk assessment programs and provide early warning system. Traditional light microscopy monitoring is still crucial for phytoplankton identification; however, limitations in species discrimination, particularly for cryptic and low abundant taxa remain to be faced. Molecular techniques represent powerful tools, enabling rapid, sensitive, and accurate detection of harmful microalgal species. Approaches such as quantitative PCR (qPCR), metabarcoding, and environmental DNA (eDNA) sequencing have significantly improved the capacity to characterize phytoplankton assemblages and identify potentially toxic species even in complex environmental matrices. In order to make molecular approaches effective for supporting timely responses to harmful algal bloom events, the harmonization of protocols and data sharing will be fundamental. Applications of these approaches in Mediterranean coastal environments have enhanced our understanding of HAB dynamics, also enabling the detection of resting stages of potentially toxic taxa in sediments and the identification of harmful taxa associated with emerging substrates, such as marine plastic debris, contributing to a more comprehensive assessment of species dispersal and persistence. Moreover, combining high-throughput sequencing technologies with environmental factors, predictive capabilities can be improved to support the development of early warning systems. In the current context of climate changes and anthropogenic pressures altering Mediterranean marine ecosystems, molecular monitoring represents a key component for understanding HAB occurrence and dynamics, assessing associated risks, and implementing effective mitigation strategies.

Microbial community descriptors to depict *Posidonia oceanica* health and conservation status (METIS)

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Posidonia oceanica meadows play several ecological roles and provide essential ecosystem services in the Mediterranean Sea. However, increasing anthropogenic pressures and climate-driven stressors are accelerating their decline, highlighting the need for more sensitive and integrative monitoring approaches. Microbial communities associated with seagrass regulate key biogeochemical processes and contribute to host resistance and resilience. Due to their rapid response to environmental changes, seagrass microbiomes can provide early indicators of ecosystem degradation.The METIS PhD project aims to identify microbial descriptors of the health of *Posidonia oceanica* meadows and provide a new predictive tool for the management and conservation of coastal marine ecosystems. The project aims to answer three questions: i) how do bacterial communities vary along gradients of thermal stress and anthropogenic impact? ii) which taxa and functional pathways are most sensitive to disturbance? and iii) can specific microbial signatures reliably indicate ecological status? To address these questions, three objectives are defined: i) characterize bacterial diversity and composition associated with leaves and sediments; ii) identify changes in community structure and functional traits related to the biogeochemical nitrogen cycling, which is critical for seagrass survival and iii) link microbial patterns with environmental conditions, host status and epiphytic community. Sampling will be conducted seasonally at three sites along the Calabrian coasts, representing a gradient of anthropic pressure: a low-impact site (Cirella), a moderately impacted site (Capo Rizzuto), and a highly impacted site (Calopezzati). Microbial communities will be characterized using an integrated approach combining traditional and innovative molecular techniques, including DNA metabarcoding and eDNA. The resulting data will be correlated with environmental parameters to assess thermal stress and anthropogenic impacts.Developing this integrated approach, METIS aims to identify microbial descriptors of seagrass health and contribute to the development of innovative monitoring tools, such as a microbial-based index, to support conservation and management strategies.

Marine Platyhelminthes of the Maldives: a review of their diversity and distribution

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The phylum Platyhelminthes is poorly studied in the Republic of Maldives, and its biodiversity remains largely undocumented. By integrating published literature, citizen-science platforms, and online photographic resources, 39 species belonging to 20 genera and nine families were compiled, including both free-living and parasitic taxa. Only a limited fraction of records came from the formal literature, whereas most were retrieved from citizen-science and web-based sources, highlighting the contribution of non-traditional data streams to biodiversity assessment. Analysis of 170 occurrence records showed a marked spatial unevenness, with most observations concentrated in the central and northern atolls, a pattern likely driven by differences in survey effort, tourism, and diving activity rather than by true biogeographic variation. Free-living species were mainly represented by conspicuous pseudocerotids, while parasitic flatworms were underrepresented because they require host-targeted sampling and are difficult to detect through photographic surveys. Overall, the review shows that current knowledge of Maldivian flatworm diversity is fragmentary and probably underestimated. Beyond compiling existing records, it establishes a baseline for future research on flatworm biodiversity in the Maldives, including systematic sampling, integrative taxonomy, and DNA barcoding, which will be essential to improve species identification, reveal hidden diversity, and support future conservation and management efforts.

Urbanization reshapes spider communities: biodiversity loss, biotic homogenization, and the importance of environmental heterogeneity

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Urbanization is among the main drivers of biodiversity loss, altering ecological communities and ecosystem functioning. Understanding how urbanization affects biodiversity is essential for biodiversity conservation in increasingly human-dominated landscapes. Arthropods play key ecological roles and are widely used to assess the impacts of environmental change. Among them, spiders are suitable indicators of urbanization because they are abundant, widespread, and sensitive to habitat alteration. Despite their ecological importance, spider communities remain relatively understudied, largely because the ecology of many species is still poorly known. Here, we present a pioneer study investigating how spider community composition and community functional traits vary along an urbanization gradient. From May to September 2025, spiders were sampled monthly at 19 urban, suburban, and rural sites across the Metropolitan City of Milan. At each site, a 15-m transect was surveyed using standardized active sampling methods and pitfall traps. We analysed spider abundance, species richness, community composition, and functional traits in relation to urbanization and environmental variables. Our results suggest that urbanization negatively affects spider biodiversity. In particular, species richness and diversity declined with increasing levels of urban development, while community composition shifted towards a dominance of a few urban-tolerant taxa, indicating processes of biotic homogenization. In contrast, sites characterized by greater environmental heterogeneity supported higher spider diversity across the urbanization gradient. Community functional traits also varied along the gradient and were associated with environmental heterogeneity, further indicating that urbanization acts as an environmental filter. Together, these findings suggest that maintaining environmental heterogeneity may help mitigate the ecological impacts of urbanization and contribute to biodiversity conservation in urban landscapes.

From global climate variability to local blooms: the role of ENSO in the bloom dynamics of *Ostreopsis* cf. *ovata* in the Mediterranean

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Over the last two decades, blooms of the benthic dinoflagellate *Ostreopsis* cf. *ovata* have become a recurring phenomenon along the Mediterranean coast, with ecological and health implications linked to the production of ovatoxins and the exceeding of risk thresholds. Although sea surface temperature is one of the main factors regulating the development of these blooms, the role of large-scale climatic drivers in modulating their intensity and interannual variability remains unclear.This study analysed twenty years of monitoring data (2006–2026) collected along the Genoa coastline, integrating epiphytic and planktonic concentrations of *O.* cf. *ovata* with ENSO (El Niño-Southern Oscillation) indices, with the aim of determining whether the different phases of the phenomenon are associated with variations in the frequency and intensity of blooms and in the exceeding of the operational thresholds established for public health monitoring. The hypothesis is that El Niño and La Niña events, through their influence on atmospheric circulation, the position of subtropical high-pressure systems and the persistence of high-pressure conditions in the Mediterranean basin, may alter the local thermal and meteomarine regime, creating conditions that are differently favourable to the development of blooms.The time series of abundances were compared with the intensity and duration of the various ENSO phases, assessing the relationships with sea surface temperature anomalies, the frequency of marine heatwaves and the number of occasions on which alert and emergency thresholds were exceeded.The aim is to determine whether a global climate index could serve as an early indicator of the likelihood of *O.* cf. *ovata* blooms occurring in the north-western Mediterranean. The identification of any statistically significant relationships could help to improve seasonal forecasting of bloom events and to complement monitoring systems that are currently based solely on local environmental parameters.

Beyond spots and genes: testing ecological niche differentiation in two species of alpine newt (genus *Mesotriton*) in Italy

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Mesotriton alpestris and the Apennine endemic *Mesotriton apuanus* are two recently recognized species characterized by distinct evolutionary histories, although their ecological differentiation has never been investigated in detail. In this study, we compared their ecological niches in northern Italy using Ecological Niche Models (MaxEnt) based on occurrence data from Trentino-Alto Adige (*M. alpestris*) and Liguria (*M. apuanus*). Models included climatic, topographic, and land-cover variables and showed fair-to-good predictive performance (AUC = 0.72–0.79). The ecological niche of *M. alpestris* was mainly driven by climatic and topographic factors, particularly annual mean temperature, precipitation, and slope exposure, whereas *M. apuanus* was more strongly associated with land-cover variables, especially deciduous forests, and precipitation. The comparison of response curves and variance partitioning highlighted different environmental relationships between the two species. Moreover, a symmetric background similarity test showed that niche overlap was significantly lower than expected by chance ($D = 0.67$, $P \approx 0.04$), supporting the presence of ecological niche divergence. These findings suggest that the long-term evolutionary separation of the two taxa was accompanied by ecological differentiation, providing ecological support for their recent taxonomic distinction and contributing to a better understanding of adaptation processes in cold-adapted amphibians.

Development of a random forest classifier for automated phytoplankton classification from imaging FlowCytobot images at the Portofino promontory eLTER site

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The phytoplankton community plays a key role in ecosystem functioning. Monitoring their biodiversity and dynamics is essential for assessing ecosystem responses to diverse environmental drivers, including but not limited to climate change. Traditional phytoplankton analysis relies on inverted light microscopy (Utermöhl method), an accurate but time-consuming and resource-intensive technique. Moreover, typical sampling frequencies are not always adequate for detecting rapid ecological events, such as harmful algal blooms (HABs). To overcome these limitations, oceanographic research is increasingly adopting automated imaging instruments and machine learning algorithms. Among these technologies, the Imaging FlowCytobot (IFCB) combines flow cytometry with high-resolution imaging, accelerating data acquisition rates and enabling high-frequency observations of phytoplankton communities. However, the large volume of images generated requires training algorithmic workflows to automate taxonomic classification. This study focuses on the implementation, standardization, and preliminary evaluation of Random Forest classifier developed using IFCB images collected at the Promontory of Portofino eLTER (Long-Term Ecological Research) site (Ligurian Sea). Classifier performance was evaluated using precision, recall, and F1-score metrics. Although further optimization is needed, the classifier showed promising performance, with F1-scores near to 1 for morphologically distinct and homogeneous groups, whereas it becomes weaker for classes characterized by high internal morphological variability or for the rare taxa. This limitation is primarily due to the insufficient number of images available to adequately cover and represent all taxonomic categories. Future developments will focus on expanding and balancing the training dataset, improving classifier performance for underrepresented taxa, exploring the use of Convolutional Neural Networks (CNNs), and integrating the workflow into collaborative image classification platforms such as EcoTaxa.

Biodiversity patterns of pollinating insects in traditional ligurian agroecosystems: a case study from Portofino regional nature park

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The importance of pollinators in agriculture has been widely demonstrated by decades of research. However, due to modern, intensive farming practices, these vital organisms are facing significant challenges. In the Mediterranean region, olive groves and vineyards dominate the landscape and account for a large share of the economy but often support low pollinator diversity. Although neither crop depends directly on entomophilous pollination, recent studies have amply demonstrated that, for example, wine production and organoleptic qualities are positively influenced by the presence of pollinating insects. Moreover, implementing pollinator-friendly management across extensive areas of olive groves and vineyards can provide favourable habitats for pollinator biodiversity, providing food and nesting resources.In this case study, we focused on a Mediterranean agricultural environment that is highly distinctive as it is situated within the Portofino Regional Nature Park. This area is characterised by a mosaic of diverse habitats and has a long tradition of viticulture and olive growing deeply rooted in the local landscape. We monitored pollinators once a month for two consecutive years on a farm with established olive groves and vineyards, and an area where new vineyards and olive groves are to be planted following restoration of dry-stone traditional terraces. The aim is to study the pollinator insect communities and to support the development of tailored conservation management practices. The mosaic of microhabitats characterising the study area was found to be reflected in the differentiation of pollinator communities, with the established vineyard community being the most diverse compared to the other areas and the natural control area outside the farm. Even micro- scale, the diversity of native flora, microclimate and landscape conformation appear to shape pollinator communities. This paves the way for sustainable, pollinator-friendly agriculture models focused on the management of native flora within a traditional agricultural landscape.

New records of the deep-sea sponge *Stylocordyla pellita* (Topsent, 1904) from the Mediterranean Sea

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The stalked lollipop sponge *Stylocordyla pellita* (Topsent, 1904) is an Atlantic-Mediterranean deep-sea species rarely reported from the Azores Archipelago, the Aegean Sea, the northern Ionian Sea, the Strait of Sicily, the Tyrrhenian Sea, and the Ligurian Sea. Despite its apparently broad geographic range, the bathymetric distribution, habitat preferences, and ecological significance of this species remain poorly understood owing to the scarcity of records at bathyal depths.This study aims to provide an updated assessment of the distribution of *S. pellita* in the Italian seas, expanding current knowledge of its occurrence, bathymetric range, species associations and habitat preferences in the Mediterranean Sea.Data were collected within the framework of the MER Seamounts project through ROV surveys, conducted between March 2025 and April 2026 aboard the vessels *Ievoli Cobalt* and *Ievoli Relume*. Occurrences, depth, and associated habitat characteristics of *S. pellita* were recorded across seven seamounts in the Tyrrhenian Sea and the Strait of Sicily, and the number, density, and size of specimens were analysed. Three specimens were collected from different sites for taxonomic identification.The species was observed in 19% of 112 ROV dives at depths ranging from 239 to 946 m. It was mainly associated with hard substrates, often occurring alongside other sponges (cf. *Hamacantha (Vomerula) falcula,* cf. *Hexadella dedritifera, Phakellia* sp., and *Pachastrella* sp.), and deep-sea corals (Acanthogorgiidae*, Callogorgia verticillata, Swiftia sp., Parantipathes* sp.). Its abundance varied from isolated individuals and small patches to dense sponge grounds, reaching up to 14.6 col. m ^{2}.The present study improves the knowledge of *S. pellita* distribution in the North-central Mediterranean Sea, highlighting its wide occurrence and association with vulnerable deep-sea habitats.

Temporal dynamics of bathymetric centers of gravity and their relationship with environmental variables in gadiforms from the Strait of Sicily (GSA 16)

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Environmental variability, particularly changes in temperature and oceanographic conditions, can alter habitat suitability and drive shifts in the bathymetric distribution of demersal fish species. The Bathymetric Centre of Gravity (CoG) is a useful indicator for detecting temporal changes in species distribution along depth gradients. This study investigated temporal changes in the bathymetric distribution of the main gadiform species in the Strait of Sicily (GSA16): *Merluccius merluccius (*Linnaeus, 1758), *Phycis blennoides (*Brunnich, 1768), *Trisopterus minutuscapelanus* (Lacepède, 1800) and *Micromesistiuspoutassou* (Risso, 1827). Bathymetric CoG was calculated from MEDITS survey data and analysed in relation to environmental variables (temperature, salinity, oxygen, pH, and phytoplankton carbon) derived from the Copernicus. Among the species examined, only *P. blennoides* showed a significant temporal decrease in bathymetric CoG, indicating a shift towards deeper waters. In contrast, *M. merluccius* exhibited a stable bathymetric distribution, while the low abundance of *M. poutassou* and *T. minutuscapelanus* prevented reliable assessment of temporal trends. For *P. blennoides*, relationships between bathymetric CoG and environmental variables were explored. Because temperature, salinity and pH were strongly correlated, only temperature was retained to avoid collinearity. The decrease in bathymetric CoG was significantly associated with increasing deep-water temperature, suggesting redistribution towards deeper habitats. These species-specific responses may reflect differences in habitat preference, thermal tolerance and ecological plasticity. The stable CoG of the eurybathic *M. merluccius* suggests a greater capacity to cope with environmental change, whereas *P. blennoides* may track its preferred thermal habitat by moving deeper. In contrast, the decline of *M. poutassou* and *T. minutuscapelanus*, species associated with upper-slope and neritic habitats, could indicate a limited ability to respond to warming through bathymetric or latitudinal shifts. Further studies are needed to confirm these patterns.

Ecologia del suolo: dalla conoscenza alla gestione sostenibile

6

Coordinatori: Flora Angela Rutigliano, Giulia Maisto, Anna De Marco

The joint diversity of plant, fungal and springtail communities in urban ecosystems

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Recent studies demonstrated that urban environments, characterized by small-scale heterogeneity and intensive management practices, induce contingency in vegetation community assembly and shifts from niche-based to stochastic assembly processes. However, the extent to which this phenomenon affects the structural and functional relationships among different communities remains poorly understood. We hypothesized that trophic interactions may mediate the cascading of stochasticity to other communities. To this end, we studied the spatial variations in biodiversity of plants, fungi and springtails in an artificial urban lawn in the University of Salerno campus (southern Italy) across adjacent lime tree canopy and open lawn areas (transects of 12 plots each). In each plot, two soil cores for fungal analyses and two for springtail analyses were collected, whereas vegetation was surveyed within a 625 cm^2 phytosociological quadrat. Plant and springtail species were identified using dichotomous keys, whereas fungal taxa were identified through DNA metabarcoding. Functional traits were measured directly or obtained from the literature.Results highlighted significant ($P < 0.05$) relationships between springtail and fungal diversities, as assessed by generalized linear models, and significant ($P < 0.001$) correlations between plant and fungal diversities, according to Mantel tests, suggesting interdependence among the three investigated communities. Given this interdependency, we supposed that vegetation contingency affects fungal community constraining in turn springtail biodiversity. Moreover, the high spatial variability in all the communities, coupled to the dependence of fungi and springtails upon environmental conditions, suggest that vegetation stochasticity cascades down to increase variability of the latter through environmental filtering at micro-scale. Such hypothesis is supported by co-occurrence network analyses that indicate higher intra-system heterogeneity and stochastic assembly processes.Collectively, findings coherently indicate that contingency in vegetation controls the structural and functional diversity of fungal and springtail communities, resulting in high heterogeneity at micro-scale deriving from fine-scale environmental filtering mediated by trophic interactions.

Soil property changes along an ecological succession from gap areas to low and high Mediterranean maquis in a nature reserve of Southern Italy

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Ecological succession influences vegetation structure, ecosystem functioning, and soil properties. This study evaluated soil changes along a Mediterranean successional gradient, from open gaps (G) to low maquis (LM) and mature high maquis (HM), in the Castel Volturno Nature Reserve (CE, Italy). Soil samples (0–10 cm) were collected over two consecutive years in early spring and early summer. Physicochemical parameters (soil organic matter-SOM, total C and N, pH) and biological indicators (soil respiration-Resp, microbial biomass-Cmic, metabolic quotient-qCO_2, mineralization rate-qM, and functional diversity) were analyzed to assess the effects of succession on soil quality.The results revealed progressive changes in soil functions along the vegetation successional gradient, with increasing vegetation complexity. SOM and C/N increased progressively along the successional gradient, and a significant decline was observed during summer in both LM and HM. Soil pH also increased significantly along the successional sequence. In contrast, N decreased from G to HM and showed significant seasonal variation only in LM soils, with lower values recorded during the summer sampling period. The quantity and quality of soil organic matter strongly influenced the microbial component, affecting both Cmic and functional diversity. Both variables increased along the successional gradient, reaching their highest values in HM soils, particularly during the summer sampling period. In contrast, Resp did not exhibit a clear trend associated with the successional gradient. Both the qCO_2 and qM were highest in LM soils.These findings demonstrate that ecological succession promotes the simultaneous recovery of soil functions and plant functional diversity in Mediterranean shrublands. The increasing complexity of vegetation communities contributes to improved soil fertility, C storage, and ecosystem resilience, highlighting the importance of conserving mature maquis and facilitating natural successional processes in restoration strategies aimed at mitigating the impacts of land-use change and climate change in Mediterranean environments.

Effects of land uses and associated disturbance regimes on soil microbial networks in Mediterranean mountain area

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Soil is an important reservoir of biodiversity, and its microbial communities play a key role in sustaining ecological functions essential for soil fertility and ecosystem stability; however, land use and management practices, such as grazing and mowing, can significantly influence the structure and functioning of these communities. The aim of this study was to assess the effects of the main land uses in the Matese mountain area (Mediterranean region) - pasture, meadow, and forest - with particular emphasis on the impacts of the associated management practices, namely grazing in pasture and mowing in meadow, on soil microbial activity, diversity, and community interactions. Soil physico-chemical parameters, microbial biomass, enzymatic activities involved in major biogeochemical cycles, and microbial diversity were analyzed. In addition, microbial co-occurrence networks analysis was performed to investigate network complexity and patterns of microbial interactions. Forest soil exhibited higher microbial biomass, enzymatic activity, and more complex microbial co-occurrence networks, reflecting a more stable ecosystem. In contrast, pasture and meadow soils showed reduced microbial networks complexity, suggesting that management-related disturbances influence microbial interactions. Despite this, meadow soil maintained high microbial diversity; this pattern is consistent with the intermediate disturbance hypothesis, which predicts that moderate levels of disturbance can favour species coexistence by reducing competition. Overall, these results highlight that the adopted management practices and disturbance regimes contribute to maintaining microbial biodiversity and ecosystem functional stability.

Interactive effects of biochar and *Lumbricus terrestris* on the fate and ecotoxicity of difenoconazole in agricultural soils

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Difenoconazole is a persistent triazole fungicide frequently detected in agricultural environments, where its environmental fate is influenced by soil amendments and soil biota. This study investigates the interactive effects of mealworm frass-derived biochar and the anecic earthworm *Lumbricus terrestris* on the fate of difenoconazole and soil ecological functions. Using two-dimensional terraria to simulate planar soil profiles, a 30-day mesocosm experiment evaluated eight treatment combinations in a full factorial design. Four amendment treatments (control, 5 mg kg ¹ difenoconazole, 2% (w/w) biochar, and a combination of both) were each tested in the presence and absence of *Lumbricus terrestris*. Soil responses were assessed by measuring nutrient cycling (C, N and P) and a suite of enzyme activities (e.g. β-glucosidase, urease and catalase) within earthworm casts, the drilosphere and bulk soil. Concurrently, the ecotoxicological response of *Lumbricus terrestris* was evaluated using oxidative stress biomarkers, including GST, GR, GPx, lipid peroxidation (MDA), and mitochondrial oxidative phosphorylation (OXPHOS) in the body wall, gastrointestinal tract and seminal vesicles. This research aims to elucidate how biochar alters fungicide bioavailability and how earthworm bioturbation influences contaminant distribution and microbial interactions. The findings provide critical insights into the potential of biochar–fauna interactions for the remediation of pesticide-contaminated agricultural soils while preserving essential ecosystem services.

Improving soil water retention through bacterial biopolymers, cyanobacteria and seaweed biomass

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Prolonged increases in droughts and heatwaves globally affect evapotranspiration rates, reducing soil water availability, thereby altering ecosystem functioning, biogeochemical cycles, and plant-soil interactions. This study examined the potential of marine-derived additives as a sustainable strategy for improving soil water dynamics. Novel biopolymers from thermophilic bacteria, including six exopolysaccharides (EPS1-EPS6) and four biosurfactants (BS1-BS4), and biomasses from seaweeds (BM1-BM4) and marine cyanobacteria (BC1-BC2), were investigated for their wetting properties and effects on water retention at a laboratory-scale soil model. Wetting properties, including reduction of contact angle (RCA) and atmospheric-air moisture uptake (AMU), were monitored for 36 hours at 30 °C. The effect on soil water retention was evaluated by measuring water loss in soil microcosms (10 g of soil and 10 ml of water) treated with each biopolymer/biomass (at 0.5 or 1% w/w) and kept at 22 °C until complete evaporation occurred (about 200 hours).BC2 derived from *Leptolyngbya* sp. 43.3 s was the best wetting agent (RCA =39%), while the EPS4 produced by Bacillus horneckiae SBP3 was the best humectant (AMU =180%). Furthermore, soils amended with bacterial biopolymers (EPS4, EPS5, EPS6, BS1 and BS3), as well as biomasses derived from cyanobacteria (BC2) and seaweed (BM1–BM4), produced better improvement in soil water retention, with marked effects at the concentration of 1% w/w. The lipopeptide BS1 was the most effective at reducing water loss during a specific time of 96-125 hours at both concentrations.These findings emphasized the ecological potential of these materials as nature-based solutions to improve soil-mediated ecosystem resilience to drought under climate change. However, future studies need to verify if these long-term positive effects persist.PRIN 2022 PNRR "SeaForSoil: Marine biopolymers to develop novel strategies to increase the water retention in soil for sustainable farming systems under water constraints" (P2022M7S2J), funded by Italian Ministry of University and Research.

Microbial characterization of waste-derived amendments and their impact on soil microbial communities in Mediterranean ecosystems

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Soils in the Mediterranean region are affected by climatic conditions that increase the risk of organic matter depletion and desertification. Intensive land use exacerbates this susceptibility, leading to soil degradation, biodiversity loss and reduced ecosystem functionality. Organic soil amendments, rich in stable organic matter, represent a sustainable strategy for restoring degraded soils. Amendments derived from waste materials align with circular economy principles; however, an integrated assessment of their ecological effects on the soil-plant system is required. Particular attention should be given to exogenous microbial groups introduced into the soil, as they can reshape the edaphic microbial communities.This research, conducted within the EMBRACE National Interest Project (PRIN 2022 PNRR), characterised the microbial communities associated with waste-derived amendments for ecological restoration purposes — a vermicompost made from marine waste and a sludge-based amendment, as well as their variants enriched with natural zeolites. Their effects on soil microbial communities were also investigated six months after application on amended Mediterranean soils. The study focused on spore-forming bacteria, siderophore-producing bacteria, actinomycetes, phosphorus-solubilising bacteria, and fungi. The antibiotic activity of all isolates against the phytopathogenic fungus *Rhizoctonia solani* was also assessed to evaluate their potential contribution to revegetation through biocontrol.The results revealed significant differences in microbial community composition among amendments, mainly driven by their organic composition. Following soil application, these differences resulted in measurable, although less pronounced, changes in soil microbial communities. However, phosphorus-solubilising bacteria, despite being abundant in several amendments, were not detected in the amended soils. Natural zeolites reduced organic fraction effects while promoting some microbial groups. Significant differences in antibiotic activity against *R. solani* were observed among treatments, with promising results for spore-forming bacteria.Overall, these findings provide valuable insights into assessing spontaneous revegetation through soil amendments in the context of ecological restoration, while offering useful information for future agronomic applications.

Urban soil functioning beneath *Quercus ilex* canopies: links between particulate deposition, platinum enrichment, and microbial activity

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Urban soils are dynamic systems increasingly affected by atmospheric inputs and anthropogenic pressures. Traffic-derived particulate matter (PM) and associated trace metals, including platinum (Pt) from catalytic converters, represent emerging contaminants with potential impacts on soil ecological functioning and the sustainability of urban spaces. This study investigates soil chemical and biological responses under *Quercus ilex* L. canopies along an urban-to-rural gradient in the Caserta area (Southern Italy), including a high-traffic road with stop-and-go conditions, an urban canyon-like square, and a rural reference site. The aim is to evaluate how atmospheric deposition influences soil contamination patterns and microbial functional quality in a context relevant for sustainable soil management. Topsoil samples (0–5 cm) were analyzed for Fe, Zn, Cu, and Pt concentrations as indicators of traffic-related contamination. Soil biological functioning was assessed through dehydrogenase activity as a proxy of microbial metabolic potential. Leaf particulate deposition was used as an indirect indicator of air pollutant load and interception by the holm oak canopy. Results showed a clear gradient in pollutant concentrations, with increasing accumulation of Fe, Zn, Cu, and Pt in soils from rural to highly-traffic sites. Platinum exhibited the highest sensitivity to traffic intensity, acting as a strong tracer of vehicle emissions. Soil microbial activity showed an inverse relationship with metal enrichment, indicating a progressive decline in soil functional quality under higher contamination loads. Significant correlation patterns between contaminant accumulation and reduced enzyme activity highlight a functional link between atmospheric deposition and soil ecosystem health. These findings suggest that urban soils beneath tree canopies act as active interfaces for pollutant transfer rather than passive sinks. Integrating emerging contaminants such as platinum into soil ecological assessments can improve understanding of urban soil functioning and support evidence-based strategies for sustainable urban green and soil management.

Wildfire effect on organic carbon stock in trees and soil of Southern Italy pine forest

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Severe wildfires, which occur frequently in Mediterranean regions, could affect the ecosystem service of carbon sequestration in the plant-soil system for a period of time that may vary depending on the considered ecosystem. In the framework of PRIN 2022 "FIRE LEGACIES AND RESILIENCE OF SOIL AND PLANT COMMUNITIES IN MEDITERRANEAN COASTAL FORESTS (FLER_MeCoFor)" (20222CT8J3), the effect of wildfires on organic carbon stock in trees and soil was assessed in a Southern Italy coastal pine forest of EU conservation interest (SAC IT9130006) historically prone to wildfires over a time span ranging from 4 to 42 years.The carbon stock in the standing above-ground tree biomass (CT) and soil organic carbon stock (SOC) in organic layer (O-layer) and mineral soil (0-5 cm and 5-10 cm S-layers) were analysed in seven stands differing for the time elapsed since fire (4, 7, 12, 30, 32, 38, and 42 years), in each of them the burned plot was compared with unburned control plot. No standing trees were detected in plots burned from 4 up to 12 years; by contrast, trees were found in plots burned from 30 up to 42 years, but the CT stock was generally significantly lower than in control up to 42 years after the fire. Compared with the control, a significant reduction in SOC was observed in O-layer and S-layer (0-5 cm) of the plots burned from 4 to 7 years. The SOC of O-layer was still generally significantly reduced from 12 to 42 years after the fire, whilst the SOC of the S-layers showed no significant differences between burned and control plots during the same period. The data show a long-term decline in the C sequestration ecosystem service within standing above-ground tree biomass and soil, suggesting a low resilience of this service to wildfires in the studied ecosystem.

Improving soil quality with waste-derived vermicompost as a nature-based solution

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Within the One Health approach, soil health plays a central role in sustaining ecosystem functioning, environmental quality, biodiversity conservation, and human well-being. Several of these functions are driven by soil microbial community, mediating nutrient cycling, plant productivity, carbon sequestration and pollutant biodegradation.This research investigates the potential of innovative vermicomposts as sustainable strategies for the amendment of agricultural and urban soils. Overall, the project aims to provide scientific evidence supporting the use of waste-derived vermicompost as a nature-based solution in a framework of circular economy. To this aim, five different vermicomposts produced from *Posidonia oceanica* residues (66%) mixed with different other organic matrices (33%), namely buffalo slurry, digestate derived from buffalo slurry, buffalo manure, digestate derived from buffalo manure, and buffalo whey, will be tested. These treatments, together with untreated controls, will be evaluated in two experimental sites in the Campania region (Southern Italy): an agricultural field, in order to assess soil fertility and functionality, and an urban soil, to evaluate soil restoration processes and spontaneous establishment of vegetation following vermicompost applications. Changes in soil physico-chemical and biological properties will be seasonally monitored following amendment applications. Furthermore, complementary experiments will be conducted under controlled environmental conditions in a climate chamber.The preliminary characterization of the two soils, based on the measurement of several physico-chemical and biological parameters, including organic matter, pH, water holding capacity, microbial community (investigated through the analyses of several enzyme activities linked to biogeochemical cycles, as well as through DNA extraction) provides a baseline framework for evaluating the effectiveness of the innovative vermicomposts along the time. The obtained information will be employed to assess the improvement of soil quality, in terms of enhanced microbial biodiversity and functionality (in relation to nutrient cycling and carbon dynamics), while supporting crop productivity in agricultural soils and vegetation establishment in urban soils.

Valorization of seaweed waste biomass to improve hydrating properties and quality of soil

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The valorization of invasive biomasses (BMs), periodically removed and treated as special waste, could contribute to the development of new strategies to increase soil water retention, especially in scarcely hydrated conditions. In the framework of PRIN PNRR 2022M7S2J SeaforSoil project, biomasses of *Agardhiella subulata* (Rhodophyta) (BMAs), *Ulva ohnoi* (Chlorophyta) (BMUo) and *Chaetomorpha aerea* (Chlorophyta) (BMCa), from the brackish lake Ganzirri (Lagoon of Capo Peloro, Messina, Italy) and their phycocolloids (PCs) were explored as novel wetting and humectant agents. To these purposes, we evaluated the BMs ability to improve soil water retention and overall soil quality, as well as their potential ecotoxicological impacts, in order to evaluate their use in agriculture.The BMs, possessing different sulphated PCs, exhibited different hydrating performances, with BMUo (ulvan rich) being the most efficient wetting agent (reduction in water contact angle from 72° to 56°), which is proposed for the recovery of high degraded soils. BMAs (κ-carrageenan rich) was the best humectant agent (moisture uptake 25.7%) and it was able to increase soil water retention under simulated high solar irradiance (2.2%). The addition of the BMs did not cause toxic effects on i) the *Vibrio harveyi* luminescence, toxicological ii) *Lepidium sativum* L. and iii) *Sorgum saccharatum* L., and did not reduce the growth of *Lactuca sativa* L. Moreover, they efficiently increased the plant-available water content in soil of approximately 2-fold as compared to the unamended ones. According to the soil quality index, the addition of BMUo improved both the properties and functions of the degraded soil and did not affect them during lettuce cultivation. As not toxic and eco-friendly hydrating agents, the macroalgae biomass can be proposed as a dual-purpose strategy: in reducing the ecological pressure of allochthonous species and in improving soil quality for sustainable agriculture, especially in degraded soils.

Marine-derived bioproducts modulate soil nitrogen cycling and plant functional responses

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Marine-derived bioproducts are increasingly proposed as sustainable soil amendments influencing nutrient availability, including nitrogen which is essential for plant nutrition and development, microbial functioning, and soil quality. The study aimed to identify which marine-derived bioproduct most effectively promoted soil nitrogen availability and to determine whether these changes would reflect in shifts in nitrogen-cycling microbial functional groups, consequently, affecting lettuce growth and functional traits. Therefore, an agricultural soil was amended at 1% (w/w) with the exopolysaccharide produced by *Geobacillus thermodenitrificans* B3-72 (EPS), the biosurfactant produced by *Bacillus* sp s7s-1 (BS), cyanobacterial biomass from *Leptolyngbya* sp. (BC), and macroalgal biomass from *Ulva ohnoi* (BM), unamended soil served as the control. Bulk-soil and *Lactuca sativa*-planted mesocosms were maintained for 60 days under controlled conditions. Soil nitrogen forms concentrations (total N, NH -N, NO -N), DNA yield, eubacteria abundance, and genes associated with N fixation (*nifH*), ammonia oxidation (bacterial *amoB* and archaeal *amoA*), and denitrification (*nirK*) were quantified. Plant shoot and roots biomasses, rosette diameter and leaf functional traits were also assessed. The results showed that, in bulk-soil mesocosms all the amendments increased soil NO -N; BS and BC increased soil total N and NH -N; BC increased DNA yield and total bacterial abundance; BS and BM increased *nifH* abundance. In planted mesocosm, the amendments reduced the increase of soil NH -N concentrations but BS and BC further increased soil NO -N concentrations, suggesting that the presence of *Lactuca sativa* L. exerted a stronger effect on nitrogen-cycling microorganisms than that observed with the only addition of amendments, largely masking treatment-specific responses. EPS produced the broadest positive response on plant growth, whereas BS resulted in the lowest shoot and root biomass and rosette diameter. Overall, EPS was the most promising amendment for plant growth, while BC provided the most balanced response across soil N status and microbial abundance.

Ecologia del paesaggio, dinamiche spazio-temporali e big data ambientali

7

Coordinatori: Laura Carranza, Irene Petrosillo, Emilio Padoa-Schioppa

Opportunities and limitations of AI-assisted image analysis in the study of pioneer benthic communities in the Ross Sea, Antarctica

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The Southern Ocean, characterized by high levels of endemism and ecological diversity, is particularly vulnerable to climate-driven environmental change. Pioneer benthic species represent effective indicators of ecosystem responses, as they are among the first organisms to react to changes in seasonality, trophic availability, and physical conditions. In recent years, artificial intelligence-based photoanalysis tools have improved the efficiency of quantitative benthic image analysis; however, most existing models focus on macro- and megabenthic communities from tropical and temperate environments and are rarely used to characterize polar communities. Automated semantic segmentation models for pioneer benthic species colonising Autonomous Reef Monitoring Structures (ARMS) deployed in the Ross Sea (Antarctica) were developed and validated using TagLab, an AI-based semantic segmentation platform. Three independent models were trained on the dominant bryozoan taxa, *Micropora* sp., *Camptoplites* spp., and *Beania erecta* Waters, 1904, collectively accounting for over 80% of the total annotated surface area. Models achieved high segmentation performance (accuracy: 0.939-0.982; mIoU: 0.890-0.965) and reduced analysis time by approximately 90% compared to manual segmentation workflows. Percent cover estimates obtained from automated and manual segmentation showed strong agreement across all taxa and immersion intervals (Spearman $\rho > 0.98$). Estimates of colony abundance, based on automated individual colony detection and counting, proved less robust, with discrepancies attributable to species-specific morphological artefacts affecting automated delineation. These findings represent a first validation of AI-assisted semantic segmentation for quantitative monitoring of pioneer benthic biodiversity in polar environments, yielding promising results that support its broader applicability to additional taxa, ARMS deployments and sites across the Southern Ocean.

Spatiotemporal changes in *Lithognathus mormyrus* (Sparidae) (Linnaeus, 1758) abundance in a Mediterranean coastal lagoon

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Coastal lagoons and adjacent marine areas form dynamic habitat mosaics, providing essential ecosystem services shaped by temporal and spatial fluctuations of local biotic and abiotic factors. The present study investigated the spatiotemporal variation in the abundance of *Lithognathus mormyrus* (Linnaeus, 1758) in Faro Lake (Capo Peloro Coastal Lagoon, Sicily), and two adjacent permanently or seasonally connected areas, the Strait of Messina and the Tyrrhenian Sea, respectively. The investigation was performed over two annual cycles (2022/2023 and 2024/2025), by combining monthly underwater visual census (UVC) data with in situ measurements of temperature and salinity. Generalized Linear Modelling (GLM) was applied to evaluate the environmental factors driving the abundance of *L. mormyrus* juveniles and adults in the three sampling sites (Faro Lake, Strait of Messina and Tyrrhenian Sea), fitting species abundance as response variable, and temperature and salinity as explanatory ones. A total of 10391 individuals were recorded across 48 UVCs performed in the three sites. Juveniles were more abundant during colder periods, especially in Faro Lake, whereas adults increased during warmer periods and were more associated with the adjacent marine sectors. Model selection based on AIC identified GLM with negative binomial error distribution as the most appropriate model for abundance data. The selected model showed a strong response to temperature and more heterogeneous salinity effects. Overall, the results highlighted that Faro Lake serves as an interconnected ecological mosaic rather than an isolated habitat, with environmental gradients shaping *L. mormyrus* distribution differently according to life stage. The marked segregation between juveniles and adults suggested the ecological relevance of Faro Lake as a key shallow habitat for early stages, while adjacent marine sectors appeared more exploited by adults during warmer periods. This study provides a non-invasive framework to evaluate the ecological roles of Mediterranean transitional ecosystems, offering baseline information for conservation and management.

LINK: a circuit-based framework integrating habitat suitability and cadastral fragmentation for urban wildlife corridor prioritisation

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Most ecologically optimal corridors cross privately or institutionally owned parcels, involving many stakeholders. Furthermore, least-cost connectivity models often ignore land ownership, creating a gap between theory and implementation. To narrow this gap, we developed LINK (Landscape Interconnectivity via Niche models and Kirchhoff current theory), a framework that integrates cadastral fragmentation as a socio-institutional layer within standard functional-connectivity modelling, introducing the conceptual novelty that the socio-institutional layer cannot be kept aside. As cadastral fragmentation can either increase or reduce biophysical resistance, we developed the Cadastral Fragmentation Index (CFI), derived from cadastral-parcel data, to quantify parcel fragmentation. When added to the resistance surface, the CFI reveals whether and where priority pinch points shift in planned corridors, while comparison with CFI-free scenarios quantifies how strongly cadastral fragmentation affects corridor feasibility.Our focal species is the European hedgehog (*Erinaceus europaeus*), a peri-urban ground-dwelling mammal. Using open occurrences from Global Biodiversity Information Facility (GBIF), we fitted a habitat suitability model (HSM, MaxEnt) and transformed suitability into a telemetry-free resistance surface. We solved connectivity with Circuitscape to identify pinch points between Natura 2000 nodes.We first tested LINK on two nodes near Naples (Astroni-Camaldoli). Adding the CFI increased effective resistance between nodes monotonically with its weight (from +150% to +316%) and relocated about 60% of the corridor's pinch points, indicating that cadastral fragmentation reshapes not merely the cost but the spatial priorities of corridor implementation. A second Special Area of Conservation near Rome (Tivoli) is currently being investigated to assess LINK's transferability. Because cadastral parcels are an INSPIRE Annex I (2007/2/EC) harmonised dataset across the European Union, the approach may be transferable beyond Italy to other member states. Built from open data, LINK integrates biophysical and socio-institutional information to prioritise the planning of feasible corridors.

Ecologia delle invasioni biologiche: dinamiche, impatti e prospettive di gestione

8

Coordinatori: Antonia Concetta Elia, Paolo Pastorino, Paolo Povero

Rapid detection of the invasive Atlantic blue crab *Callinectes sapidus* using a LAMP assay

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Molecular tools are reshaping biodiversity monitoring by enabling the detection of species from trace DNA released into the environment. In this context, environmental DNA (eDNA) represents a sensitive and non-invasive approach for surveying species presence in environmental matrices, complementing other conventional surveys. eDNA analysis is particularly suited for aquatic environments and can be applied to a wide range of purposes, including the detection and monitoring of invasive species. Indeed, when coupled with targeted amplification assays, eDNA-based surveillance can provide rapid presence/absence information to support early warning systems, management decisions, and mitigation actions.Among targeted molecular approaches, loop-mediated isothermal amplification (LAMP) is particularly suitable for rapid eDNA detection because it does not require thermal cycling, can be performed with simple equipment, and shows high sensitivity and specificity. These features make LAMP a promising tool for scalable surveillance programs, especially in coastal and transitional environments where fast detection is crucial to guide timely management actions.Here, we developed and validated a LAMP-based assay targeting a short mitochondrial DNA region for the rapid detection of the Atlantic blue crab *Callinectes sapidus*, an invasive crab that is currently expanding across the Mediterranean basin. The species has become established in several Mediterranean areas, where its spread has been associated with brackish lagoons, estuaries, shallow coastal habitats, and areas of high benthic productivity. Its broad diet, predatory behaviour, and interactions with fisheries raise ecological and socio-economic concerns, making this species a priority target for early detection and monitoring. The assay was designed to support fast, species-specific detection of *C. sapidus* from eDNA samples, providing a practical tool for the surveillance of invaded and at-risk Mediterranean habitats. Overall, this approach can contribute to more timely and effective monitoring of *C. sapidus* and support rapid management responses in areas vulnerable to its establishment and spread.

Rapid degradation of *Silurus glanis* environmental DNA: implications for species detection and monitoring in freshwater systems

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Quantitative real-time PCR (qPCR) analysis of environmental DNA (eDNA) has become a sensitive and cost-effective tool for monitoring freshwater ecosystems and for the early detection of invasive fish species. The European catfish (*Silurus glanis* L.) is one of the largest apex freshwater predator worldwide and can exert a significant negative impact on local fauna in non-native areas, therefore its early detection is crucial for effective management. In this study, qPCR and standardized sampling methods (i.e., multi-mesh gill nets, both benthic and pelagic, and point-abundance electrofishing) were compared to assess the presence of *S. glanis* in 15 lakes in northern Italy. The species was absent in eight lakes, whereas it was detected in seven lakes using standardized sampling methods. Among these, eDNA analysis detected the species in only one lake, suggesting limited persistence of its DNA in the environment. To further investigate this aspect, we experimentally evaluated the release and degradation dynamics of *S. glanis* eDNA in indoor tanks. Our results show that eDNA concentration declined rapidly after fish removal, and *S. glanis* became undetectable by qPCR within six days. Our results suggest that, although eDNA analysis is a promising approach, it cannot yet replace standardized sampling methods for detecting and monitoring elusive fish species. Furthermore, understanding the release and degradation dynamics of genetic materials in the environment is crucial for the correct interpretation of eDNA results.

The Atlantic blue crab (*Callinectes sapidus* Rathbun 1896) in Sardinian coastal lagoons: distribution, impacts, and prospective management strategies

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Callinectes sapidus is an invasive species in the Mediterranean Sea, causing significant impacts on native biodiversity and small-scale fisheries. In Sardinia, the species was first recorded in 2017 and has rapidly spread to several coastal lagoons. To study its expansion and support management actions, the Autonomous Region of Sardinia promoted a scientific monitoring program aimed at assessing its distribution, abundance, and population dynamics in 14 lagoons under regional concession. The monitoring programme was carried out through a coordinated effort between the University of Cagliari and Sassari. Here, we report data from monthly samplings conducted over a 19-month period in seven lagoons monitored by the University of Cagliari: two on the west coast (S'Ena Arrubia, Cabras), two on the south (Santa Gilla, Porto Pino) and three on the east (Colostrai, Feraxi and San Giovanni). Specimens were collected using baited pots equipped with four entrances and double chamber. The sampling design was based on a Triple-Catch-Unit (TCU), consisting of three traps arranged in a triangular configuration. The number of TCUs varied on the lagoon surface area. Traps were left fishing for 24 h to standardize catch per unit effort (CPUE).The study assessed CPUE, population structure and reproductive dynamics across spatial and temporal scales. Among the investigated lagoons, Colostrai showed the highest CPUE, whereas no individuals were recorded in Cabras throughout the monitoring period. Our results highlight the presence of a stable population, with a marked presence of ovigerous females occurring from April to October, indicating an extended reproductive period. Juveniles were mainly observed from March to July in stations located farther from lagoon sea inlets. The sex ratio favored males, except in Santa Gilla.These findings provide useful information for the development of science–based management strategies of the species, aimed at reducing the ecological and economic impacts of *C. sapidus*.

Automated zooplankton analysis: monitoring of the non-indigenous species (NIS) *Paracartia granigrani* (SARS G.O., 1904) in the port of Genoa, 2024–2025.

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Monitoring plankton biodiversity is a key tool for assessing the status of marine ecosystems, particularly in port areas subject to strong anthropogenic pressure and the introduction of non-indigenous species (NIS) through ballast water. In the Port of Genoa, the presence of the non-indigenous copepod *Paracartia grani grani* (Sars G.O., 1904) has been known since 1997.In accordance with Descriptor 2 of the Marine Strategy Framework Directive (2008/56/EC), monitoring was conducted at Marina Fiera, Genoa, with two main objectives: (i) to assess the presence and seasonal variability of *P. grani grani*, and (ii) to test the effectiveness of a screening protocol based on optical imaging (ZooScan) for detecting NIS.Zooplankton samples were collected on a monthly basis during the 2024–2025 period, along with the main physicochemical parameters of the water column. Samples were subsequently digitised, and taxonomic identification was performed using a semi-automated workflow combining artificial intelligence algorithms with expert visual validation.Our results confirm the seasonal presence of *P. grani grani* from August to October period, in agreement with previous observations, while the species was absent during the rest of the year. This seasonal pattern suggests the possible presence of resting stages in the sediments, which represent a potential target for future studies.The semi-automated approach allowed the analysis of the entire dataset, substantially reducing processing time compared with traditional methods and producing a permanent digital archive. These results highlight the potential of optical imaging and semi-automated classification as a rapid and efficient tools for monitoring NIS in port environments.

Habitat heterogeneity and salinity gradients shape the establishment of the invasive blue crab *Callinectes sapidus* in western Sicily

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The blue crab *Callinectes sapidus,* native to the western Atlantic, is one of the most successful marine invaders in the Mediterranean Sea, where transitional waters may function as key invasion landscapes. However, the ecological mechanisms shaping its local persistence in heterogeneous lagoon-channel-salt-pan systems remain poorly understood. We investigated the spatial distribution, population structure and reproductive evidence of *C. sapidus* in two coastal wetland systems of western Sicily, Italy: the Stagnone di Marsala lagoon and the Trapani salt-pan/channel complex. Monthly monitoring was conducted throughout 2025 using standardized baited traps combined with environmental measurements, enabling the assessment of habitat-specific abundance patterns, seasonal dynamics and population traits. *C. sapidus* was recorded at most monitored sites, with catches strongly structured by habitat type and environmental gradients. Abundance was highest in lagoon habitats, where spring-summer peaks were observed, whereas the channel showed lower but persistent year-round occurrence. Salt-pan habitats supported lower abundances but hosted larger individuals, suggesting habitat-specific filtering of population structure. A negative relationship between salinity and trap-level abundance indicated that hypersaline conditions may constrain densities, whereas sheltered lagoon sectors appear to provide favorable conditions for persistence. The population showed a consistent male bias, together with the co-occurrence of adults and juveniles. Reproductive activity was supported by ovigerous females across multiple months and egg developmental stages, primarily in lagoon sites, indicating an extended reproductive window.

Ecological epidemiology of the invasive pumpkinseed (*Lepomis gibbosus*) in northwestern Italy: implications for pathogen circulation and zoonotic risk

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Lepomis gibbosus is one of the most widespread invasive freshwater fish species in Europe. Its ecological plasticity, broad trophic niche, and high adaptability facilitate its establishment in lentic ecosystems, where it may alter native communities and contribute to pathogen circulation. Besides its ecological impacts, this species may act as an epidemiological reservoir for infectious agents of relevance to wildlife and public health. Understanding its health status is therefore essential for assessing the ecological consequences of biological invasions. This study evaluated the sanitary status of pumpkinseed populations inhabiting ponds within the Crava Morozzo Nature Reserve and Madonna del Lago (Piedmont, NW Italy) during 2024-2025. At Madonna del Lago, fish sampling in 2024 preceded the complete drainage of the pond in 2025 as part of an invasive species eradication programme. Bacteriological analyses were performed on kidney, eye, and brain samples, while parasitological examinations were carried out on all collected specimens. Bacteriological investigations mainly revealed environmental bacterial communities together with opportunistic or potentially pathogenic taxa, including species belonging to the genera *Carnobacterium* and *Pseudomonas*. Parasitological analyses detected the zoonotic nematode *Eustrongylides excisus* in a limited number of specimens collected from Crava Morozzo in 2024. Although prevalence was low, the occurrence of this parasite confirms the involvement of *L. gibbosus* in the maintenance of pathogen life cycles within freshwater ecosystems. Our findings highlight the importance of integrating ecological epidemiology into invasive species monitoring programmes. Health surveillance of non-native fish provides valuable information on pathogen circulation, potential transmission to native fauna, and emerging zoonotic hazards. This integrated approach supports biodiversity conservation, invasive species management, and ecosystem health assessment within a One Health framework.

Capitale naturale, servizi ecosistemici e contabilità ambientale

9

Coordinatori: Pier Paolo Franzese, Fausto Manes, Chiara Paoli, Paolo Vassallo

Macrozoobenthic community associated with a *Cystoseira sensu lato* marine forest of the Cilento coast (Italy)

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Cystoseira sensu lato (*s.l.*) forests are among the most complex and productive habitats along the rocky shores of the Mediterranean Sea. These habitats provide many ecosystem services, including carbon sequestration and coastal protection, and due to their three-dimensional structure and ecological role provide shelter and trophic resources for a wide range of benthic organisms. Indeed, although being poorly studied, macrozoobenthic communities associated with *Cystoseira s.l.* forests are considered a key component of biodiversity in Mediterranean coastal ecosystems and can provide valuable information for assessing the ecological status of these habitats.This study aimed to characterize the composition and diversity of the macrozoobenthic assemblages associated with *Cystoseira s.l.* forests in Santa Maria di Castellabate Marine Protected Area (Tyrrhenian Sea, Southern Italy). Samples were collected in January 2024 using the suction-brush technique, at three stations with three replicates per station and at a depth of 6.5 m. Algal material and associated fauna were sorted and macrozoobenthos was identified, reporting its abundance, taxonomic richness, Shannon’s diversity index, and Pielou’s evenness index. A total of 6 taxa were identified. Crustacea, Polychaeta, and Mollusca were the most abundant groups. Specifically, Crustacea accounted for 62% of the total abundance, followed by Polychaeta (24%) and Mollusca (10%). The mean values of the Shannon’s diversity index and Pielou’s evenness index among samples were 1.07±0.25 and 1.37±0.32, respectively. The results showed that three-dimensional *Cystoseira s.l.* forests support diverse biological communities. This confirms the role of *Cystoseiras.l.* as habitat-former, sustaining complex communities and enhancing the resilience of coastal habitats. Their conservation is therefore essential for preserving Mediterranean marine biodiversity.

Monitoring the temporal evolution of *Posidonia oceanica* banquettes: integrating historical imagery and coastal CCTV observations

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Coastal management in the Mediterranean often prioritises beach usability for tourism over ecosystem functioning, leading to the routine removal of the stranded seagrass biomass. This reflects a broader mismatch between short-term tourism demands and the sustainable management of coastal ecosystems. However, *Posidonia oceanica* banquettes, accumulations of dead leaves along shorelines, play a key role in coastal protection by reducing coastal erosion, retaining sediments, and storing carbon. Their systematic removal and disposal as waste can therefore undermine coastal resilience and long-term sustainability.In this context, we analyse nearly two decades (2009-2025) of banquette extent at Maltese beaches using historical Google Earth Pro imagery, comparing seasonally groomed sites against those left undisturbed. Preliminary results reveal that Xatt l-Aħmar (Gozo), never groomed, showed the most stable deposits (228-349 m²), while Pembroke, also not groomed, displayed the highest variability of all sites (294-1677 m²). Among groomed sites, St. Thomas Bay fluctuated between 485 and 906 m², settling around 580 m² recently, while Għajn Tuffieħa's sparse record (524 to 267 m²). Xemxija, though ungroomed, oscillated considerably (147-800 m²).To overcome the discontinuous nature of satellite imagery, this study proposes the deployment of coastal CCTV cameras to provide continuous, high-frequency monitoring of banquette dynamics. The imagery will be integrated with wave, wind, and storm data obtained from the Copernicus Marine Service to investigate the environmental drivers influencing banquette accumulation and erosion. The monitoring programme will be complemented by field and laboratory analyses. Sediment samples collected from groomed and non-groomed beaches will be analysed to determine sediment organic carbon content, grain-size distribution, and heavy metal concentrations. By integrating historical satellite imagery, continuous CCTV monitoring, hydrodynamic data, and sediment analyses, this study aims to provide an evidence-based framework for understanding *P.oceanica* banquettes dynamics and supporting sustainable coastal management.

Integrating ecosystem services, green infrastructure connectivity and environmental justice in urban green planning

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Traditional urban green planning often relies on per-capita indicators, overlooking the spatial distribution of ecosystem service (ES) and socio-demographic inequalities. This study presents a geospatial framework developed for the Green Plan of Cento (Italy), integrating ES assessment, landscape ecology and environmental justice to support urban green planning.The framework combined three analyses: (i) biophysical modelling of key regulating ES, including flood mitigation, air depuration (PM_{10} and O_3 removal) and heatwave mitigation; (ii) assessment of urban green infrastructure connectivity; and (iii) evaluation of compliance with the 3-30-300 rule. To account for environmental justice aspects, the outputs of these analyses were integrated with a socio-demographic Risk Factor (RF) representing vulnerable population groups.The results highlighted a "private–public green paradox", whereby compliance with visual greenness targets was mainly driven by private gardens, while shortcomings remained in public canopy cover and accessibility to green spaces. Results also support the hypothesis that habitat fragmentation and spatial isolation were associated with lower levels of regulating ES, underlining the importance of connectivity within urban green infrastructure.Combining ES assessments with socio-demographic vulnerability allowed the identification of priority areas for intervention and the definition of Nature-based Solutions adapted to local conditions. Connectivity metrics and 3-30-300 compliance mapping were also used to identify areas where new public green spaces could improve accessibility and ES provision.The framework was directly applied to support planning decisions within the municipal Green Plan. The proposed approach provides a transparent and replicable method for integrating ES, environmental justice and green infrastructure planning in support of climate adaptation and more equitable urban environments.

Developing function-specific plant systems database for resilient urban design

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Traditional urban green infrastructure design has often prioritised aesthetic criteria, highlighting a lack of systematic approaches to maximising ecosystem services. However, today's urban greening projects increasingly focus on the functional role of plants in mitigating critical environmental issues such as urban heat islands, air and soil contamination, flood risk and biodiversity loss.The aim of this project is to develop a web platform for selecting and comparing plant species based on specific functional traits. The objective is to optimize performance across three macro-areas: urban landscapes, biodiversity and human health. This tool will provide planners, agronomists, and public administrations with a scientifically valid instrument for integrating Nature-Based Solutions (NBS) into territorial planning.Funded by the Campania Region as part of the RIS3 2021–2027 programme, this research forms part of the Industrial PhD programme in 'Technologies for Resilient Living Environments' at the University of Campania Luigi Vanvitelli. The project is being carried out in collaboration with Barretta Srl to ensure that scientific knowledge is transferred into practical urban planning tools.The interdisciplinary methodology combines botany, ecology, computer science and technology transfer. The first phase involves analysing key functional traits relevant to urban resilience, including reducing pollutants and tolerating water or salt stress. Around 100 species will be catalogued by integrating bibliographic data with standardised field measurements in Naples and Caserta. The second phase will involve the development of a database and related tools to populate, organize, friendly present and analyse such data.Ultimately, the project will significantly enhance digital environmental design skills, while strengthening collaboration between academia and industry for sustainable urban environments.

Linking economic activities to biodiversity loss: a spatially explicit assessment framework

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Human activities are a major driver of biodiversity loss yet understanding how economic activities contribute to ecological degradation remains a challenge. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) identifies five direct drivers of biodiversity loss: land and sea use change, direct exploitation of organisms, climate change, pollution and invasive alien species. However, translating these drivers into quantification of biodiversity loss remains a key limitation. This study aims to develop an integrated and spatially explicit framework to trace the pathways linking economic activities to biodiversity loss. Economic activities are grouped into macro-sectors according to the ecosystem types they affect and linked to IPBES drivers. These drivers are translated into pressure indicators that characterize the intensity and spatial distribution of anthropogenic pressures. Subsequently, the framework evaluates how these pressures may influence ecosystem conditions, reflecting changes in the state of natural capital and the capacity of ecosystem assets to sustain ecological functions. Ecological sensitivity is incorporated to account for ecosystem vulnerability and response capacity, recognizing that pressures may generate different ecological responses depending on environmental conditions. Changes in ecosystem conditions are translated into biodiversity impacts, enabling the identification of pathways through which economic activities may contribute to biodiversity loss. Biodiversity impacts are also considered in relation to ecosystem services provision, highlighting how biodiversity degradation may reduce the capacity of ecosystems to deliver benefits upon which human well-being and economic activities depend. By linking economic activities, anthropogenic pressures, ecosystem condition and biodiversity impacts within a single assessment framework, the proposed approach enables an integrated understanding of the mechanisms through which biodiversity loss may arise. The framework provides a methodological basis for biodiversity loss assessment to support sustainability reporting and biodiversity-related decision-making. It also highlights that safeguarding biodiversity is essential for maintaining ecosystem services that underpin the productivity, resilience and sustainability of economic systems.

Marine natural capital and shellfish health: the role of phytoplankton biodiversity and harmful algal taxa in the Adriatic Sea

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Marine phytoplankton is a key component of natural capital, supporting ecosystem functioning and the provision of ecosystem services related to seafood production. Harmful algal blooms (HABs) can impact these services by producing biotoxins that accumulate along the food chain, in particular in shellfish *Mytilus galloprovincialis* tissues. Within the PNRR PRIN ENDRIMUS Project, temporal and spatial variability of phytoplankton communities was investigated, with emphasis on potentially toxic taxa, and their influence on physiological and skeletal traits of mussels along the Adriatic coast. Significant spatial and seasonal differences were observed in chlorophyll-*a* (Chl-*a*), particulate matter and phytoplankton. Chl-*a* concentrations were found to be elevated during winter and spring months. Particulate organic matter peaked in spring, particulate inorganic matter in autumn and total phytoplankton abundances in winter. Meanwhile, qPCR analyses revealed marked variability in target diatom and dinoflagellate taxa in mussel tissues. qPCR approach revealed consistent trophic exposure of mussels to dominant diatoms such as *Chaetoceros socialis*, with the highest accumulation during winter. Dinoflagellates were consistently detected in mussel tissues. Notably, toxic dinoflagellate *Dinophysis* spp., occurring at low concentrations in water column, was positively detected in mussel tissues (up to 10^2 cells g^{-1}), with peaks in winter and spring, indicating persistent exposure to potentially toxic taxon even in the absence of bloom conditions. Furthermore, the random forest analyses indicated that shell properties responded primarily to particulate matter, salinity, and carbonate chemistry, while trophic variables, including dinoflagellates, small phytoplankton fractions, and toxic *Dinophysis* spp. in tissues, emerged as key predictors of condition index (CI), accounting for 36.8% of its variance. These findings demonstrated that plankton biodiversity, including low-abundance harmful taxa, influences shellfish condition and should be considered in ecosystem-based aquaculture management. The detection of *Dinophysis* spp. in mussel tissues highlights the importance of monitoring harmful algal taxa even in the absence of bloom conditions.

Assessing the impacts of global change on ecosystem services through a multi-trophic ecotoxicological approach

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Global change is increasingly altering the structure and functioning of aquatic ecosystems through the combined action of chemical pollution, nutrient enrichment, temperature variations and other environmental stressors. Understanding how these pressures affect ecological functions and ecosystem services is essential to assess ecosystem resilience and to support effective management and conservation strategies.In this study, we propose a multi-trophic ecotoxicological approach to evaluate the effects of global change on ecosystem services by integrating the responses of three key biological levels: decomposer bacteria, unicellular algae as primary producers, and echinoderm embryos as primary consumers.Ecotoxicological assays were carried out under controlled conditions, comparing optimal scenarios with exposure scenarios characterized by the presence of chemical contaminants, temperature variations and their combined effects. Biological responses were assessed through endpoints such as abundance, bioluminescence, biomass, growth rate and mortality.To translate ecotoxicological endpoints into ecosystem-scale implications, laboratory results were linked to ecological functions and ecosystem services using indicators derived from the scientific literature, with particular reference to regulating and supporting services. The comparison between exposed organisms and controls made it possible to estimate potential functional changes associated with the stressors considered.By linking effects observed at the organism level to ecosystem processes, the proposed approach provides an integrated assessment of how global change factors may impair ecosystem services in aquatic environments. The study highlights the value of multi-trophic bioindicators as early-warning tools for detecting functional alterations and strengthening the understanding of the links between ecotoxicological stress and the provision of ecosystem services.

Integrating rhodolith beds into ecosystem accounting: a SEEA-EA approach for supporting sustainable marine ecosystems management

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Rhodolith beds are complex marine habitats that sustain high biodiversity and provide a wide range of ecosystem services (ES), including habitat provision, fisheries support, and carbon cycling. However, despite their ecological relevance, these habitats remain underrepresented in ecosystem services accounting and marine management frameworks. This study proposes the application of the System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA-EA) as an operational framework for assessing the ecosystem services provided by rhodolith beds.The proposed approach integrates ecological and spatial datasets to evaluate ecosystem extent and condition through habitat mapping techniques, including acoustic surveys and in situ observations. Indicators such as live rhodolith cover, structural complexity, and biodiversity indexes are used to characterize ecosystem condition. These biophysical accounts are then linked to provisioning, regulating, and cultural ecosystem services according to the Common International Classification of Ecosystem Services (CICES).The framework also incorporates the effects of major direct and indirect anthropogenic pressures, including bottom trawling, climate change, and pollution, on ecosystem condition and ecosystem services supply. This enables the identification of potential degradation pathways and supports the evaluation of management-related trade-offs. Organizing ecological information into standardized ecosystem accounts provides a consistent and spatially explicit assessment of ecosystem services.Overall, this study highlights the potential of the SEEA-EA framework as a decision-support tool for integrating rhodolith beds into conservation policies and marine spatial planning. By providing a standardized assessment of ecosystem services, this approach supports evidence-based management and contributes to the conservation and sustainable use of marine and coastal ecosystems.

Nature-based solutions for coastal lagoons: restoring aquatic vegetation to enhance ecosystem services

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Deltaic transitional lagoons are highly productive and ecologically valuable coastal ecosystems, providing multiple ecosystem services. However, they are vulnerable to anthropogenic pressures such as channelization, hydrological alterations and marine intrusion, leading to habitat loss and degradation of ecosystem functions. The study aims to evaluate the effectiveness of hydrological restoration and native aquatic vegetation recovery as a nature-based solution (NbS) to improve ecosystem condition and service provision in the Valle di Gorino lagoon, located in the Po Delta, Italy.In this complex ecosystem, progressive marine intrusion since the 1990s, driven by hydraulic modifications, caused salinization of inner lagoon areas and loss of characteristic habitats. Between 2016 and 2020, the implementation of hydraulic interventions to restore natural salinity gradients were carried out, and the outcomes in terms of water quality and ecological functioning were experimentally measured.Monitoring before, during, and after implementation showed that freshwater inputs controlled salinity dynamics. Despite higher nutrient loads deriving from the freshwater intake, eutrophic conditions did not intensify. Since 2016, anoxic and dystrophic events, one occurring with high frequency, have not occurred, as indicated by stable dissolved oxygen. Concurrently, emergent vegetation (*Phragmites australis*) recovered, while recently established halophytic species regressed.The restoration of low-salinity conditions and native vegetation enhanced the lagoon's capacity to regulate nutrients and mitigate eutrophication, improving regulating services, habitat provision and ecosystem resilience. This case demonstrates that combining hydrological management with vegetation recovery is an effective NbS to sustain ecosystem services in deltaic transitional wetlands under anthropogenic pressure.

L’ecologia, tra società, educazione e sostenibilità

10

Coordinatori: Giuseppe Barbiero, Stefania Pinna, Paolo Guidetti

Integrating *Ocean Literacy* into school programs through extracurricular activities can significantly enhance students' learning experiences, both in coastal and in non-coastal areas.

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Awareness of ocean-related challenges has grown considerably in recent years. Since the early 2000s, research in *Ocean Literacy* (OL), defined as the understanding of the ocean's influence on humans and humanity's influence on the ocean, has increased significantly.Nevertheless, despite considerable efforts worldwide and broad support from UNESCO's Intergovernmental Oceanographic Commission, academics, educators, and policymakers, a fully integrated 'blue curriculum' in schools remains an aspirational goal, with Brazil as a notable exception. Moreover, studies reveal a worryingly low level of knowledge.Here we present two projects, where OL has been successfully integrated into schools' activities:The Be_Natural project, conducted in the Liguria region (Italy, NW Mediterranean) focusing on *Seafood Literacy*. It extends far beyond the simple understanding of the fish nutritional values or creating recipes, but it encompasses a broader scope, such as the understanding of fishery's ecological impact and marine species ecology. In a 1st t phase of the project we administered a questionnaire on the above topics to 280 pupils (aged 9-11) of 16 classes. In a 2nd phase students went in situ in order to reinforce their understanding of concepts. A significant gap in knowledge regarding common local fishes and marine conservation measures was detected."An oceanographer in the classroom" project conducted in the alpine province of Biella (Piedmont region), far from the sea. It explored key themes in physical oceanography, marine biology, and sustainability through a combination of theoretical lessons, hands-on experiments, and creative activities, fostering a holistic understanding of ocean systems and the ocean–human relationship. It consisted in a 30-hour project divided into 15 lessons and involving a group of 12 pupils, all aged 8 years.These projects show that specialized environmental educators significantly enhance educational pathways, supporting teaching efforts contributing to more inclusive and effective learning experiences in both coastal and non-coastal areas.

WM-classroom v1.0: a didactic multi-species agent-based model to explore predator-prey-harvest dynamics

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Understanding ecological systems requires students to grasp the interactions among wildlife populations, human activities, and environmental processes. Yet these relationships are characterized by nonlinear dynamics, feedback loops, and emergent behaviors that are often difficult to communicate through traditional teaching approaches. Agent-Based Models (ABMs) offer an opportunity to transform these abstract concepts into interactive learning experiences.This contribution presents *WM-Classroom v1.0*, a didactic multi-species agent-based model developed in NetLogo to support environmental education and wildlife-management training. The model simulates a simplified predator-prey-harvest system composed of wolves, deer, wild boar, and human harvesters operating within a virtual landscape. Through a transparent set of behavioral rules governing movement, feeding, reproduction, predation, legal harvest, and optional predator control, learners can explore how individual decisions and management interventions influence system-wide outcomes.Although designed primarily as an educational tool rather than a predictive management instrument, exploratory simulations produced ecologically meaningful patterns. Population trajectories reproduced predator-prey oscillations consistent with theoretical expectations, while the two ungulate species displayed contrasting responses to harvest pressure, with wild boar showing greater resilience than deer. Changes in hunter density and hunting season length also generated indirect effects on wolf populations through prey depletion, illustrating how management actions targeting a single component of the system may propagate across trophic levels.From a pedagogical perspective, WM-Classroom v1.0 supports inquiry-based learning by allowing students to formulate hypotheses, conduct virtual experiments, and interpret the consequences of alternative management scenarios. The visual and interactive nature of the model bridges the gap between theoretical ecology and real-world decision-making, fostering systems thinking and a deeper understanding of sustainability challenges.The model is suitable for undergraduate and graduate courses in ecology, conservation biology, and environmental management, as well as for outreach activities and stakeholder workshops. More broadly, it demonstrates how agent-based modelling can promote environmental literacy by making the complexity of human-wildlife systems both accessible and experimentally explorable.

Citizen science and outdoor education for microplastic monitoring in the Portofino marine protected area

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The Water Code – The Formula for the Sustainable Management of the World's Water Resources is an active global citizenship and sustainability education project, aimed at promoting knowledge, skills, attitudes, and behaviours supporting environmental protection and the sustainable management of water resources. Within the project, outdoor educational activities focused on microplastic (MP) pollution were carried out to actively engage students in scientific research while fostering environmental awareness and a stronger connection with the coastal marine environment. The initiative led by CNR-IAS was carried out in collaboration with Outdoor Portofino, building upon the methodology and results of the previous *Micro Plastic Hunters Project*. The latter demonstrated the effectiveness of an innovative citizen science approach for monitoring MPs in nearshore coastal environments, using Mini-Mantas, a smaller version of Mant nets (MSFD instrument for MPs sampling), designed to be towed by recreational watercraft. The Water Code project involved 80 students aged 11–14 across the Liguria region participating in field activities to monitor MPs in the surface waters of the Portofino Marine Protected Area. Participants were actively engaged in all stages of the scientific process, from collecting samples using kayaks and Mini-Manta nets to analysing them in a field laboratory equipped with microscopes, supported by CNR-IAS researchers. This experience transformed scientific learning into a hands-on emotionally engaging journey, allowing students to explore local marine ecosystems while contributing to real research activities. The results highlight the educational value of experiential and outdoor learning approaches in promoting scientific literacy, critical thinking, and responsible environmental behaviours. Furthermore, the initiative demonstrates how citizen science can strengthen the relationship between schools, research institutions, and local communities, fostering active participation and a deeper sense of stewardship toward nature and coastal environments.

Playing ecology: dungeon maestra as educational model for ecological literacy

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This work is situated within the field of ecology education and addresses the theme of ecological literacy through an innovative approach based on active and participatory methodologies. The study presents the design of an educational role-playing activity entitled "Dungeon Maestra", inspired by the dynamics of tabletop role-playing game "Dungeons & Dragons" based on the use of a 20-sided die. The creation of the game represents the core of the research and is accompanied by a meta-analysis of the relevant literature, which highlights the still limited number of studies specifically focused on ecological literacy, particularly in relation to the use of game-based and narrative methodologies.The study aims to examine the impact of the proposed educational device on learning processes and on the development of ecological literacy competencies. Within this framework, a structured evaluation grid is designed and applied in order to systematically assess both cognitive learning outcomes and the participatory and decision-making dimensions activated during the gameplay experience, such as cooperation, engagement, and problem-solving skills.The proposed model highlights the educational potential of narrative and game-based methodologies in sustainability education by promoting immersive, collaborative, and meaningful learning experiences. Furthermore, the flexibility of the proposal makes the model applicable in different educational contexts, contributing to the dissemination of innovative pedagogical practices aimed at fostering ecological citizenship and students' active participation.

Thalassa movement: an educational project for the conservation of marine ecosystems through embodied experience

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Thalassa Movement (TM) is an environmental education project aimed at promoting scientific knowledge and behaviors that support the conservation of marine ecosystems through movement practices.The TM project's methodology is based on a theoretical framework that integrates the theory of Embodied Cognition (Varela), the theory of perception (Merleau-Ponty), and the concept of mimesis (Scaramuzzo), recognizing the lived body as the primary channel for experiencing the world.The TM experiential workshops (1 hour in duration) are structured in three phases: (1) activation of prior knowledge through natural specimens, images/videos, vocalizations, and environmental audio recordings; (2) observation of the motor behaviors of marine organisms in natural habitats and analytical breakdown of motor patterns (postures, points of contact, weight shifts, individual and collective dynamics, rhythmicity); (3) bodily experimentation through a motor alphabet, in which participants replicate, imitate, and reflect on specific motor elements.The evaluation design includes qualitative and semi-structured pre- and post-workshop questionnaires aimed at measuring cognitive (understanding of biological concepts), affective (empathy toward the marine world), and behavioral (intention to adopt pro-environmental practices) variables, supplemented by an ethnographic survey featuring brief autobiographies on the human-sea relationship.Preliminary results show an improvement in the understanding of biological concepts. TM serves as a replicable model for environmental education, offering a detailed methodological protocol that can be adapted to different audience contexts.

Preserving tradition while facing change: fishers' perspectives on the challenges and future of the Caribbean spiny lobster fishery in Punta Allen (Mexico)

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The Caribbean spiny lobster (*Panulirus argus*) fishery of the Punta Allen fishing cooperative, located within the Sian Ka'an Biosphere Reserve (Mexico), is widely recognized as a successful example of community-based and sustainable fisheries management. However, in recent years this fishery has been increasingly challenged by climate-related environmental changes, illegal fishing, and economic pressures, raising concerns about its long-term resilience. This study investigates fishers' perceptions of climate change, its impacts on lobster fishing, and the future prospects of the fishery and the local community. Semi-structured interviews were conducted during the summer of 2024 with 39 local fishers to document their experiences and perspectives. Notably, a hurricane struck the area only a few days before the interviews, highlighting the growing exposure of the community to extreme climatic events. The respondents consistently reported a decline in lobster catches over recent years, accompanied by increasing operational challenges, including the need to fish at greater depths, increasing seasonal unpredictability, and more frequent adverse weather conditions. Fishers also identified the degradation of key coastal habitats, particularly seagrass meadows and coral reefs, as an important factor affecting lobster abundance and productivity. Although the reserve's cooperative management system is still considered effective in promoting resource conservation, many interviewees expressed growing concern about the cumulative impacts of climate change, illegal fishing, and the sharp decline in lobster market prices following the COVID-19 pandemic. This widespread uncertainty about the future of the fishery has encouraged many community members to diversify their livelihoods by developing complementary activities such as ecotourism, hospitality services, recreational fishing and marine wildlife watching. Overall, the study highlights the importance of integrating local ecological knowledge into adaptive management strategies and emphasizes the need to strengthen climate resilience, habitat conservation, and socio-economic diversification to ensure the long-term sustainability of one of the Caribbean's most emblematic small-scale fisheries.

Small-scale fisheries as socio-ecological sentinels: integrating participatory monitoring, Ocean Literacy and sustainable blue economy

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Small-scale fisheries (SSF) are not just a 'productive sector' important for local coastal economies; they are complex socio-ecological systems linking marine biodiversity, from species to ecosystems, with traditional knowledge, cultural heritage, and food supply systems involving diverse actors and infrastructures. We present an integrated framework developed across two complementary projects, BE-NATURAL and CORE. Aimed at redefining and strengthening SSF from a socio-ecological and blue-economy perspective, these projects investigate the role of SSF as sentinels of socio-ecological change and drivers of sustainable transitions across seven Marine Protected Areas (*sensu latu*) and two urban harbour contexts in the north-western Mediterranean.The framework combines three interlinked components: i) collaborative monitoring with fishers to characterise catches and fishing practices through ecological and socio-economic descriptors; ii) translation of the collaborative approach into initiatives fostering Ocean Literacy, Marine Citizenship, Generational Turnover of SSF operators and stakeholder engagement, targeting schools along educational pathways, citizens, consumers, clients, restaurant owners and chefs, and tourism operators; iii) implementation of pilot initiatives, ranging from direct sales and seafood valorisation through high-quality catering and processing to fishery-based tourism, hospitality, and fisher-led environmental monitoring, to test pathways to increase SSF resilience and competitiveness while potentially reducing pressure on marine ecosystems.Expected outcomes of integrating the two projects include best practices and harmonised monitoring protocols for SSF management and public engagement, together with a shared, transferable toolkit to support the diversification of SSF activities towards tourism and high-quality yet equitably accessible catering. This approach highlights that conservation and sustainable use of marine resources require not only bio-ecological data, but also socio-cultural and governance transformations able to reconnect coastal communities with the sea, including at an emotional level, thereby improving the environmental and socio-economic sustainability of SSF and promoting Seafood Literacy.

Sustainability awareness relates to higher agroecological maturity and lower vulnerability of small farmers: an example from the Rome metropolitan area

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One of the paradigms of a just sustainable transition of food systems, is that respecting sustainability principles for food production reduces vulnerability to environmental and socio-economic stressors. This is particularly relevant for small producers, who are the back bone of local economies, but also the most fragile elements of the food system. Addressing environmental challenges requires not only the adoption of sustainable agricultural practices but also the awareness, motivation and competencies that enable food producers to contribute to the ecological transition. In this perspective, sustainability education can play a strategic role in strengthening farmers' capacity to understand, value and implement agroecological practices, generating benefits that extend beyond environmental protection to social and economic resilience.This study explores whether sustainability-related coping capacities are associated with the adoption of agroecological practices and lower vulnerability among 124 small local food producers within the Rome Hub of the European Horizon SWITCH project. Sustainability awareness was assessed through a psychosocial construct reflecting producers' motivation, understanding and perceived ability to engage in sustainable production. Agroecological sustainability was assessed across six domains of the FAO agroecology framework, while vulnerability was analysed through three dimensions: exposure, sensitivity and adaptive capacity.Preliminary analyses indicated that producers with stronger sustainability-related coping capacities also exhibited higher agroecological sustainability (Pearson's $r = 0.383$, $p < 0.001$) and lower vulnerability ($r = -0.264$, $p = 0.003$). These findings support the idea that sustainability awareness may represent an important enabling factor for strengthening environmental sustainability and producers' resilience.From an educational perspective, framing sustainable agricultural practices a win-win situation in which environmental protection, social well-being and local economic resilience reinforce one another, may mobilize and inspiring more producers to become more sustainable. The study contributes to sustainability education by showing how empowering producers can support the transition towards more resilient and sustainable food systems.

A new MPA is born: an integrated model of conservation, environmental education, and citizen engagement

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Establishing a Marine Protected Area (MPA) is crucial not only for biodiversity conservation and coastal ecosystem restoration, but also for the sustainable development of local communities. MPA effectiveness depends on integrating protection, scientific research, and socio-economic and educational dimensions by overcoming the traditional conservation–human activities dichotomy.We present the first activities of the Capo Spartivento MPA (Domus de Maria, Sardinia, Italy), an area of high ecological value with extensive *Posidonia oceanica* meadows and species of community interest, subject to substantial anthropogenic pressure like mass tourism and fishing. The establishment administrative process spanned nearly 12 years, reaching full operational status in spring 2026 with the appointment of dedicated staff. Initial activities focused on four main actions:Regulation of fishing and anchoring within the MPA.Assessing biodiversity status and planning restoration activities.Raising awareness among residents and tourists through participatory events.Assessing local perceptions of MPA-related constraints and opportunities.Action 4 is part of a wider survey-based study covering 11 Italian MPAs, aimed at assessing public perception of MPA value among people living/visiting the MPA during summer. The study is composed of an online questionnaire for the general public and semi-structured interviews with local small-scale fisheries.In its first months of enforcement, the MPA held 3 biodiversity and awareness events. Public receptiveness was good, but standardized, long-term, stakeholder-specific awareness and engagement programs are needed. Long-term monitoring of biocenoses and tourism, small-scale, and recreational fishing impacts is also required to define the best strategy for responsible coexistence.This contribution shares best practices and lessons learned during this initial phase, and aims to foster collaborations with universities and research institutions for joint projects in biological monitoring, ecological economics, and social impact assessment — all essential for the MPA's long-term management and effectiveness.

BLUECO-TAP action within the framework of the Sustainable Blue Economy Partnership (2026-2028)

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The BLUECO-TAP (Thematic Annual Programming) initiative represents a strategic effort to strengthen collaboration among nationally funded research projects within the framework of the Sustainable Blue Economy Partnership (SBEP). Rather than duplicating existing research, the TAP focuses on creating added value by connecting different national projects through a structured network. Its primary objective is to foster knowledge exchange, improve the visibility and impact of scientific outputs at the European level, and build a dynamic research community centered on shared thematic priorities.Running from February 2026 to February 2028, the TAP aims to provide a collaborative space for researchers, enabling the sharing of results, experiences, and best practices across projects. It also supports the capitalization and dissemination of research outcomes beyond individual initiatives, promoting the production of policy-relevant documents, knowledge syntheses, and high-impact scientific publications. Additionally, the initiative encourages mobility, capacity building, and the identification of opportunities for joint research and coordinated responses to funding calls.The core theme of BLUECO-TAP is "Building resilience of coastal and marine socio-ecosystems under multiple pressures to support a sustainable blue economy in a changing world". The initiative adopts an integrated approach that combines environmental, social, economic, and legal aspects, involving key actors from the "quadruple helix" (academia, policymakers, industry, and civil society). The projects cover complementary areas, including the development of digital tools and monitoring systems, the study of ecosystems and their climate-related changes, and the design of adaptation, mitigation, and restoration strategies. Currently, the BLUECO-TAP brings together national projects from Italy, France, Greece, and Sweden covering topics such as digital twins, augmented observatories, coastal flooding models, biodiversity and ecosystem connectivity, and advanced monitoring technologies. Through its implementation phases and collaborative framework, BLUECO-TAP seeks to strengthen European research integration and contribute to a more resilient and sustainable blue economy in a rapidly changing global context.

Ecology as a unifying framework for teaching biology: an educational experience in an international programme

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Biology is commonly taught by progressing through hierarchical levels of biological organization, from the very small scale of molecules and cells to the very large scale of ecosystems and biomes. While this approach provides a logical structure for introducing biological concepts, students may struggle to appreciate how processes occurring at different scales contribute to the functioning of life on Earth as an integrated system. This work describes a novel educational approach to teaching biology through the lens of ecology, developed and implemented within the "Foundation Year programme" at the Ca' Foscari University of Venice - School for International Education. The course adopted ecology as a unifying conceptual framework through which all biological topics were explored. Throughout the curriculum, students were encouraged to continuously relate each biological process to its role in the broader functioning of the biosphere and according to the energy and matter flows across living systems. Student feedback and qualitative observations suggested that the ecological framework facilitated the integration of biological concepts across scales and promoted a more holistic understanding of life processes. The experience suggests that ecology may provide an effective conceptual scaffold for biology education, helping students connect different levels of biological organization and fostering systems-thinking competencies that are increasingly relevant for addressing contemporary environmental and societal challenges.

Author index