BOOK OF ABSTRACTS



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Degrado ambientale
Sintesi dei risultati ottenuti

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Environmental Degradation in Focus: Insights into the Temporal and Spatial Scales of Stressors

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Abstract

Environmental degradation constitutes a critical challenge for European ecosystems, manifesting as progressive and cumulative alterations in ecosystem structure and function under both anthropogenic pressures and climate variability. Contemporary research emphasizes the necessity of robust, high-resolution, and temporally up-to-date datasets to accurately characterize these processes. The proliferation of cloud-based remote sensing platforms, combined with advances in algorithmic development and environmental modeling, has substantially enhanced the capacity to detect, quantify, and monitor degradation phenomena across multiple spatial and temporal scales.

Within the framework of the RETURN project (Spoke VS4, WP4.2), this study aims to: (i) delineate the principal drivers of environmental degradation as evidenced in the scientific literature, and (ii) provide a synoptic evaluation of the spatial extent and observation scales associated with these processes.

To achieve these objectives, a bibliometric investigation was conducted using the Scopus database. Search queries were defined along two dimensions - environmental pressure and geographic context - and applied to titles, abstracts, and keywords. The dataset comprised Articles, Reviews, Conference Papers, and Book Chapters published between 2016 and 2023, yielding a total of 19,748 publications. Analyses were performed using VOSviewer and the R-based bibliometrix package to identify thematic clusters and research trends.

Keyword-based cluster analysis revealed four principal thematic domains: (1) pollution and wastewater treatment, microplastics, toxicity, and pesticide dynamics; (2) forest degradation monitoring, including deforestation assessment via remote sensing; (3) sustainable land resource management; and (4) an integrative cluster synthesizing elements from the preceding domains. These clusters highlight the dominant drivers of environmental degradation and the methodological approaches applied in contemporary studies.

Subsequent analyses distinguished between terrestrial and marine degradation processes, with a focused evaluation of stressors of particular relevance to the RETURN project, including plastics, wildfires, pathogen proliferation, and eutrophication. Publications were further categorized according to RETURN-specific themes, including Database development, Spatial Mapping, Transport Modeling, and Innovative Modeling Approaches, providing a comprehensive thematic framework of recent research.

Finally, a synoptic scheme was developed to position the RETURN project components (VSs, TSs, DS, and VS4 themes) relative to measurement support and spatial resolution. This framework elucidates the critical trade-offs between spatial coverage and resolution, reinforcing the relevance of scale in environmental degradation assessments and guiding the design of multi-scale monitoring strategies.

In conclusion, this study delivers a systematic, up-to-date overview of environmental degradation research, integrating bibliometric mapping with an evaluation of spatial and temporal scales. The results provide critical insights into the scope, drivers, and methodological patterns of environmental degradation studies, supporting evidence-based monitoring and management of terrestrial and marine ecosystems.

Enhancing NDVI Trajectory Analysis for Improved Productivity Metrics in National-Scale Land Degradation Assessment: The Case of Italy

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Abstract

Achieving land degradation neutrality (LDN) is a central objective of SDG 15.3, adopted to address desertification, restore degraded land and soil, and achieve a land degradation-neutral world. Target 15.3, which aims to end desertification and restore degraded lands, is monitored by indicator 15.3.1, measured as a combination of three sub-indicators: land cover change, land productivity, and soil organic carbon. The United Nations Convention to Combat Desertification (UNCCD), the custodian agency for this indicator, has developed a standardized methodological approach to guide global and national reporting.

Despite its global adoption, increasing evidence suggests that indicator 15.3.1 has inherent reliability issues, potentially leading to contestation and misleading policy guidance (Xoxo et al., 2022). The greatest limitation concerns the assessment of land productivity dynamics. The UNCCD methodology relies on the trajectory of mean annual NDVI values to compute pixel-level analysis. Recent work (Di Leginio et al., 2024) has highlighted the value of using maximum annual NDVI instead of mean values to provide a more robust signal of primary productivity, at the regional level (Campania region).

In light of these concerns, this research aims to develop a procedure that enhances the reliability of SDG 15.3.1 by improving its critical components, with a specific focus on the land productivity sub-indicator. The study presents an innovative and scalable approach designed to monitor land degradation at the national scale using Earth observation data.

A self-adjusting algorithm was developed on the Google Earth Engine (GEE) platform to visualize, assess, and define land degradation changes and drivers at the pixel level over an 11-year period (2013-2024). Multispectral Landsat 7 and Landsat 8 imagery were evaluated and compared, for their ability to capture productivity dynamics. Maximum annual NDVI time series were generated across Italy and corrected for changing climatic conditions. To test reliability, 1500 random ground-verified points were used, covering diverse climates, land uses, and vegetation types. Initial land degradation

classification maps achieved overall accuracies of 65% for Landsat 7 and 70% for Landsat 8, confirming the superior performance of Landsat 8.

To refine trend analysis, we modified the standard UNCCD approach. While the official protocol typically employs the Mann-Kendall test to detect NDVI trends, we computed Sen's slope for each Landsat 8 pixel, enabling direct quantification of productivity trends. By analyzing the distribution of Sen's slope values across degraded, stable, and improved areas, class-specific thresholds were established to define the extent of each category. These thresholds were then applied to generate a new national-scale land degradation classification map.

Validation using an independent set of 650 random points confirmed the superior performance of the proposed methodology. The Sen's slope-based approach achieved an overall accuracy of 93%, substantially higher than the 70% obtained with the Mann-Kendall method. The resulting map aligned more closely with ground observations and provided a more reliable representation of land degradation processes in Italy.

This study demonstrates that integrating maximum annual NDVI with Sen's slope-based trend analysis constitutes a significant methodological advancement for monitoring land productivity at national scales. The approach enhances sensitivity to both degradation and restoration, and produces maps that are more interpretable and operationally relevant.

By enabling precise detection of land productivity changes, this method supports evidence-based land management, targeted conservation actions, and informed policymaking. Its adaptability to heterogeneous landscapes makes it a valuable tool for strengthening national SDG 15.3 reporting. Ultimately, it ensures that LDN assessments are scientifically robust, operationally useful, and directly actionable, thereby contributing to sustainable land use, effective restoration planning, and long-term ecosystem resilience.

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Vulnerability of *Posidonia oceanica* habitats to climate change

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Habitat vulnerability is defined as the susceptibility of ecosystems to degradation from external pressures. Climate change is a primary driver of this degradation, primarily through rising temperatures and more frequent extreme weather events (Gauthier, 2013). Seagrass meadows, including *Posidonia oceanica* in the Mediterranean, provide vital ecosystem services such as carbon storage, stabilising sediments and providing nursery habitats. However, they are highly sensitive to increases in temperature and salinity (Stipcic et al., 2022; Litsi-Mizan, 2023). Understanding these vulnerabilities is essential for predicting ecological changes, prioritising conservation actions and informing adaptive management strategies.

In a mesocosm experiment, we examined the response of *P. oceanica* to elevated temperature and salinity using plants collected from inside and outside a lagoon-like basin (Stagnone di Marsala, Sicily). Combined stressors reduced photosynthetic efficiency and pigment content; however, lagoon plants showed partial adaptation, indicating resilience despite slower growth.

Additionally, we investigated barrier reefs, which are unique and ecologically significant structures formed by *P. oceanica* in very shallow waters through the accumulation of biogenic matte. Using radiocarbon dating, $\delta^{13}C$ analysis and lepidochronology, we studied three reefs in Sicily (Maragani, Solanto and Marsala). Reef formation began approximately 600–1,250 years ago, with each site displaying distinct growth patterns and carbon signatures. Maragani exhibited the healthiest seagrass growth under stable conditions, while Solanto displayed reduced growth indicative of ecological stress. Marsala exhibited intermediate patterns. These differences emphasise the connections between reef development, carbon storage and environmental pressures, providing valuable insights for conservation planning.

Furthermore, we observed several Posidonia mats stranded along the southern coast of Sicily in front of a barrier reef. We hypothesise that these blocks originally formed on a rocky substrate, which may have been colonised by boring bivalve molluscs. This suggests an unrecognised plant–animal interaction (Tomasello et al., 2025). Using a shoot density model and historical wave data, we indirectly estimated the blocks' original depth. This suggests that a severe storm uprooted and stranded them in very shallow waters. This raises concerns about the increasing vulnerability of these ecosystems to more frequent and intense storms in a changing climate.

In conclusion, our study has revealed that *P. oceanica* is sensitive and vulnerable to climate-related stressors. Both experimental and historical evidence reveal site-specific differences in growth and

resilience. Although some adaptive responses exist, the combined effect of stressors significantly reduces physiological performance and growth, threatening the essential ecosystem services that these meadows provide, including carbon sequestration, coastal protection and support for biodiversity. Our findings emphasise the urgent need for integrated conservation strategies to mitigate human impact and bolster the resilience of these vital marine ecosystems.

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Coastal monitoring infrastructure: The case of Genoa

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Abstract

Monitoring the coastal and port marine environment requires the involvement of different scientific and technical skills, starting with the interdisciplinary nature of the sea and the complexity of the port environment (Robinson et al. 1999; Cutroneo et al. 2017). Consequently, it is necessary to involve different disciplines in monitoring activities, but it is also necessary to use different types of infrastructure. Here we report on the infrastructure commitment that the University of Genoa (UniGe) has put in place as part of the RETURN marine environment monitoring activities, specifically in the case of the Port of Genoa.

UniGe is involved in VS4 WP4.2 with two departments – DISTAV and DCCI – which have implemented both a capitalization action for existing infrastructure and a major acquisition action for new, latest-generation infrastructure dedicated to RETURN activities (Figure 1). The different infrastructures involved were used in the activities planned, either in situ or ex situ, namely sampling of the matrices under investigation, characterization of the physical parameters of the water column, sedimentological characterization and chemical analysis of sediments (bulk chemical analysis of 65 analytes), speciation and quantification of the mineral component including asbestos, and speciation and quantification of emerging pollutants.

Thanks to the enthusiastic approach to the RETURN project by the Port System Authority of the Western Ligurian Sea, it was possible to involve the port system of Genoa in the implementation of project activities. Two sites, located at the western and eastern entrances to the port, have been chosen as reference sites for all RETURN activities carried out in the Port of Genoa. These activities involved not only WP4.2, but also WP4.3 for the monitoring of microplastics in bottom sediments, WP4.5 for the remediation of dredged sediments, and the collaboration with WP4.4 for the contaminant quantification in water and sediments and ecotoxicological response.

As regards capitalization activities, thanks to the fixed monitoring stations deployed on the port breakwater, it was possible to acquire a dataset on temperature and water mass dynamics covering a period of two years (May 2023-April 2025). This dataset is extremely important for understanding the port system and relating the results obtained on the different matrices at individual points to the port environment as a whole, and also to the climate change currently underway. Similarly,

thanks to the weekly use of the DISTAV monitoring boat and the scientific instruments associated with it (multiparameter probes and ADCP current meters), it was possible to expand the dataset acquired by fixed stations with data on temperature, salinity, turbidity, and density of water masses for the same two-year period, not only at the two reference sites but throughout the entire port area. The last pre-existing infrastructure at DISTAV involved in RETURN activities is micro-Raman, used for the identification of plastic polymers present in port sediments in the framework of the WP4.3 activity.

As regards the acquisition of new infrastructure, UniGe has made two major investments. The first involved the acquisition of an ultra-high resolution scanning electron microscope, ideal for characterizing nanomaterials. It has been added to the existing Scanning Electron Microscopy Laboratory of DISTAV for the qualitative and quantitative determination and analysis of fibrous phases in samples of excavated earth and rocks, artificial materials, and airborne samples, accredited by the Italian Ministry of Health. In particular, the system was applied to investigations into the presence of asbestos fibers in marine sediments, activity never carried out in the Port of Genoa. Two sediment sampling campaigns were carried out in the port (17 sampling sites), allowing the concentration of fibers in the sediments to be mapped and specific areas of accumulation in the port to be identified. These areas can be monitored continuously to obtain data on seasonal variability or their link to ongoing port activities.

The second major investment involved the acquisition by DCCI of a liquid chromatograph coupled with a high-resolution Q-TOF mass spectrometer. The Q-TOF analyzer provides accurate molecular mass measurements and can be used for both target analysis and suspect screening. In the first case, the analytes to be analyzed and quantified are chosen in advance; in the second case, a large database of substances potentially present in the sample is used. Q-TOF is an extremely effective technique for studying emerging contaminants in different matrices. The RETURN analyses were conducted on POCIS passive samplers, dedicated to sampling organic compounds present in the water column, and directly on water samples taken in the port. The results allowed the identification of emerging pollutants in port waters, such as pharmaceuticals and ultra-violet (UV) filters.

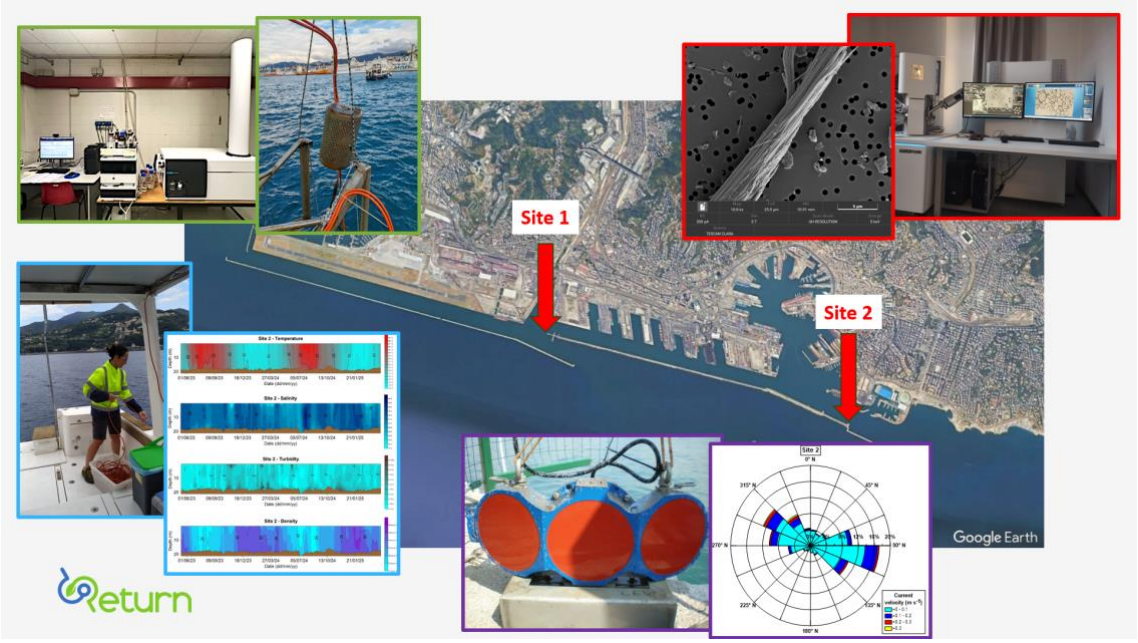


Figure 1 – The infrastructure complex used in the port of Genoa.

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Emerging contaminants in seawater: POCIS passive sampling and HR mass spectrometry analysis. The case of Genoa port

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Abstract

The present contribution is part of the case study regarding the infrastructure commitment of the University of Genoa (UniGe) in the framework of the RETURN marine environment monitoring activities, specifically applied to the Port of Genoa. UniGe is involved in VS4 WP4.2 with two departments, DISTAV and DCCI. Here we describe the research activities carried out for the study of chemical pollution of seawater (in collaboration with WP4.4), particularly focusing on emerging contaminants.

Emerging contaminants (ECs) are substances for which limited information is available regarding their distribution and their environmental effects. ECs are a wide group of substances whose presence in the environment has raised the attention of the scientific community in the last two decades; they are not only "new contaminants" but also chemical species which have been in the environment for a while but for which concerns have been raised much more recently. These contaminants are not currently included in routine monitoring programs, but many of them have been introduced in some "watchlists", and they may be subjected to future regulation.

Monitoring these compounds in marine waters, particularly in port areas, is crucial for assessing their impact. However, their detection is challenging due to their typically low concentrations. To enhance analytical sensitivity, passive samplers such as POCIS (*Polar Organic Chemical Integrative Samplers*) were deployed in the Genoa port area. These devices integrate contaminant presence over extended periods, allowing for the estimation of time-weighted average (TWA) concentrations. To obtain more comprehensive data, passive sampling was complemented by water spot sampling followed by Solid-Phase Extraction (SPE).

Two main sampling campaigns, covering a period of two years (May 2023-April 2025). During the *1st* campaign *(2023-2024)* a total of 11 seawater samples were collected in the port of Genoa, selecting strategic sampling points located near the discharge outlets of wastewater treatment plants (WWTPs). Among these, 3 samples were collected using passive sampling with POCIS devices, while the remaining 8 were obtained through spot sampling, using appropriate glass bottles. The study areas were located in the Polcevera, Puntavagno, and Bisagno zones. During the 2nd campaign *(2024-2025)*, a total of 10 samples were collected from the same locations. Specifically, 4 samples were obtained using POCIS passive sampling, 2 using ROCKS passive sampling, and 4 through spot

sampling followed by SPE. ROCKS (*Resistant Organic Chemical Kinetic Samplers*) are novel passive samplers developed in our laboratories to overcome certain limitations of POCIS, particularly membrane fragility and low sampling rates for more hydrophobic contaminants.

During the sampling campaigns, about forty ECs were investigated, including drugs, additives, tracers, pesticides, and UV filters. The analytical determination was performed by liquid chromatography coupled to a high-resolution tandem mass spectrometer. The instrument, an HPLC-Q-TOF, was the second major investment of UniGe in the RETURN project and provides high resolution and accurate molecular mass measurements. It can be used for both target and suspect screening analysis; in the first case, the analytes to be measured are chosen in advance while, in the second case, a large database of substances potentially present in the sample is used to identify unknown chemicals. Q-TOF is an extremely effective technique for studying emerging contaminants in different matrices.

The results obtained by target analysis on port seawater sampled by POCIS and spot sampling, are summarized in figure 1, for both the sampling campaigns; for brevity, detected ECs have been gathered in 5 classes, highlighted in different colours. Up to 21 ECs were detected in POCIS extracts, much more than in spot samples.

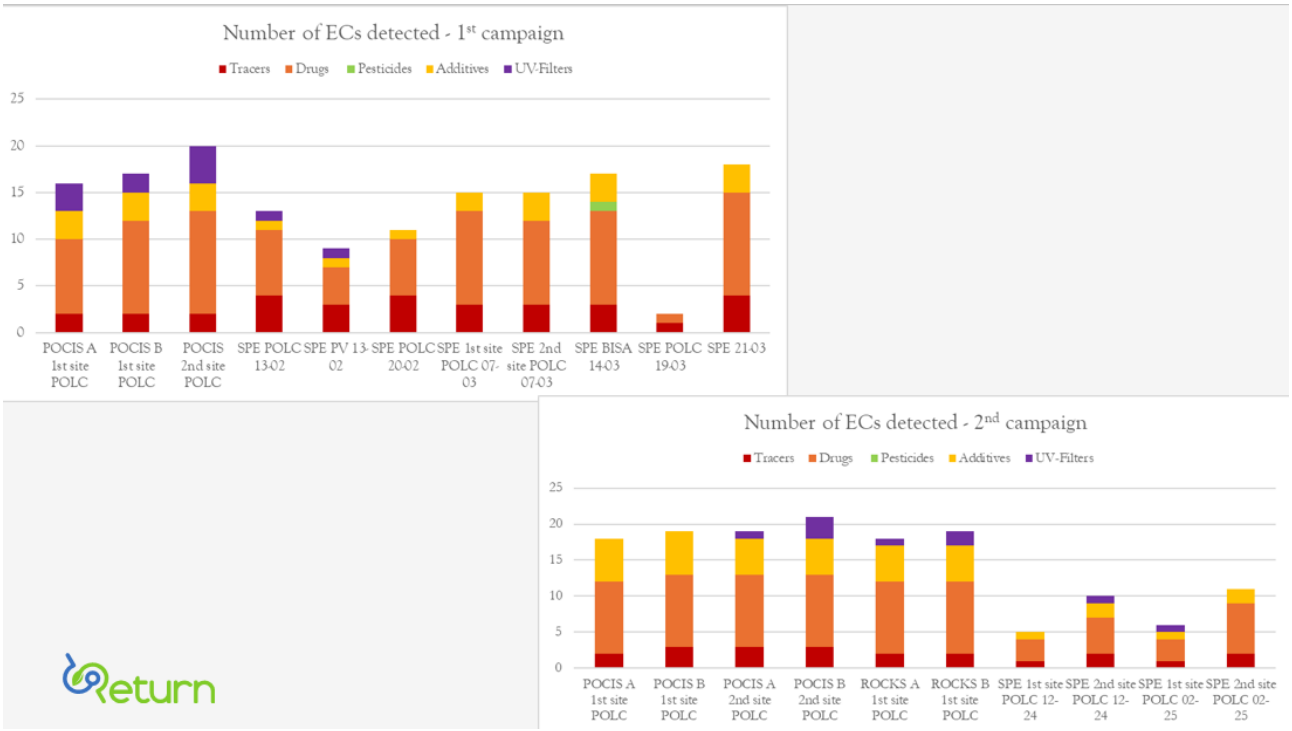


Figure 1 – Targeted analysis: number of ECs detected in the port of Genoa during the two campaigns.

Regarding suspect screening analysis, besides the ECs measured by target analysis, further unknown compounds were detected: 44 ECs in the POCIS extracts of the *1st* campaign and 41 ECs in the POCIS extracts of the 2nd campaign. Also in this case, the spot sampling was less effective; in fact, it allowed

the identifications of 15 unknown chemicals. Most frequently identified ECs were pharmaceuticals, in particular beta-blockers.

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Effects of multiple stressors on the ecosystem functioning of Grado lagoon: an experimental assessment using mesocosms

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Abstract

This experimental study, carried out in June 2024 within Spoke VS4 (Task 4.4.1), investigated the response of the Grado Lagoon ecosystem to combined stressors – oxygen depletion and mercury (Hg) contamination (***Figure 1a***) – under a future climate change scenario. The aim was to assess how water column segregation, high organic load and contamination levels might affect resident communities of transitional ecosystems.

Located along the northern Adriatic coast, the Grado Lagoon is a high-value transitional habitat that, despite persistent urban and industrial pressure (Acquavita *et al.*, 2012; Covelli *et al.*, 2006), remains among the Mediterranean's best-preserved wetlands. The experiment was performed in the most Hg-contaminated, organic-enriched and shallowest (<80 cm) part of the lagoon, prone to stratification and late-summer hypoxia or anoxia events, which also enhance the production of toxic, bioavailable monomethylmercury (MeHg) (Rice *et al.*, 2014). Eighteen mesocosms (~0.8 m^3 each), divided into three clusters (R1, R2, R3) (***Figure 1b***), were deployed to mimic semi-confined conditions: horizontal water and gasses exchanges were restricted, while vertical fluxes at the air–water and sediment–water interfaces were preserved. Each mesocosm was formed by a transparent nylon cylinder supported by two galvanized iron rings (Ø ~100 cm) (***Figure 1c***) (Baldassarre *et al.*, 2023). Sampling of water and sediments for physical-chemical (i.e. inorganic nutrients, chlorophyll a, phaeopigments, grain-size, TOC and TN content) and biological analyses was performed at the start (T_0), after 4 days (T_1), and after 10 days (T_2); temperature, salinity, and dissolved oxygen were measured daily inside and outside the mesocosms using a multiparameter probe. Passive samplers were also adopted to quantify the accumulation of organic and inorganic contaminants. Planktonic and benthic (including macrofauna, microeukaryotes, prokaryotes) community structure was assessed via taxonomy and molecular tools. Key biological processes – Community Respiration (CR), Gross Primary Production (GPP), and prokaryotic Heterotrophic Carbon Production (HCP) – were also estimated.

Despite hypoxic conditions did not establish due to adverse meteorological conditions, a significant decline in dissolved oxygen was obtained in mesocosms at T_2 (–48.1 ± 7.3%), triggering shifts in structural variables and primary productivity.

Inorganic nutrients concentration in the water column as well as TOC and TN contents in the sediments increased progressively from T_0 to T_2, indicating strong microbial remineralization. Notably, nitrates increased by +63.5 ± 2.5% at T_1 and +69.7 ± 1.0% at T_2; silicates by +18.8 ± 7.0% at T_1 and +31.3 ± 3.6% at T_2; phosphates by +84.6 ± 0.1% at T_2. TN and TOC increased at T_1 by +16.4 ± 0.2% and +10 ± 1.0%, respectively, compared to external conditions. This nutrient enrichment initially stimulated phytoplankton growth inside the mesocosms at T_1, followed by a sharp decrease at T_2 (–75.6 ± 2.4% compared to T_1), likely due to confinement-induced resource limitation. Microphytobenthos (MPB) biomass increased significantly inside the mesocosms (+46.4 ± 19.8% at T_1, +46.6 ± 99.1% at T_2 compared to external conditions), supported by the deposition of organic matter from the water column.

HCP in the water column increased at T_1 (+21.0 ± 1.9% compared to external) but dropped by T_2 (–31 ± 2.7%) as external organic inputs increased due to mucilage and wind mixing. Sediment HCP reached +31.2 ± 0.5% at T_1 internally compared to external values while it dropped to –22.4 ± 1.5% at T_2, indicating fresh organic substrate exhaustion.

GPP in water was lower inside than outside the mesocosms both at T_1 (–5.1 ± 2.0%) and at T_2 (–20.4 ± 0.7%). It also decreased by –44 ± 2.0% from T_1 to T_2 inside the mesocosms. Benthic net primary production (NPPs) also dropped in the enclosures (–26.6 ± 4.1% at T_1; –21.4 ± 1.0% at T_2 compared to T_0), whereas externally increased (+45.5% at T_1; +67.1% at T_2), highlighting the importance of water renewal in supporting benthic autotrophy. CR inside mesocosms dropped by –63.4 ± 2.9% at T_2, indicating a general slowing down of the biological processes under confinement conditions.

Multivariate analysis (NMDS, stress = 0.12) confirmed a shift from oxygenated, productive conditions (T_0), towards a pelagic autotrophic peak at T_1, followed by a transition to benthic-dominated heterotrophy at T_2, with mass and energy fluxes shifting from the water column to sediments. Even a moderate oxygen decrease (–48.1 ± 7.3%) triggered cascading effects in biological and biogeochemical processes. The patchy distribution of *Cymodocea nodosa* prevented the establishment of a proper hypoxia event but modifications in nutrient cycling, productivity, or communities' structure were still observed in both pelagic and benthic domains.

These integrated results highlight how confinement, oxygen depletion and organic matter accumulation can rapidly alter biological processes and biogeochemical cycling in lagoon environments. The dynamic interplay between phytoplankton, microbial communities, and benthic producers under stress provides insights into how semi-enclosed ecosystems may respond to climate-driven scenarios, such as increased stratification, organic loading, and contaminants mobilization.

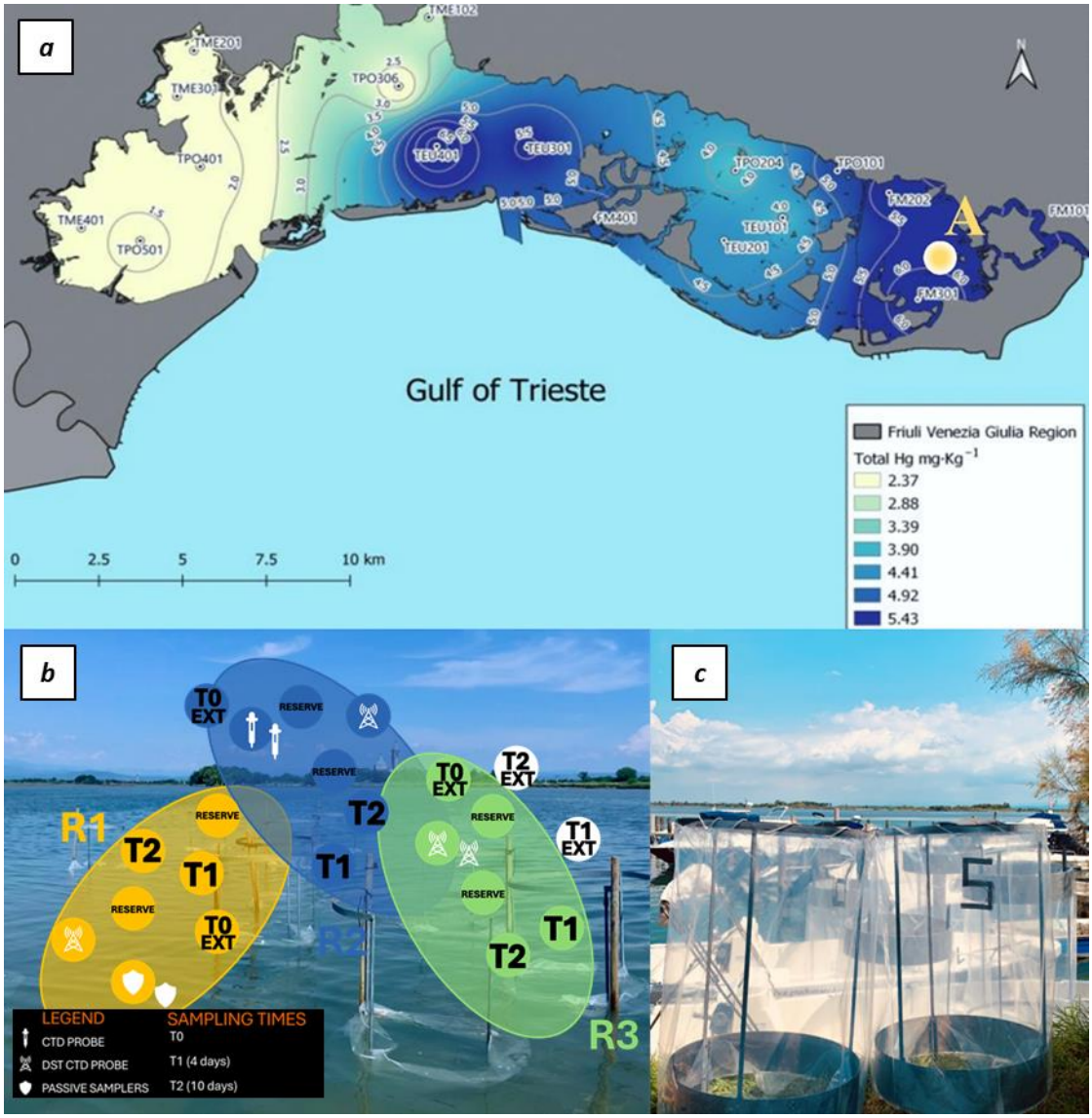


Figure 1. *(**a**) Surface sediment total Hg distribution in the Grado-Marano Lagoon (IDW interpolation, modified from Bettoso et al., 2023). Experimental area in Grado (point A); (**b**) Experimental setup: 18 mesocosms in 3 groups of 6 for triplicate sampling at 3 timepoints; (**c**) Mesocosm detail.*

Field experiments reveal the joint impact of climate stressors and chemical contaminants on *Posidonia oceanica* meadows

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Abstract

The global ocean is experiencing profound transformations driven by climate change and chemical pollution. Rising atmospheric CO_2 levels cause ocean warming and acidification, altering seawater chemistry and threatening marine biodiversity (IPCC, 2023). These stressors affect fundamental physiological processes such as calcification, photosynthesis, and nutrient uptake, leading to large-scale ecosystem changes (Gattuso et al., 2015). Concurrently, contamination by heavy metals (e.g., mercury, arsenic) and sulfide compounds from industrial, agricultural, and urban sources adds further pressure. These toxic substances accumulate in sediments and organisms, disrupting metabolism and reducing resilience to environmental change (Turner, 2021). In coastal systems, the interaction between climate stressors and pollutants can amplify their effects, leading to complex and unpredictable ecological outcomes (Nardi et al., 2020). Within this context, *Posidonia oceanica* meadows in the Mediterranean Sea represent key, yet highly sensitive, habitats. Their physiological vulnerability and ecological role make them ideal models for studying the combined impacts of multiple stressors and for assessing the resilience of coastal ecosystems in a rapidly changing ocean. Studies in natural CO_2-vented areas indicate that elevated CO_2 can enhance photosynthesis and carbon assimilation in *P. oceanica*. However, these potential benefits may be counteracted by increased sulfide intrusion or metal toxicity under warmer, more acidic conditions (Signa et al., 2024; Relitti et al., 2024). Despite this, knowledge of the cumulative effects of climate change and pollution on the long-term functionality of *P. oceanica* and its ability to support biodiversity remains limited. To address this, field experiments were conducted in the fumarolic field of Panarea (Aeolian Islands)—one of the Mediterranean's largest shallow hydrothermal systems. Here, *P. oceanica* meadows display unique traits, such as reduced plant size, lack of a seasonal growth cycle, and a poor epiphytic leaf community (Vizzini et al., 2010; Gambi et al., 2023). These characteristics, combined with the presence of the ECCSEL Nat-Lab Italy laboratory of OGS, make it one of the most suitable natural laboratories to investigate the effects of climate stressors and environmental degradation on this seagrass. Based on the several years of research studies conducted by the OGS

in the area, two representative shallow hydrothermal systems (Hot/Cold and Campo 21), differing in physico-chemical conditions and depth, along with three control sites in Salina Island, were selected for two sampling campaigns (September 2024 and May 2025) to account for the seasonal cycle of *P. oceanica*. Metal element contents were determined in seawater by direct measurements and using passive samplers (DGT). Sediments were chemically characterized by ICP-MS; Hg concentrations in sediments were measured by FKV AMA-254. The physico-chemical characterization evidenced no temperature anomalies in the water column, while confirming the high temperatures of sediments (41°C in September and 54°C in May) in the hot patch of the Hot/Cold site. Average spectrophotometric pH values were lower in May (7.21–7.79), with the lowest at Campo 21 (16 m depth). Continuous pH monitoring revealed stronger fluctuations in September (minimum 6.8) compared to May. Interstitial waters appeared to be strongly acidified with a minimum in samples collected among the *P. oceanica* rhizomes in Campo 21 (21 m) site (pH=5.5). *P. oceanica* showed altered phenology and reduced growth in the first campaign at Panarea sites compared to the controls. Notably, in the former leaf area and leaf number were higher, while rhizome elongation rate decreased. Regarding environmental contamination and carbon dynamics, higher trace element concentration and lower carbon isotope values were observed in surface sediment and *P. oceanica* tissues from Panarea sites, supporting the hypothesis of a strong influence of hydrothermal emissions on contaminant input and carbon uptake. Furthermore, depth appeared to modulate most of these patterns, suggesting possible compensatory strategies to cope with environmental stressors.

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Natural CO_2 Vents as Models to Unravel Ocean Acidification Impacts on Pollutant Dynamics and Health Risks

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Abstract

This study investigates how ocean acidification (OA) influences contaminant bioaccumulation and induces biochemical and molecular stress responses in the Mediterranean mussel *Mytilus galloprovincialis*. Organisms chronically exposed to naturally acidified environments often experience higher energetic demands and oxidative stress, which may impair their detoxification capacity and tolerance to pollutants. To explore these interactions under realistic conditions, mussels were deployed along natural CO_2 gradients off Ischia Island during two distinct seasons (early autumn and early spring) spanning from September 2024 to April 2025. The experiment was designed to assess how seasonal variation in relation to reduced pH modulates contaminant uptake, antioxidant and detoxification enzyme activity, and other cellular stress markers. Results indicate that while acidified environments can lower contaminant accumulation, they simultaneously enhance physiological stress and disrupt cellular homeostasis, particularly under warmer conditions. These findings highlight the complex interplay between OA, contaminant dynamics, and seasonal factors, carrying significant implications for marine ecosystem functioning and, ultimately, human health within a One Health framework.

Ocean Acidification and Human Health: Effects on Contaminant Bioaccessibility and Intestinal Pro-inflammatory Response

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Abstract

Intestinal inflammation is now recognized as a crucial node of the gut-body axis, with significant impacts on the onset of numerous systemic diseases, including metabolic, autoimmune, and neurodegenerative disorders. In this context, the present study investigated how ocean acidification (OA), driven by increased anthropogenic CO_2 emissions, may influence the chemical speciation and bioavailability of environmental contaminants, thereby modulating their toxicity and pro-inflammatory potential at the level of the human intestine.

An in vitro experimental study was conducted using the Caco-2 intestinal epithelial cell line, exposed to extracts of *Mytilus galloprovincialis* collected from two sites on the Island of Ischia (Castello Aragonese and Vullatura), characterized by different degrees of natural acidification and hydrodynamic conditions. Mussels, exposed in situ to three pH levels (ambient, intermediate, and low), underwent in vitro digestion to simulate the human gastrointestinal environment. The resulting extracts were used to treat Caco-2 cells for 24 hours, 72 hours, and three weeks.

Gene expression analyses revealed a differential activation of pro-inflammatory markers (COX-2, IL-6, iNOS, SOD2, p65) and protective markers (ZO-1, IL-10), indicating a significant influence of both pH and collection site on the inflammatory response. Samples from the Vullatura site, subjected to chronic acidification conditions, induced more attenuated inflammatory responses compared to those from Castello Aragonese, suggesting a potential local ecological adaptation.

The results highlight the relationship between environmental changes, contaminant bioaccessibility, and human health, emphasizing the importance of considering the impact of OA on food safety and intestinal inflammatory balance, with relevant implications for systemic health.

Use of passive sampling techniques for the chemical availability evaluation in seawater at various costal marine areas throughout Italy

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Abstract

Assessing the current situation of the global ecosystem is essential to fully understand the current state of the marine environment. Detecting all biologically active inorganic and organic pollutants, analyzing aquatic species (e.g., mussels), which concentrate different kind of contaminants in their tissues in seawater, is often challenging due to a number of factors, primarily their enormous biological variability. Seawater sample collection and analysis are also often inadequate, requiring large-volume sampling systems to ensure quality results while maintaining low detection limits. Significant shortcomings in monitoring the presence of contaminants from various chemical groups lead to well recognized challenges in developing increasingly innovative monitoring techniques, coupled with related measurements of ecological and ecotoxicological impact.

For the time-integrated measurement of available contaminants, passive samplers (PS) represent a proper monitoring technique (Vrana et al., 2005). These devices are demonstrating their reliability, robustness, and cost-effectiveness, and can be very useful for accurately assessing ecotoxicological effects and ecological risk posed by chemical pollutants.

Our group's objective, within the framework of the Italian PNRR project "Return" (which benefits from the collaboration of OGS, University of Padua, within WP4, and University of Siena, involved in the E-Trace project, within the Return project, and DISTAV and University of Genoa, within WP3), is to monitor marine waters in various Italian locations, identified with their different source of contamination and ecological stressors, including those related to climate changing scenarios.

In particular, key study areas are represented by: the harbours of Genoa and Trieste, where a wide range of anthropogenic chemicals occur due to industrial and port activities as well as urban and sewage discharges; the islands of Panarea, Vulcano and Ischia, where secondary volcanism, causing water acidification and temperature increases, allows the study of interactions between aquatic pollutants and climate-change parameters in a natural laboratory; and Grado-Marano and Orbetello lagoons, where chemical pollutants from diverse sources (e.g., rivers) coexist with physical stressors due to limited water exchange.

For each location, from two to six sites were selected for PS placement, as well as for sediments and water sampling. Using a multiparametric probe (CTD), physical measurements, specifically temperature, conductivity, pH, and oxygen were integrated with water samples collection.

Organic compounds were sampled using Semi-Permeable Membrane Device (SPMD) and Polar Organic Chemical Integrative Sampler (POCIS) for lipophilic and hydrophilic compounds, respectively, and were operated for 21 days (Huckins et al., 1990; Alvarez et al., 2004). Additionally, Diffusive Gradients in Thin films (DGT) were deployed for 7 days to sample metals and mercury (Schintu et al., 2008; Vrana et al., 2005; Zhang and Davison, 2000).

Through diffusion (DGT) or adsorption (SPMD and POCIS), they capture the labile fraction of the elements, thus simulating their accumulation in marine biota, allowing to estimate their impact on the environment and organisms.

For metal analysis, the extremely complex matrix often prevents the detection of many trace elements, such as Cr, Cd, and Pb, during seawater analysing. The same is true for Hg: the low concentrations of this analyte in seawater samples and the high salt content of these samples do not allow for accurate analyses of mercury to be carried out with the analytical instruments generally used. Therefore DGT analysis offers an effective method for their detection, and for estimating their bioavailability. For PAHs, at almost all sites, the various components could be detected more effectively than in seawater samples.

Although these devices also have a few disadvantages, such as the inability to identify point events, hydrodynamic conditions that can be highly variable (currents, waves, tides), and, under certain conditions, greater difficulty in implementation, recovery, and logistics, they nevertheless prove to be an useful alternative to the generally used dynamic methods, thanks to the significant simplification of field sampling. Furthermore, time-integrated data obtained by these devices, and in-depth research on biological factors and substance availability, along with ecotoxicology experiments to examine the impacts of chemical mixtures in the marine environment, will be used to improve chemical monitoring and ecological risk assessment of chemical pollution.

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NEWERA – Approcci iNnovativi e Elaborazione Weight of Evidence per l'analisi di Rischio Ambientale

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Abstract

The NEWERA project (iNnovative Approaches and Weight of Evidence Elaboration for Environmental Risk Assessment) was aimed to develop an innovative tool, useful for ecological risk analysis, based on the Weight of Evidence (WOE) approach. The model can elaborate different typologies of data (Lines of Evidence, LOEs), using weighted criteria which allow to summarize the overall significance of complex scientific data in synthetic hazard indices. Such elaborated data are finally integrated into a WOE scheme to provide a comprehensive assessment of environmental hazards across different environmental contexts.

The project was structured around three main components, the conceptual model, data processing and integration, software development. The conceptual model allows the description of the environmental context and a guided or custom selection of relevant LOEs which have been included in an easy-access module, ensuring alignment with European and national directives. In the description of the conceptual model, the user can provide information related to environmental and ecological characteristics relevant to the case-study, such as the proximity to protected areas or biological resources, socio-economic factors, territorial and anthropogenic use, evidence of potential sources of pressure, presence of sensitive biological receptors and routes of exposure, potential implications for human health, information on past contamination events, just to cite a few.

Concerning data processing and integration, standardized procedures and algorithms have been designed to process heterogeneous datasets and generate hazard quotients (HQs) for each LOE, which are then integrated into a synthetic WOE risk index. An interactive module has been developed that allows for the collection of results obtained from different LOEs which include chemical characterization, bioavailability of pollutants, sublethal biological effects measured through biomarkers, ecotoxicological bioassays, and several community-level or ecological indicators for either marine or freshwater environments. The model contain a structured database with the main chemical parameters of interest and the most commonly used references and guidelines for comparing the concentrations of such chemicals in different marine, freshwater, and terrestrial matrices; from the biological perspective, a wide list of species typically used in environmental investigations, allows the end user to make a targeted selection based on the type of contamination, the regulatory or experimental context of reference; a large number of biomarkers relevant for the assessment of sub-lethal and chronic effects on different levels of biological organization, and an

integrated battery of ecotoxicological tests (with marine and freshwater species), have been assigned specific "weights" based on their toxicological relevance and "thresholds" for variations considered of significant biological relevance; the most commonly accepted community descriptors and ecological indices are supported by a taxonomic database containing over 6,000 benthic species, and specific information required at the normative level.

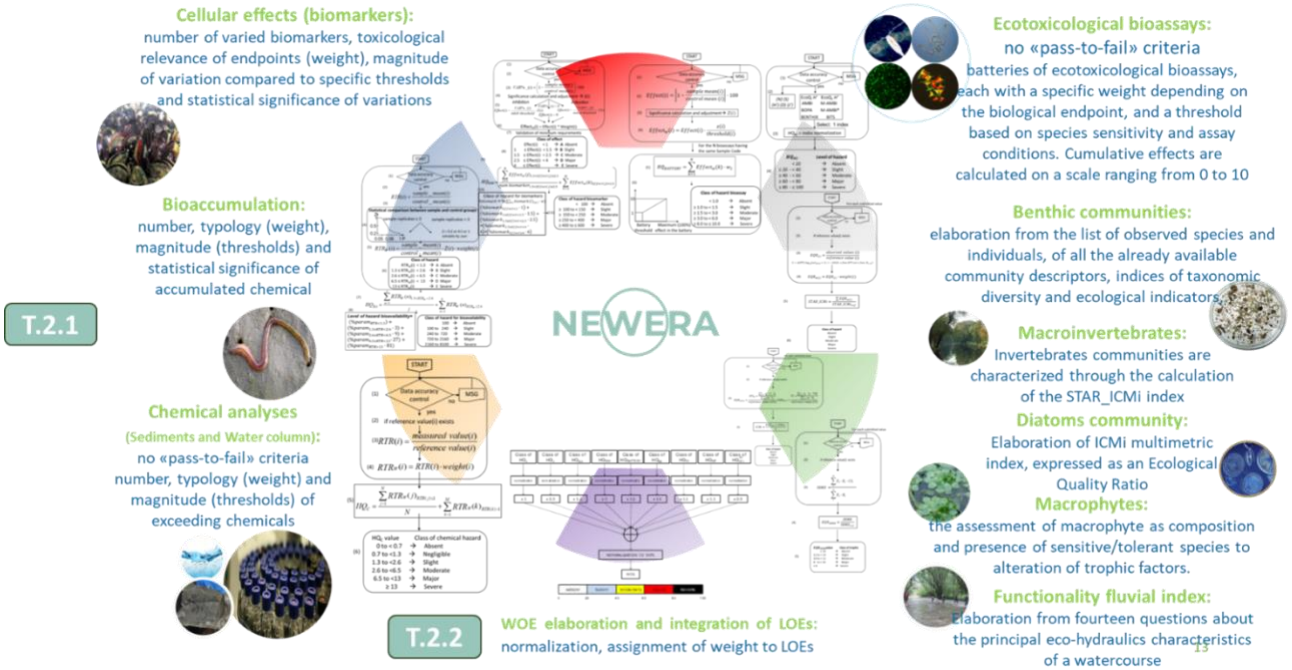


Figure 1. Individual LOEs, weighted data processing procedures, WOE integration, and model validation.

The developed NEWERA software is modular and versatile, enabling application to various environmental scenarios, facilitating the synthesis of complex scientific data into interpretable results, and thus supporting decision-making for environmental management and regulatory authorities. For the first phase of validation of the Weight of Evidence (WOE) model, the results of three case studies representing different environmental contexts were used: a freshwater riverine environment, a coastal marine area subjected to disposal of harbour dredged sediments, and the results obtained from the ETRACE project, also funded in the same cascade call of NEWERA.

All the methodologies are implemented into an open-access, user-friendly web application that allows stakeholders to upload datasets, perform analyses, and visualize outputs as synthetic indices and geospatial maps (Web Application NEWERA link: https://woe-model.univpm.it/newera). The availability of step-by-step user manuals and demo datasets will further strengthen the dissemination and usability of the developed WOE model. By combining scientific rigour, methodological innovation, and digital accessibility, NEWERA provides a robust and flexible tool for

environmental monitoring, fostering knowledge transfer and improving site-specific monitoring and risk management strategies.

E-TRACE – EcoToxicological Risk Assessment of Contaminants and climate change in Ecologically relevant areas

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Abstract

The E-TRACE project applies a multidisciplinary approach articulated into five work packages (WPs) to be tested and applied in a relevant ecological area, the Orbetello Lagoon (Figure 1), characterized by a fragile ecosystem particularly sensitive to the combined effects of anthropogenic activities and climate change. The approach, once validated, could subsequently be transferred and applied to other Mediterranean areas of high ecological interest.
In detail, the results obtained within the different WPs, concerning contamination by microplastics (MPs) (WP1), emerging and legacy contaminants (WP2), will provide data on the distribution, abundance, and characterization of these contaminants in the different environmental matrices considered (sediment, water column) as well as in organisms. A set of ecotoxicological effects in bioindicator organisms (WP3) will also provide the ecotoxicological status of the lagoon by considering alterations in cellular detoxification and biotransformation processes, oxidative stress, neurotoxicity, and endocrine-metabolic toxicity associated with exposure to single compounds or mixtures of substances monitored in the previous WPs. By integrating the different biological responses obtained through toxicity assays and *in vitro* exposures of human cells (via laboratory tests), data will provide insights into the actual impacts across various levels of structural complexity. The results of WP4 will be fundamental for studying ecosystem-level impacts, particularly in ecologically relevant areas such as lagoon environments. Through metagenomics and DNA metabarcoding, it will be possible to assess impacts on biodiversity in relation to the results obtained on the contamination status of the different sites, to investigate the presence of associations and drivers of environmental degradation, such as anthropogenic impacts and climate change.

In detail, Two sampling campaigns were carried out in different seasons (autumn 2024/winter 2025 and spring/summer2025) by collecting from abiotic matrices (surface water, water column, and sediment) during both seasons and subsequently analyzed to determine microplastic abundance and characteristics. Regarding the organisms, 86 specimens of *Chelon labrosus* were collected in autumn 2024 and spring 2025 from two sampling stations (one for half-lagoon: Nassa channel and Ansedonia channel). Additional control organisms were obtained from a control site (the Diaccia Botrona Nature Reserve). Specimens of *Mytilus galloprovincialis* were transplanted, caged and exposed for approximately one month (T1) at four sites within the Orbetello Lagoon. The exposure experiments were carried out in winter and spring 2025.

The analyses of organochlorine contaminants, heavy metals (Hg, Cd, and Pb), and emerging contaminants (PAEs, BPA, and PFAS) were conducted on sediment samples (N = 10), as well as on

specimens of *C. labrosus* (N = 86) and *M. galloprovincialis* (N ≈ 180 per contaminant class), collected from the Orbetello Lagoon in two different seasons, as described aboce

C. labrosus (N = 86) and *M. galloprovincialis* (N ≈ 180), collected during both seasons, were analyzed to evaluate the biological effects by using biomarkers of oxidative stress, immunotoxicity, neurotoxicity, and lipid and energy metabolism in various tissues. Sediment samples (N = 10) collected during the two seasons were also used to prepare eluates, which were subsequently employed in toxicity assays at different trophic levels and *in vitro* tests on human cells.

Water (N = 30) and sediment (N = 30) samples were collected at the five sampling sites (in triplicates) during the autumn 2024 and spring 2025 and subjected to DNA sequencing to assess biodiversity in the Orbetello Lagoon in relation to contamination levels. Metagenomic analyses were conducted on sediment samples to evaluate microbial diversity, while DNA metabarcoding was performed on the water samples to assess metazoan biodiversity.

The integration of the whole results will enable the development of schemes and models for assessing the health status of the ecosystems under consideration, based on the parameters evaluated in the different environmental matrices and in synergies with the Weight of Evidence approach applied in the NEWERA project.

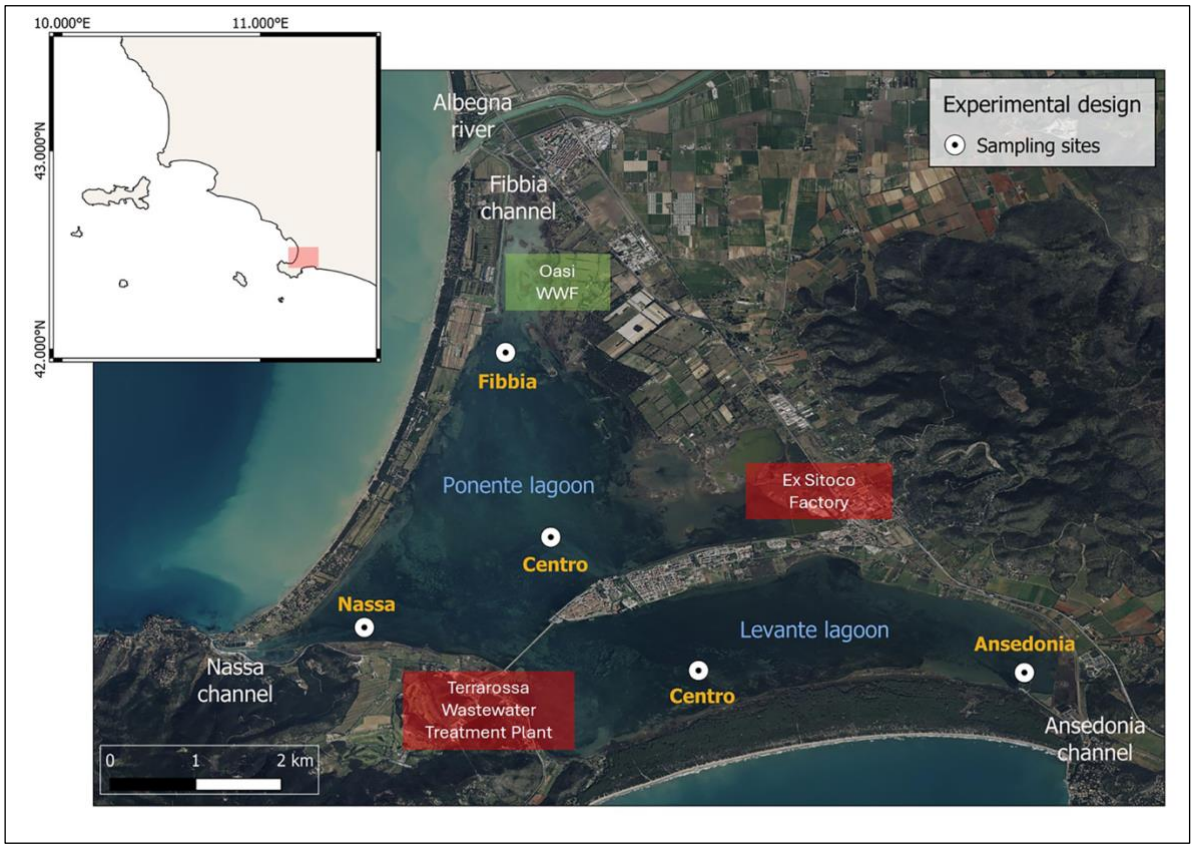


Figure 1. Map of the Orbetello Lagoon showing potential sources of contamination (red) and the WWF natural Reserve (green). The lagoon's connections with the open sea and the sampling sites included in this study (yellow).

Toward Operational Decision Support Systems for Wildfire Risk Management: Lesson Learnt on Data Integration and Modelling from a Benchmark Case Study

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Abstract

Wildfires cause important impacts on human lives, infrastructure, ecosystems, and soil properties, and can induce cascading effects such as enhanced surface runoff and landslides. Advancements in technology and applied research represent fundamental instruments for understanding and mitigating this complex phenomenon. To advance wildfire risk management, novel technologies such as artificial intelligence (AI), Earth Observation (EO) techniques, sensor networks, and drones, should be embedded and integrated into Decision Support Systems (DSSs) to support all the management phases: before, during and after the wildfires.

Considering prevention, remote sensing and proximal sensor techniques, coupled with wildfire modelling, can be used to improve both long term landscape planning and early detection. During the event, fire spread scenarios can provide timely info on potential fire behavior, coupled with drone operations to support firefighting actions. After the event, the quantification of the burned area extent and the severity of the fire can be used to support recovery and restoration planning considering more resilient nature-based solutions adapted to climate change scenarios. This

research focused on the different aspects mentioned above, exploring the use and integration of LiDAR, UAV-based technologies, earth observation techniques, and sensor networks for the development of DSSs.

In this framework, wildfire modeling plays a central role integrating data from different sources to provide wildfire scenarios that support risk assessment, operational response, and post-event learning (Salis et al., 2020). However, the reliability of model outputs depends strongly on both the characteristics of the modeling framework and the accuracy of the input data. To understand the specifications necessary to develop an efficient DDS, it is therefore important to also evaluate tools and data that can be efficiently integrated.

To test this aspect, a comprehensive, data-rich analysis of a single, well-documented wildfire in Central Italy (Venafro, Molise) has been designed to probe the performance and operational implications of three simulation tools well documented in the literature: Farsite (Finney, 1998), Tiger (Giannino et al., 2017), and PROPAGATOR (Trucchia et al., 2020). The selected case study offers an unusually detailed wildfire record for Italy. Ignition time and location, and a reconstruction of fire evolution was obtained via georeferentiation of images from local cameras (perimeters and active fronts) (Fig. 1); fuel information was obtained through expert-based analysis of satellite images and validated in the field; meteorological parameters were measured in local weather stations, and through fine-scale weather models; and a structured chronology of firefighting activities was obtained directly from the firefighting crew. This documentation, assembled through collection of data from multiple sources, allowed to benchmark simulations against observed fire behavior, and to examine how model accuracy evolves as input data are varied from coarse, minimally processed datasets, to detailed inputs that reflect terrain complexity and fine-scale weather variability present in a real-case scenario.

Multiple objectives were addressed in this case study. First, we assessed each model's ability to reproduce the spatiotemporal dynamics of the event, focusing on perimeter evolution and final burned area. Then, we quantified the sensitivity of each model's performance to input data resolution and quality modifying fuel map and weather data, thereby identifying data drawbacks that have a practical implication and that can guide in data collection improvements. We also characterized model-specific constraints – algorithm assumptions, computational costs, and workflow requirements - that influence model adoption for planning, prevention, or emergency operations. We ran simulations for each model and different data sets, from coarse to detailed data, then evaluating performance using qualitative assessments of simulated versus observed wildfire behavior and standard quantitative metrics.

Based on these results, we derived suggestions and key priorities for data collection and software implementation that could enhance wildfire analysis and simulation tools for risk management. These efforts would not only support the calibration, improvement, and testing of wildfire propagation models such as Farsite, Tiger, and PROPAGATOR, but also strengthen post-event analysis. The dataset presented in this study serves as an important benchmark and proposes a practical playbook for reconstructing and simulating wildfire case studies. Also, it simulated the integration of different data sources for developing wildfire scenarios, as required in DDSs.

In conclusion, this research activity has made it possible to explore the latest technological advances in data collection and integration, and their application within simulation models, with the aim of assessing their potential use in operational decision support systems to enhance and advance wildfire risk management.

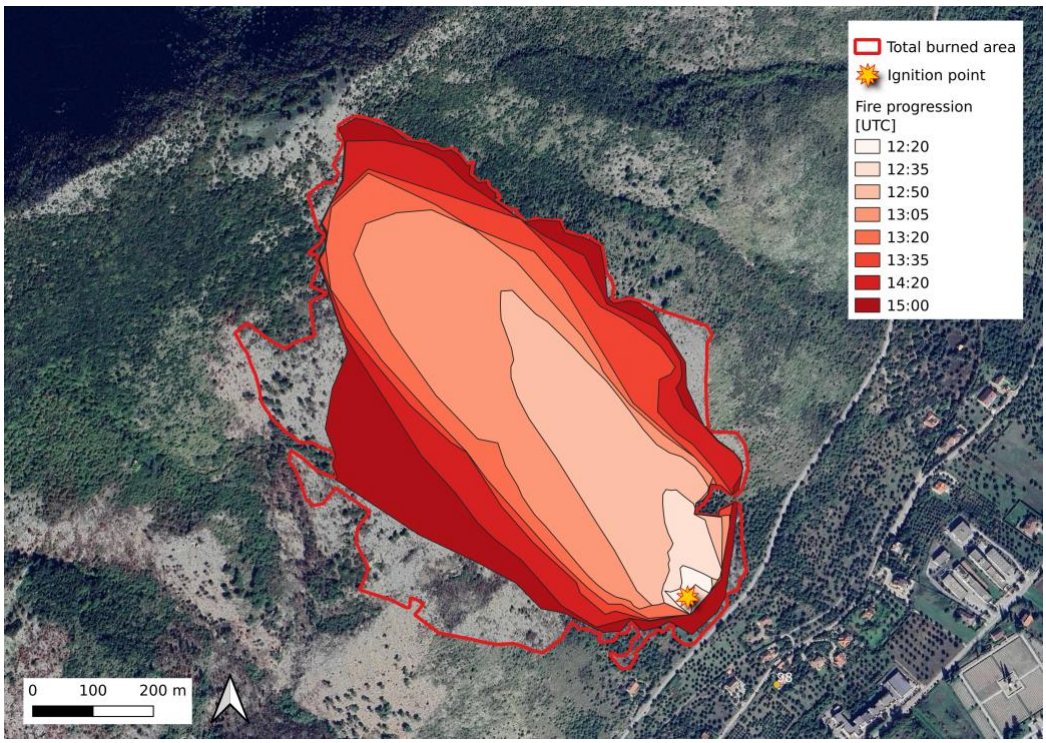


Figure 1 – Venafro Wildfire – total burned area, ignition point and fire progression polygons obtained from satellite images and local cameras.

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Wildfires and Critical Zone processes

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In this talk we summarize the results obtained so far on the analysis of the interplay of wildfires and Critical Zone processes, using the example of the instrumented site in Spotorno, Liguria. We discuss the outcomes of the field measurements (carbon and water fluxes, meteo-climatic variables), of the drone surveys using different sensor types, and the properties of the modelling framework which combines soil-vegetation carbon dynamics and vegetation succession dynamics. The work was done in the framework of the project “CriticalFires”, as a recipient of one of the “Bandi a Cascata” of RETURN, in strict collaboration with the researchers of the CIMA Research Foundation.

UAV Fast Software Development in the AI Age

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Abstract

Despite the expanding capabilities of Unmanned Aerial Vehicles (UAVs), their integration into scientific research remains a developing field, as evidenced by the limited volume of publications across various domains (Kemarau et al., 2024). This gap is often attributed to the significant technical barriers and protracted development cycles required to translate theoretical algorithms into field-deployable prototypes (Pal et al., 2024).

This paper summarizes the results of the DRONERUN project, which addresses this challenge by focusing on the transition from theoretical modeling to the practical implementation of a UAV control system. The primary objective was the validation of an operational methodology based on the Model-Based Design paradigm, aimed at significantly shortening the development lifecycle, from algorithmic conception to field operation.

The implemented methodology was based on the use of the integrated MATLAB/Simulink ecosystem, selected following a comparative analysis for its ability to unify the modeling, simulation, automatic code generation, and validation phases. For the hardware component, the Parrot Mambo drone was chosen for indoor testing, due to its structural robustness and full native compatibility with the software environment.

The core activities involved the development of an autonomous flight application, validated through the simulation of a firefighting mission. The developed algorithm integrates waypoint navigation logic with computer vision functionalities for real-time target identification. Furthermore, advanced architectures were explored through Hardware-in-the-Loop (HIL) testing with Edge AI platforms, such as the NVIDIA Jetson Nano, demonstrating the system's readiness for implementing complex artificial intelligence solutions fully and independently deployed on the UAV.

The process concluded with the automatic generation of C code from the Simulink model and its subsequent deployment on the drone's hardware. Experimental trials, conducted in a controlled indoor environment, confirmed the results obtained during simulation with a high degree of consistency, thereby validating the effectiveness of the entire workflow. This outcome attests to the efficiency of the chosen methodology in reducing the time and complexity associated with prototyping UAV applications, laying a solid foundation for the rapid prototyping of complex autonomous robotic applications for the benefit of the scientific community.

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Enhancing Wildfire Management Through AI-Driven Social Internet of Things and Multisensory Systems

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Abstract

Early Detection and Monitoring of Wildfires through IoT and AI Integration

1. Context and Challenges

The preservation of natural ecosystems, particularly forests, is a global priority due to their vital role in carbon sequestration and climate change mitigation. However, forests are increasingly threatened by extreme weather events, such as prolonged heatwaves and droughts, which heighten the risk and severity of wildfires. These fires not only destroy ecosystems but also release vast amounts of carbon dioxide, amplifying global warming.

Current fire management systems face two major limitations. First, **ineffective early detection**: traditional methods, including satellite imaging, are too slow for real-time intervention. Second, **high costs and poor scalability**: many existing monitoring systems depend on expensive infrastructure, limiting their deployment over large and remote forested areas.

The research presented here—conducted within larger frameworks such as the **RETURN Project**—aims to develop a **cost-effective, scalable, and real-time wildfire detection system**. The approach integrates **ubiquitous IoT sensors** with **Artificial Intelligence (AI)** on a **Social Internet of Things (SIoT)** platform to support prevention, early warning, and coordinated response.

2. Architecture of the IoT/SIoT Solution

The system architecture is designed around three synergistic components: **sensing nodes**, **network transmission**, and a **centralized analysis platform**.

A. Sensing Nodes (Data Acquisition)

At the core of the system is a distributed network of intelligent devices designed to capture environmental and chemical indicators associated with the earliest stages of combustion. Unlike conventional smoke or heat detectors, these nodes act as **electronic noses**, able to sense volatile organic compounds (VOCs) produced during pre-fire conditions.

The chosen hardware includes **Bosch BME688 sensors**, capable of measuring temperature, humidity, barometric pressure, and an Indoor Air Quality (IAQ) index related to VOC concentration. Their ultra-low-power operation and low cost enable large-scale deployment. These sensors can

detect even minimal parameter variations, allowing the system to estimate both **fire direction and propagation speed** in real time.

B. Network and Transmission

Communication reliability and energy efficiency are critical in vast and remote forest environments. To address these needs, the system employs **LoRa (Long Range)** wireless technology within a **Wireless Sensor Network (WSN)** architecture. LoRa enables the low-power sensing nodes to transmit small data packets across long distances, ensuring scalability and minimal maintenance.

This network design provides wide coverage at low cost, overcoming the constraints of cellular or Wi-Fi systems. Data is transmitted efficiently to the SIoT platform for real-time analysis, enabling rapid detection and response.

C. Platform and Analysis (SIoT)

Data collected by the sensing network is aggregated on a **Social Internet of Things (SIoT)** platform. In this environment, IoT devices interact socially—sharing data, forming relationships, and influencing each other's behavior based on reliability and reputation metrics. AI algorithms analyze these data streams to detect anomalies and identify early signs of fire.

A particular focus is placed on **system trustworthiness**. Reputation and reliability models are incorporated to reduce false positives and negatives, ensuring robust operation under changing environmental conditions.

3. Artificial Intelligence Model and Implementation

AI constitutes the decision-making core of the system. The project developed and validated **neural network models** capable of classifying fire states into four categories: *No Fire*, *Start Fire*, *Fire*, and *End Fire*.

Machine learning approaches such as **K-Nearest Neighbors (KNN)**, **Recurrent Neural Networks (RNN)**, and **feed-forward neural networks** were tested. The final configuration—a lightweight **Multilayer Perceptron (MLP)** with one hidden layer—was selected for its balance between expressive power and deployability on **edge devices** with limited computational resources.

Training and Validation

Training data were collected from **controlled ignition and extinguishing campaigns**, where BME688 sensors simultaneously recorded temperature, humidity, pressure, and gas resistance. This dataset captured all fire phases under realistic conditions, enabling the model to learn subtle correlations between environmental changes and fire evolution.

The **AI model achieved over 98% accuracy** in detecting and classifying fire states, successfully predicting both ignition and spread direction. Validation in real forest environments confirmed its operational reliability and scalability.

Error Analysis and Optimization

Error analysis revealed that most misclassifications occurred during **transition phases** (Start/End), where sensor responses overlap between states. Proposed mitigation strategies include:

- **Temporal smoothing and hysteresis** in decision-making;
- **Class reweighting** to address imbalance in transitional states;
- Simplified **binary (Fire/No Fire)** or **ternary (No Fire/Fire/End)** classification for operational deployment;
- **Improved measurement campaigns** to ensure better label balance and synchronization across nodes.

The results demonstrate that the 4–8–4 neural network, combined with standardized preprocessing and robust evaluation, provides a strong foundation for wildfire state classification. Future improvements will focus on incorporating temporal data and cross-node validation to further enhance resilience and accuracy.

4. Conclusions

This research presents a **validated, scalable, and low-cost wildfire detection system** combining **IoT sensing, LoRa networking, and AI-based analysis** within a **Social IoT framework**. The system detects early combustion signatures with high accuracy, enabling **real-time fire monitoring and prediction**. Its architecture supports large-scale, autonomous operation in remote environments, ensuring resilience, trustworthiness, and adaptability.

By uniting **low-power distributed sensing** with **intelligent data analysis**, the proposed approach represents a significant step toward next-generation, data-driven environmental protection and **proactive forest management**.

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FLAME - Forest Learning for Autonomous Machine Early fire detection

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Abstract

The FLAME project directly addresses the increasing global threat of wildfires, which are aggravated by climate change and pose significant risks to ecosystems, biodiversity, and community safety. Responding to the urgent need for advanced early detection and prevention systems, FLAME leverages technological innovation and Artificial Intelligence. The project focuses on developing high-reliability machine learning algorithms for early wildfire detection, integrated within a low-cost Social IoT network. Core activities include the collection and analysis of environmental data, the development and tuning of AI algorithms for low-cost microcontrollers, and the creation of a structured database for AI training and event archiving to enable comprehensive risk analysis and mitigation strategies. The overall goal is to prevent wildfires, reduce damage to ecosystems and communities, and optimize rescue resources. The project ultimately aims to improve fire management capabilities for local authorities and competent bodies, while promoting sustainable development through the use of renewable energy and eco-compatible technologies.

Post-fire ecological trends and support to forest fire simulation

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Abstract

This short presentation summarises the contribution of Università degli Studi di Padova, TESAF Department, to the activities of WP 3.4 in the second period of the Project. The topic of forest fires has been analysed both in terms of their effect on forest ecosystems, and in terms of data collection to realistically reconstruct a forest fire history.

To answer the two research questions extensive field data sampling has been carried out in Spotorno (Savona, Italy) and Venafro (Isernia, Italy). In the first case, all forest regeneration individuals have been georeferenced in a burnt area to search for the ecological factors that drive forest expansion after fire; along with ancillary data collected on the ground (shrubs species and location), and data collected with UAVs by the partners (digital surface and terrain models), geospatial models have been trained to identify the most suitable micro-sites for post-fire forest regeneration establishment, obtaining satisfactory results. In the second case, field data were collected and shared with the other Partners to enhance the representation of a simulation scenario where three different pieces of software and 10 combinations of simulation parameters where contrasted to find pros and cons of each simulation model.

The activities of UNIPD-TESAF fall within those carried out together, and by the other Working Package partners, with the aim of better understanding of the effects of forest fires on the ecosystems, and how simulators can be used to predict and reduce their negative effects.

Drivers of spatial variability in post-fire forest regeneration

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Abstract

This study examines spatial distribution of post-fire forest regeneration in a Mediterranean case study. Wildland fires have a profound and long-lasting effect on forest ecosystems, but Mediterranean forests show adaptations to this natural disturbance, and forest regeneration, i.e. juvenile trees, may onset early after fire. Naturally occurring forest regeneration rarely distributes evenly in burnt areas, leveraging the best micro-sites to germinate and survive; in addition, post-fire biological legacies, especially remnant mature trees, have a pivotal role in determining seed dispersal, and consequently regeneration distribution.

In this study we recorded the geographical coordinates with centimetrical precision of all regeneration of *Pinus halepensis* Mill. (Aleppo pine) in an area burnt first in 2006, and successively in 2015, near Spotorno (Savona, Italy). This pine species is adapted to severe fires thanks to its serotinous cones, specific fruits that preserve seeds from fire heat and release them after fire extinction: this strategy guarantees an early colonisation of burnt areas, although post-fire distribution of regeneration was heterogeneous also for this species.

To identify the areas with the highest suitability for post-fire pine regeneration we set up a spatial modelling framework combining environmental predictors and regeneration presence data to feed a Random Forest model calibrated with ecologically weighted pseudo-absences. We observed a direct relationship between sapling occurrence and favorable micro-site conditions (Fig. 1), such as proximity to mature remnant trees, moderate wetness values quantified through the Topographic Wetness Index (Beven & Kirkby, 1979), and high potential solar radiation estimated through the Heat Load Index (McCune & Keon, 2002).

The findings add to the literature on post–fire forest regeneration dynamics and shed light on the ecological response of a fire-adapted species to successive burns, showing an early response after the event and unexpected trends which will require special attention.

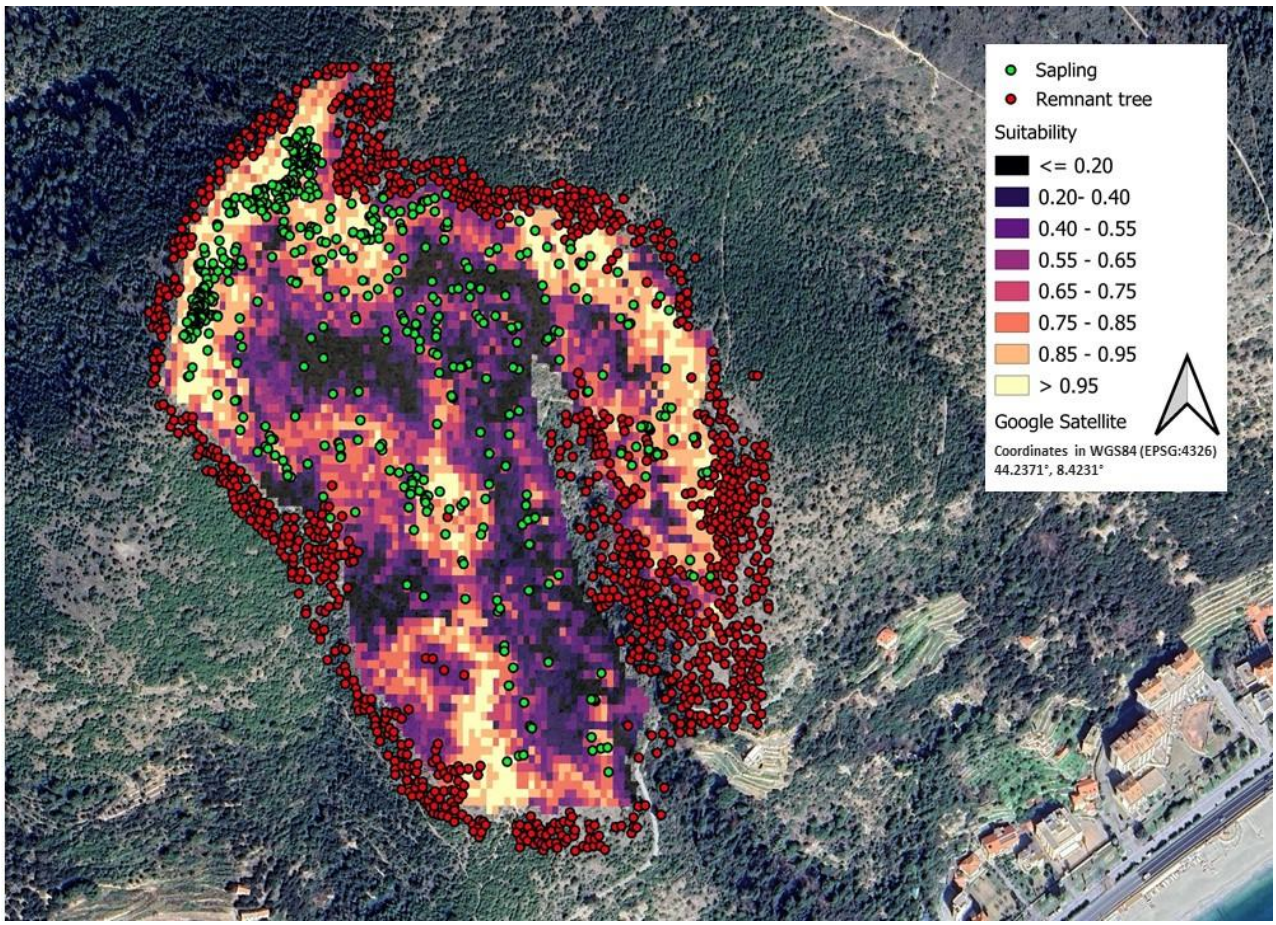


Fig. 1: Ecological suitability map derived from the Random Forest model. Lighter colours indicate a higher spatial probability of encountering post-fire *Pinus halepensis* Mill. regeneration.

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Advancing the PROPAGATOR Wildfire Simulator: Modeling Surface-to-Crown Fire Transitions with LiDAR-Based Fuel Characterization

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Abstract

Wildfires represent a growing threat to ecosystems, human lives, and infrastructures, particularly in Mediterranean regions where extreme weather and fuel accumulation drive increasingly severe fire events. Accurate simulation of wildfire dynamics is fundamental for effective risk mitigation and emergency response planning. To this end, the PROPAGATOR model - a stochastic Cellular Automata (CA)-based wildfire simulator - has been developed to provide fast and reliable fire spread predictions, integrating complex interactions between topography, vegetation, and meteorological conditions (Trucchia et al. 2020). Initially conceived under the request of the Italian Civil Protection Department, PROPAGATOR has evolved into an operational tool supporting real-time decision-making (Trucchia et al. 2024), with promising application in risk mitigation planning (Perello et al. 2024). The model is available both as an online application for selected users and as open-source code on GitHub (https://github.com/CIMAFoundation/propagator_sim).

The model adopts a raster-based implementation where each cell represents a portion of the landscape characterized by specific fuel type, slope, aspect, and elevation, while dynamic inputs include wind fields, fuel moisture, and ignition points. Through a stochastic contamination process between burning and unburned cells, the simulator accounts for uncertainties in fire behavior by generating ensembles of independent realizations. This approach enables the derivation of probability maps describing the likelihood of fire occurrence in time, and statistics on rate of spread and fire-line intensity, providing valuable information for emergency managers. Moreover, the simulator allows the inclusion of firefighting strategies, such as artificial modifications of fuel moisture – emulating use of Canadairs or helicopters' water drops - or the introduction of firebreaks, enhancing its operational utility during ongoing fire events.

While PROPAGATOR has demonstrated robust performance in simulating surface fire propagation, a major challenge in advancing wildfire modeling lies in introducing information on fuel structure and accurately representing the transition from surface to crown fires. Crown fires are characterized by faster spread rates, higher energy release, and greater unpredictability than surface fires. These dynamics lead to increased difficulty in suppression, enhanced spotting, and severe ecological consequences including canopy mortality and soil degradation. Thus, capturing crown fire behavior is critical to improving both risk assessment and tactical firefighting operations. Also, by the introduction of fuel structure information, the model would better support its use for fuel

management planning, thus offering a comprehensive tool to integrated into Decision Support Systems (DSSs) for wildfire risk management, which would support from risk mitigation to emergency response.

The current research focuses on the integrationof crown fire processes into PROPAGATOR, expanding its capabilities from two-dimensional to quasi three-dimensional (2.5D) representation of the fuel structure. Two main processes are considered: Crown Fire Initiation, which depends on surface fireline intensity and *Crown Base Height*, and Crown Fire Rate of Spread, which is influenced by *Canopy Bulk Density* and foliar moisture content. Based on established empirical and semi-empirical models (Cruz et al. 2005; Scott & Reinhardt 2001), a Crown Fire Module has been designed to include this fire behavior within the stochastic CA framework of PROPAGATOR.

Implementing these modules requires a detailed description of surface and canopy fuel characteristics and structure, which are difficult to obtain at large scales. To address this, LiDAR and UAV-based remote sensing can be employed to estimate fuel parameters (Martin-Ducup et al. 2025). Preliminary analyses have been conducted for Venafro (Molise) and Spotorno (Liguria) sites, providing high-resolution datasets for model calibration and validation. This analysis allowed us to explore the possible integration of this data into PROPAGATOR model, and to analyze the feasibility in extending this information to large scale areas, bridging the gap between local-scale detailed observations and operational-scale wildfire simulations.

The enhanced PROPAGATOR version will therefore include Crown Fire Initiation and Spread Models within its stochastic propagation rules, maintaining computational efficiency while improving realism in complex fuel scenarios. By incorporating Vertical Interaction Mechanisms, the upgraded system can simulate transitions between surface and crown fires, as well as mixed fire behavior conditions, thereby offering a more comprehensive representation of wildfire dynamics.

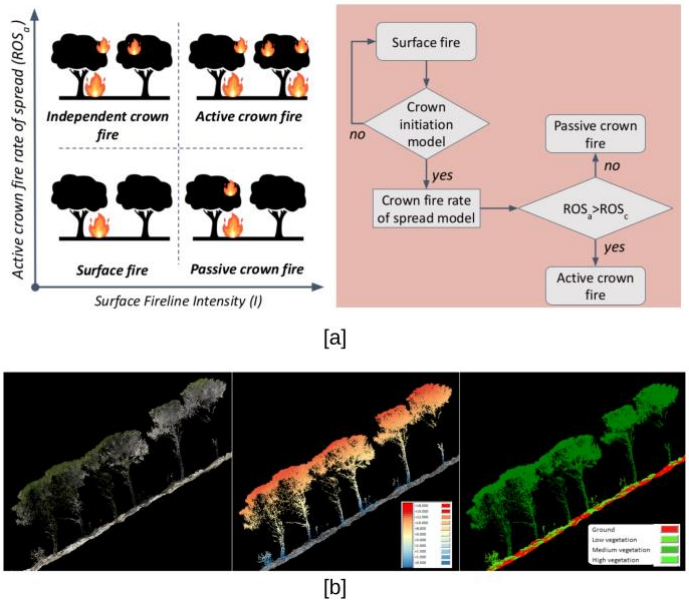


Figure 1 – In [a], the Crown Fire Module schema for PROPAGATOR; in [b], the analysis of a section from a LiDAR acquisition in Venafro (Molise, Italy).

In conclusion, the integration of crown fire dynamics into the PROPAGATOR simulator will represent a significant step forward in wildfire modeling. It enhances the capacity to capture critical vertical interactions within vegetation layers, contributing to improved operational scenarios, strategic planning, and risk mitigation. Moreover, the combination of remote sensing technologies and stochastic modeling establishes a pathway to better understand and manage extreme wildfire behavior in a changing climate.

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The use of drones for firefighting operations enhancement: mathematical models and legal constraints

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Abstract

The main purpose of the project is to integrate an automated robotic drone management platform into the activities of firefighting teams. The platform is able to enable the continuity of UAV use by automatically changing the payload of drones and replacing the exhausted battery. In order to understand how to integrate a continuous use of drones and the use of an automated management platform, the current firefighting procedures, chain of command (from detection of a fire outbreak, determination of shooting hotspots, to damage assessment), vehicles and personnel, and existing infrastructure were first studied and analyzed. These analyses have been collected in a paper to be submitted to IEEE Access (Rossi et al., 2025). However, the use of drones to be effective requires the development of algorithms that can assist firefighting teams. Therefore, predictive fire models, automatic strategies for deciding where to direct firefighting, and an observer capable of estimating the rate of spread were studied, leading to the publication of (Alessandri et al., 2024).

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Multiscale modeling framework for contaminants transport and reaction with uncertainty quantification

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Abstract

In the framework of the PNRR-RETURN project - VS4 "Environmental degradation" The task 3.5 aims to improve our understanding of processes related to biological threats to coastal marine ecosystems/natural aquatic environments, particularly the spread of microbial pollutants (i.e., genes conferring antimicrobial resistance and the presence of potentially pathogenic bacteria) and the expansion of invasive alien species. Investigations will combine the use of sampling surveys, collection of existing data, and numerical modelling.

The present document provides a summary of the results of the activities conducted in the framework of WP4.3 ("Enhancing capability to observe, model, and assess environmental hazards"), task T4.3.1 ("Contaminant fate and transport models in water, groundwater and soils; innovative approaches to monitoring environmental pollution and quantification and reduction of uncertainty").

In compliance with the executive working plan of the whole project, T4.3.1 involved using innovative techniques to detect and measure contaminants in different environmental compartments as well as in animal and plant organisms to provide the framework for risk assessment of anthropic activities. Target contaminants include **microplastics** (from both conventional plastics and bioplastics), **elongated mineral particles** (EMP), **hydrocarbons**, **heavy metals**, **antibiotics**, **drugs**, **pesticides**, and other **contaminants of emerging concern** (CECs).

A range of approaches including advanced analytical determination, lab-scale studies, full-scale monitoring, theoretical assessment of contaminant dispersion in the environment, modelling of transformation/ transport/bioaccumulation/biomagnification mechanisms, quantification of hazard and risk related to the presence of contaminants were developed and used at different time/space scales to determine the evolution and transformation of contaminants in terrestrial water ecosystems, groundwater and soils. Specific attention has also been paid to the evaluation and quantification of uncertainty in the assessment and modelling of hazard and risk.

Task T4.3.1 is complementary to the companion task T4.3.2 that focuses on the same issues for marine ecosystems, so that the approaches adopted and the results obtained should be regarded in mutual combination.

The results of the investigation activities of T4.3.1 delivered as the final output of the project are grouped based on the three main thematic areas indicated below.

1. Development, application and validation of methods and protocols for the detection and quantification of contaminants in the environment (examples of some results obtained are reported in Figure 1):
   i. Microplastics detection in groundwater and drinking water (UNIFI);
   ii. Advanced identification/classification of micro-bioplastics in organic matrices through SWIR hyperspectral imaging (UNIROMA1);
   iii. Direct measurements of vapour emissions in contaminated site by means of dynamic flux chambers (UNIPA)
   iv. External polymeric substances for metal removal from wastewater (UNIFI).
2. Development, application and validation of methods for advanced environmental monitoring (examples of some results obtained are reported in Figure 2):
   i. Spatial distribution and contamination indices in Sicilian soils, including determination of the geochemical baseline and geostatistical mapping (UNIPA);
   ii. Monitoring of microplastics at river basin scale (Arno River) and related mass balance, and evaluation of microplastics removal efficiency by wastewater treatment systems (UNIFI);
   iii. Conceptual framework and material flow analysis for the assessment of bioplastic flows in the environment (UNIROMA1).
3. Data analysis and modelling of transport, diffusion, transformation, degradation of contaminants as well as prediction of their effects on human health, flora, fauna and environment quality (examples of some results obtained are reported in Figure 3):
   i. Geochemical processes related to nanoscale dissolution in porous systems and reactive transport models for diclofenac fate in soil-water systems (POLIMI);
   ii. Simulations of contaminant transport with varying bed topography in wetlands (UNIPD);
   iii. Prediction of micropollutant fate in urban water, including integrated hydraulic–pollutant transport modelling, risk assessment and evaluation of risk mitigation strategies (POLIMI)
   iv. Assessment of the environmental impact of microplastics and bioplastics with regard to effects on plant-pollinator interactions, resistance to pathogens and plant physiology, and persistence in soils (UNIFI, UNIROMA1);
   v. Study of anaerobic degradation of bioplastics to assess the environmental impacts of end-of-life bioplastic products (UNIROMA1).

Considerable efforts to efficiently integrate the multiple competences of the participants to T4.3.1 (encompassing the fields of chemistry, geology/mineralogy, hydrogeology, fluid mechanics, biology/botanic, civil and environmental engineering) were made in order to attain the main target of WP4.3, involving the development of advanced methodologies and tools to observe, model and assess environmental hazards as thoroughly and comprehensively as possible.

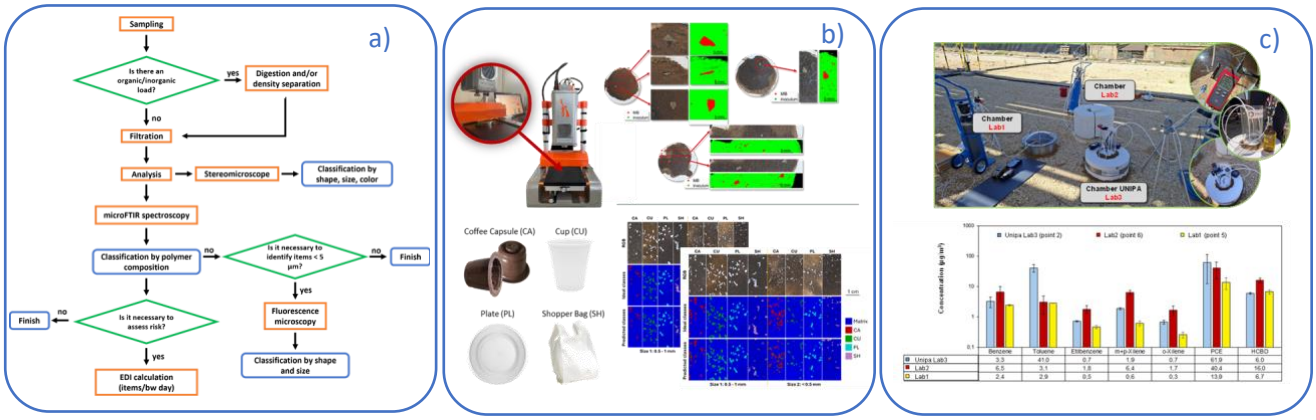


Figure 1 – Examples of results obtained for the thematic area 1: Microplastics detection in groundwater and drinking water (a); Advanced identification/classification of micro-bioplastics in organic matrices through SWIR hyperspectral imaging (b); Direct measurements of vapour emissions in contaminated site by means of dynamic flux chambers (c)

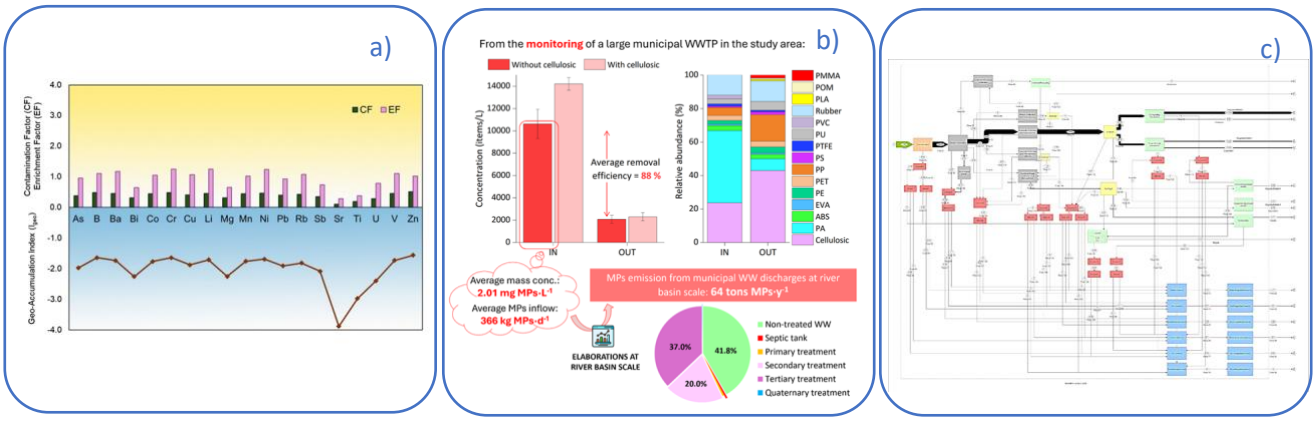


Figure 2 – Examples of results obtained for the thematic area 2: Spatial distribution and contamination indices in Sicilian soils (a); Monitoring of microplastics removal by wastewater treatment systems (b); Conceptual framework and material flow analysis for the assessment of bioplastic flows in the environment (c).

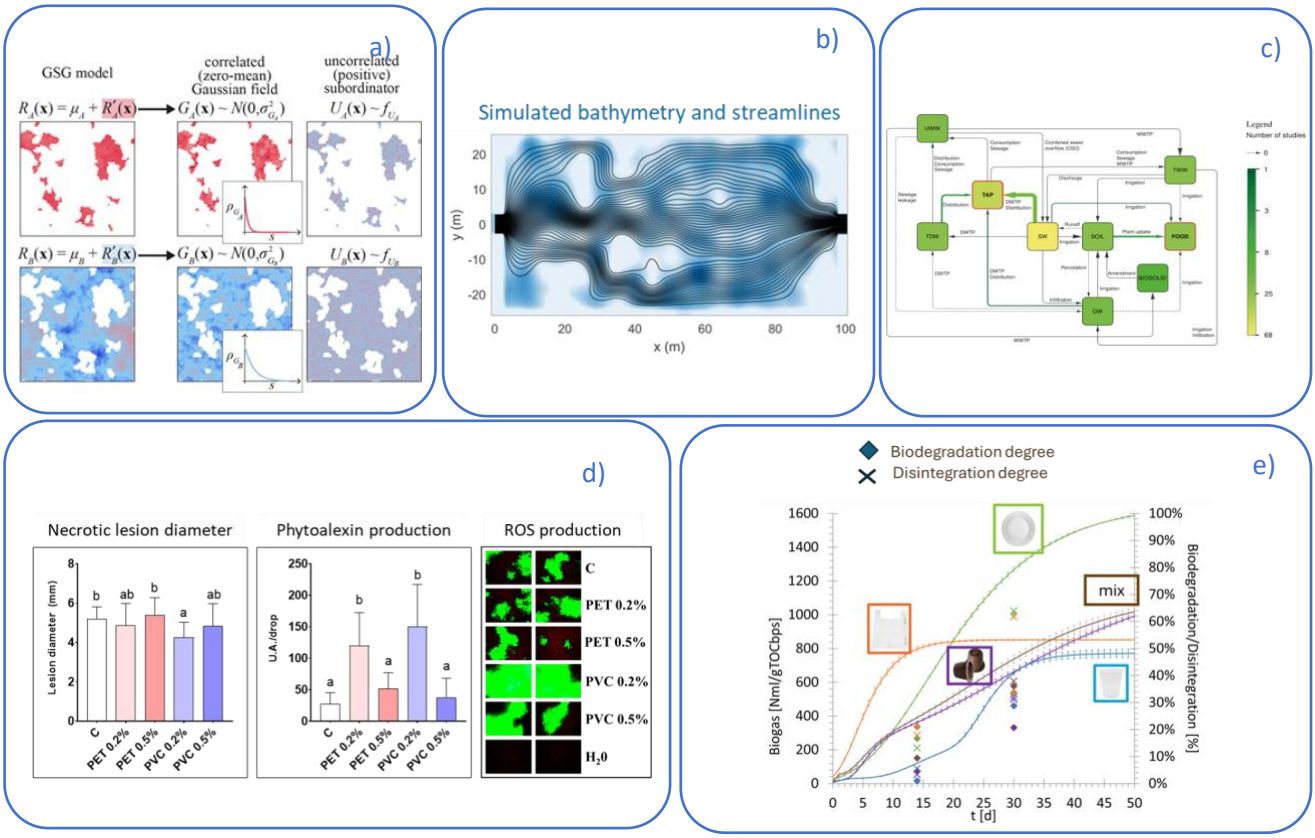


Figure 3 – Examples of results obtained for the thematic area 2: Geochemical processes related to nanoscale dissolution in porous systems and reactive transport models (a); Simulations of contaminant transport with varying bed topography in wetlands (b); Prediction of micropollutant fate in urban water (c); Assessment of the environmental impact of microplastics and bioplastics on soils (d); anaerobic degradation of bioplastics (e).

Contaminants and plastics fate in coastal and marine areas: main outcomes from Task 4.3.2 activities

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Abstract

A comprehensive overview of multidisciplinary research activities addressing the distribution, transport, and impact of contaminants in coastal and marine environments, with special focus on microplastics (MPs), macro litter, mercury, and pharmaceuticals is proposed. The activities, carried out by the research groups involved in Task 4.3.2, integrate field sampling and surveys, advanced modeling tools, and innovative analytical techniques and procedures to understand contaminant dynamics and their implications on human health and biota in different spatial and temporal scales. The modeling component has addressed the fate and transport of contaminants (mercury, plastics, oil, and pharmaceuticals) in the sea up to biota (mercury) using spatially explicit models that integrate different approaches to simulate the contaminant pathways from coastal inputs to marine biota. Sampling and analytical activities have provided critical data and approaches to characterize contaminant sources, distributions, and effects.

Investigated themes include:

- Monitoring and modeling of macro and micro litter in coastal zones;
- Modelling pollution hazards in marine ecosystems;

- Assessment of MPs in surface waters and benthic fish, with evaluation of human exposure via seafood
- Investigation of sediment contamination in port areas, accounting for marine dynamics and riverine inputs
- High-resolution mapping and modeling of plastic and bioplastic transport using drone-based and in situ observations with integrated uncertainty quantification;
- Hyperspectral imaging techniques for precise identification and classification of plastics in various environmental matrices;
- Evaluation of physiological responses of aquatic plants exposed to MPs, and potential use of phytoremediation in contaminated waters.

In detail, the contribution of the OGS group focused on spatially explicit models for simulating the fate and transport of coastal pollutants, including mercury, plastics, oil, and pharmaceuticals, up to their bioaccumulation in marine organisms. Multiple modeling approaches are employed, such as Lagrangian transport, biogeochemical cycles, food web modeling, and genomics. UNIBA activities focused on the analysis and distribution of macro and micro litter in coastal zones through multi-technology monitoring and modeling, with a focus on beach litter and MPs found in sediments and the water column. UNIFI group assessed the presence of MPs in surface waters and benthic fish (e.g., red mullet) across Mediterranean ports, with a specific evaluation of human exposure and MPs intake in different population groups from contaminated fish. In addition, the UNIFI team examined the physiological effects of MPs in model aquatic plants (*Spirodela polyrhiza*) grown in water with blue-fluorescent MPs, investigating the role of root exudates in MPs aggregation and exploring phytoremediation potential in contaminated waters. UNIGE investigated the presence of MPs in port sediments to analyze the influence of marine hydrodynamics and freshwater inputs. Water dynamics and physical parameters were acquired with ADCP and CTD probes. UNIPA group conducted high-resolution mapping of plastic and bioplastic transport through drone and in situ surveys, coupled with multiscale modeling approaches, incorporating uncertainty quantification. UNIROMA1 developed innovative HSI-based strategies to identify and classify macro- and microplastics in complex matrices such as sandy beach and marine sediments, including the use of a custom HSI micro-scanner for improved MPs detection.

In line with the aims of WP 4.3, activities envisaged in Task 4.3.2 were focused on the analysis of processes related to pollutants distribution, transport, and their bioaccumulation and magnification in marine and coastal areas and related matrices (i.e., sediments, water column, and biota). By combining field surveys, analytical strategies, and innovative modeling tools, the activities envisaged in the frame of this Task have contributed to the definition of an integrative framework for the analysis of contaminant behavior and environmental risks in marine coastal systems, supporting both environmental and public health protection.

Challenging the complexity: high resolution modeling tools for coastal regions and open ocean areas

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Abstract

Here we introduce a series of high-resolution modeling tools that have been developed and used to produce hindcasts and climate projections datasets for the Northern Adriatic region (proof of concept area of Return DS8) and the Orbetello lagoon. These modeling tools come from the synergistic efforts within the Return project among participants of spoke VS4 and between spoke VS4 and DS8, in collaboration with the PNRR project TeRABIT and the computational resources of the ICSC – Centro Nazionale di Ricerca in High Performance Computing, Big Data and Quantum Computing – Spoke 4 Earth and Climate.

In particular here we introduce:

- the Northern Adriatic configuration of Regional Climate Model RegCM v5 (hereafter $RegCM5_{std}$, Giorgi et al., 2023) with a horizontal resolution of 3 km and 41 vertical levels (convection permitting). Furthermore, the model adopts CLMU as an urban climate model. The model has been employed to produce convection permitting hindcast for the period 1987-2020 by using ERA5 as initial and boundary conditions and climate projections for three 10-years windows (under emission scenarios SSP3-7.0) corresponding timely to three different levels of Global warming (GLW), namely 1.5°C (2005-2014), 3°C (2053-2062) and 4°C (2072-2081). For the latter the initial and boundary conditions derive from a previous downscaling at 12 km of the CMIP6 model EC-EARTH3-Veg (also produced by $RegCM5_{std}$).
- the Northern Adriatic configuration of the Cetemps Hydrological Model CHyM (hereafter $CHyM_{std}$, Coppola et al., 2007) with a horizontal resolution of approximately 1 km. The model has been employed to produce high-resolution hindcasts and climate projections for the same time windows considered in $RegCM5_{std}$.
- The Northern Adriatic Sea configuration of the ocean circulation model $MITgcm_{STD}$ (Marshall et al., 1997 a,b) with a horizontal resolution of approximately 700 m and 27 vertical levels. The model has been employed to simulate the dynamics of the basin in three 10-years windows (1995-2005, 2041-2050 and 2090-2099) under RCP8.5 emission scenario. The $MITgcm_{STD}$ is forced offline by precomputing fields derived from a previous downscaling of the CMIP5 HadGEM-ES model made by using RegCM v4.7 in convection permitting configuration (Pichelli et al., 2021).
- the Northern Adriatic configuration of Regional Earth System Model RegCM-ES (Reale et al., 2020) that uses RegCM5 (Giorgi et al., 2023) with a horizontal resolution of 3 km and 41 vertical levels (convection permitting), CHyM (Coppola et al., 2007) with a horizontal resolution of approximately 1 km and MITgcm with a horizontal resolution of approximately 700 m and 59 vertical levels. The modeling tool has been used to produce an hindcast for the period 1987-2004.
- A two-dimensional coupled model of the hydrodynamic and ecological processes of the Orbetello Lagoon (central Italy). The model includes the simulation of pumping stations installed at the lagoons inlet and allows for the prediction of water temperature and salinity, the nutrient cycle in the water and bottom sediment, the growth and decay of rooted vegetation, macroalgae, phytoplankton, and

zooplankton, as well as the oxygen cycle, with a primary target being the accurate simulation of hourly dissolved oxygen levels in the lagoon.

In the Northern Adriatic region, the analysis of the newly available datasets for the atmospheric and ocean compartments (more than 100 TB of data so far) has shown for example a general improvement in the simulated precipitation regime in Autumn (the wetter season over the region) by RegCM-ES with respect to the only-atmosphere model $RegCM5_{std}$ (Figure 1). Moreover, projections show a significant warming of the region (for example in summer, Figs. 2) and of the Northern Adriatic Sea (in particular in the coastal areas) along the 21st century with respect to the beginning of the century (Figs. 3) as well as significant changes in the precipitation regime (Figs. 4).

For the Obertello lagoon the numerical output was used to evaluate the impact of some lagoon management strategies (e.g., the effect of pumping systems, removal of obstructions at inlets, and channels dredging), on dissolved oxygen content that was not previously available in the scientific literature (Figs.5).

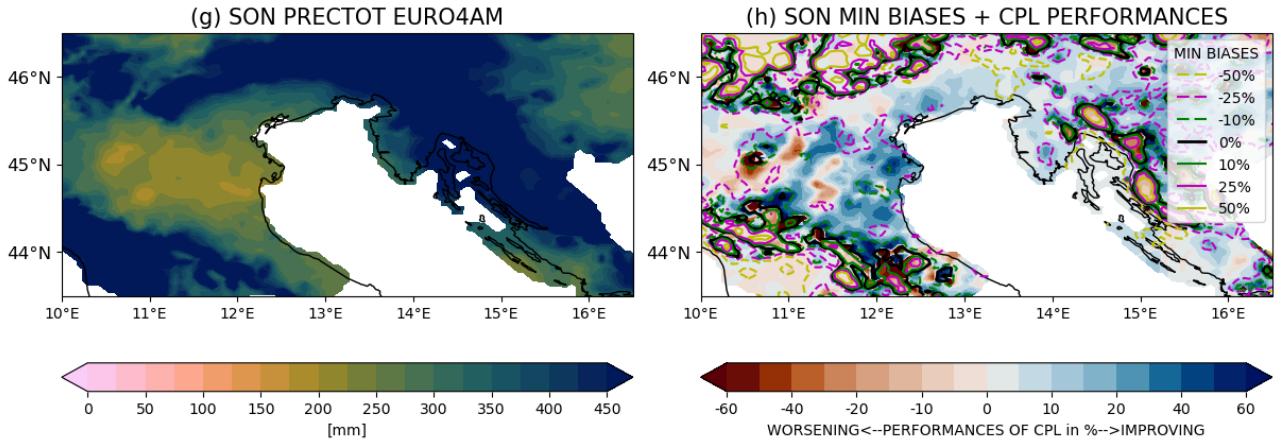


Figure 1 – Autumn (September, October, November, or SON) total precipitation (in mm) in the period 1989-2004 according to EURO4AM dataset (left panel): minimum bias between the simulated values (in %, right panel, contour lines) with respect to EURO4AM and added value of RegCM-ES with respect to $RegCM5_{std}$ (right panel, shaded colours).

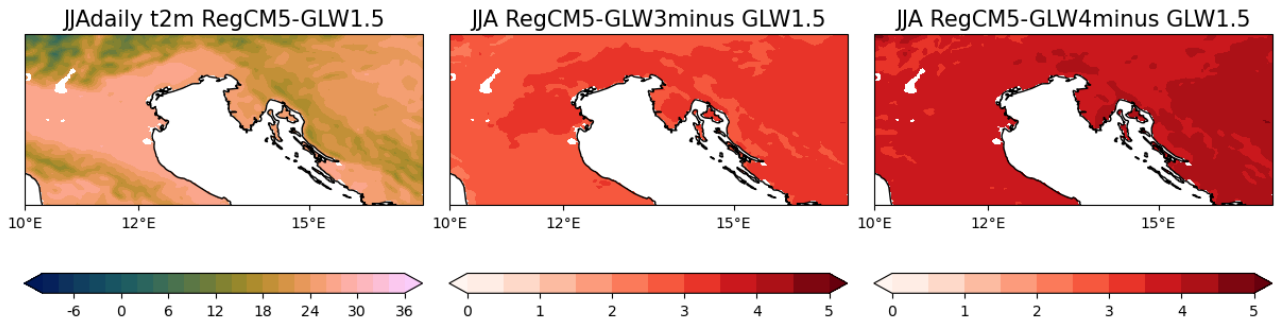


Figure 2 – Summer (June, July, August, or JJA) 2m temperature (in °C) simulated by $RegCM5_{std}$ in the GLW1.5 period (left panel) and differences between JJA temperature in GLW3.0 period (central panel) and GLW4.0 period (right panel) with respect to the GLW1.5 period.

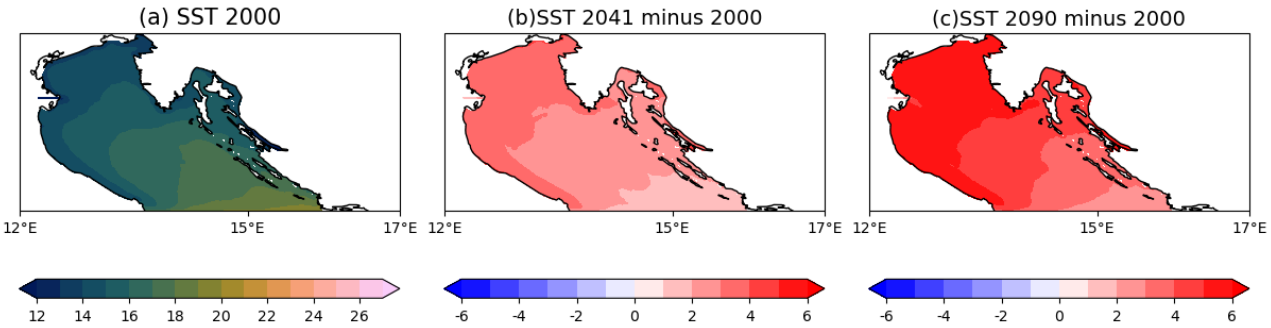


Figure 3 – Average sea surface temperature (in ◦C) in the 2000 period (a, left panel) and differences between temperature in 2041 year (b, central panel) and 2090 year (c, right panel) with respect to the beginning of the 21th century . Simulations are produced with MITgcm$_{std}$ offline forced by RegCM (Pichelli et al.,2021)

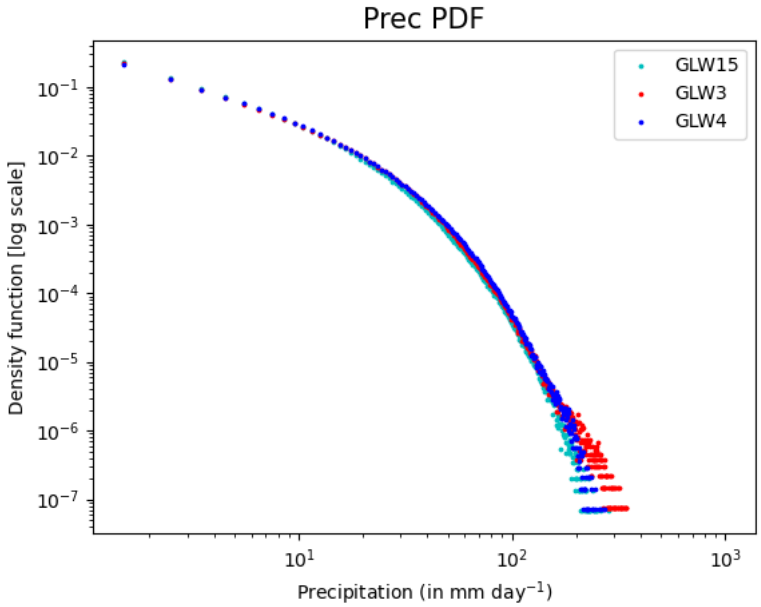


Figure 4 –Relative frequency of daily precipitation values simulated by RegCM$_{std}$ over the Northern Adriatic region in the GLW1.5 (cyan), in GLW3.0 (red) and GLW4.0 period (blue).

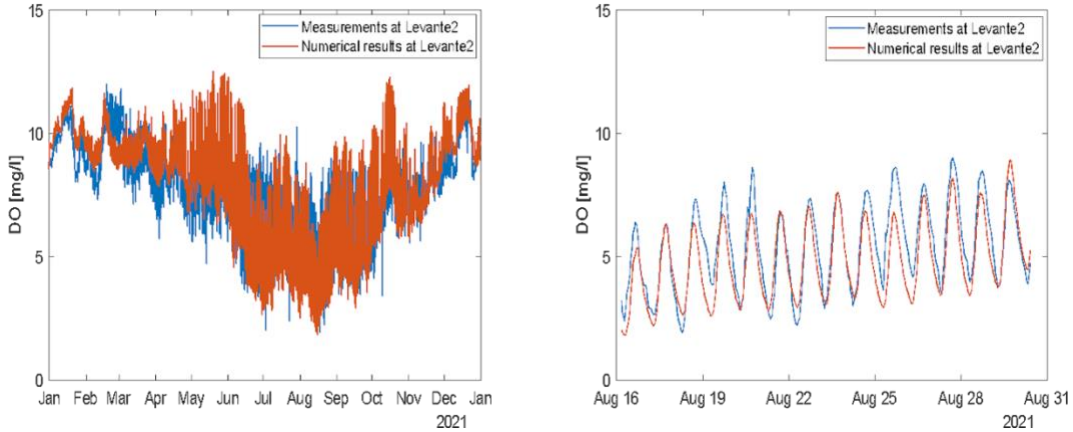


Figure 5– Dissolved oxygen concentrations simulated by the numerical model (red line) and measured in the Orbetello lagoon (blue line) at Levante monitoring station for the year 2021 (left) and in the period 16-31/08/2021 (right).

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Pathogens and biological invasions: biological threats to coastal marine environments – Summary and main outcomes from Task 4.3.5

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Abstract

Within the framework of the PNRR-RETURN project – VS4 "Environmental degradation" – Task 3.5 was designed to address biological threats to coastal marine ecosystems. Activities within the Task leveraged advanced techniques, such as Next Generation Sequencing (NGS), lagrangian transport models, and Machine Learning, with the aim of investigating i) the spread of microbial pollution and ii) the expansion of invasive alien species, which represent critical threats to the economy, society, and environmental health. A multi-approach strategy combining sampling surveys, the collection of existing data, and numerical modeling was the core methodology.

Natural aquatic environments play a pivotal role in the dissemination of Antimicrobial Resistance (AMR) and pathogenic bacteria. Coastal marine environments, in particular, are final receiving bodies of microbial pollutants from multiple sources (e.g., rivers, wastewater discharges, agricultural runoff and stormwater). Due to the increasing anthropogenic pressure and to their direct connection to the land, coastal marine environments have the potential of disseminating and promoting the establishment of antibiotic resistance genes (ARGs) and opportunistic pathogens, with the cascade effect of promoting the spread of AMR and exposing millions of people to health risks (e.g. through food consumption and recreational activities).



Figure 1 – Sampling sites in the Gulf of Trieste.

The Gulf of Trieste was under study to assess the presence, prevalence and distribution of microbial pollutants (e.g. genes conferring resistance to antimicrobials, potentially pathogenic bacteria) through NGS techniques, in line with the modern principles of "Genomic Surveillance". The sampling strategy was designed to describe the main sources of mesoscale variability (Figure 1); a one-year timeframe was chosen to capture the seasonal variability at each site.

Four amplicon-based sequencing approaches were tested for the detection of potentially pathogenic bacteria in seawater and sample sediment. Long-read metabarcoding allowed sequencing the full-length 16S gene (~1500 bp), providing improved taxonomic resolution and pathogen detection compared to short-read metabarcoding. Shotgun metagenomics was applied to elucidate the presence, prevalence, and distribution of ARGs and genes conferring resistance to disinfectants and other antimicrobials. To cover the maximum range of the ARG diversity we choose a "read-based" approach, using RGI (Resistance Gene Identifier) against CARD (Comprehensive Antibiotic Resistance Database).

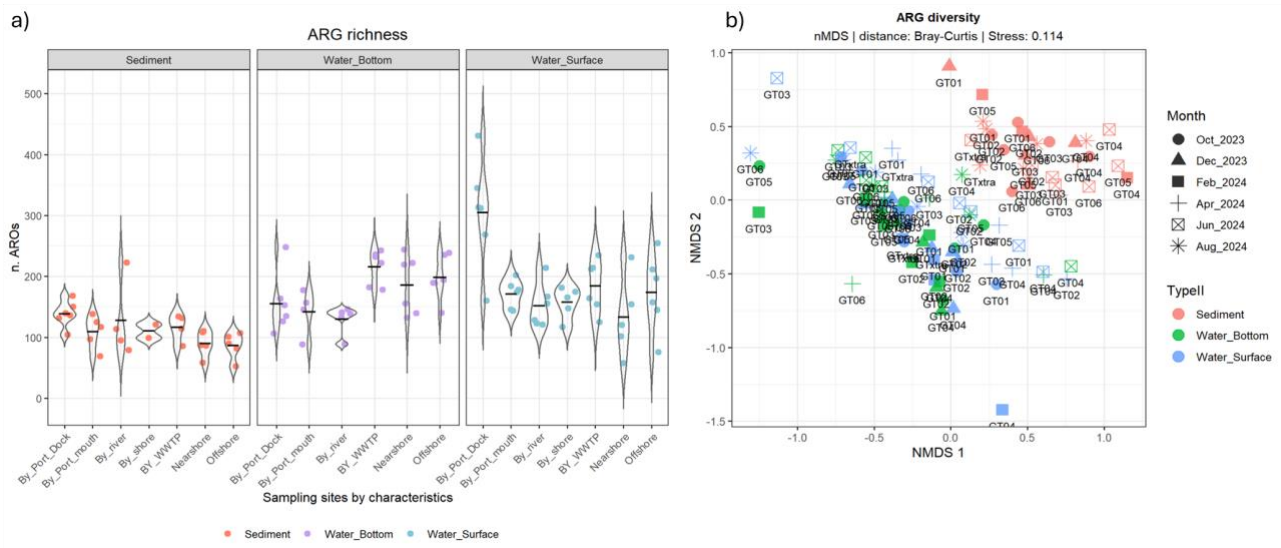


Figure 2 – ARG richness (a) and diversity (b) in the Gulf of Trieste.

Marine sediment revealed a more spatially and temporally stable resistome than the water column (Figure 2a), which on the contrary was characterized by a clear seasonal pattern (Figure 2b). The most abundant and recurrent genes found in the Gulf of Trieste cause resistance to the following antibiotic classes: fluoroquinolones, macrolides, cephalosporins, beta-lactams, tetracyclines, aminoglycosides, carbapenems, peptide antibiotics, rifamycin, lacosamide and streptogramins. However, gene conferring multidrug resistance (often based on efflux pump mechanisms) were found with high abundances and frequency, both in the sediment and the water column.

Data obtained by whole-genome and amplicon sequencing were coupled with the Gulf circulation data, organic load characterization, and other environmental variables, with the final scope of shedding light on the transport and fate of microbial pollutants in an archetypical coastal marine environment. At the same time, the untargeted metagenomic investigation is an extremely powerful

tool to identify ARGs and to reveal their partitioning across environmental matrices, providing crucial information for planning high-resolution and site-specific AMR monitoring programs via targeted approaches (i.e. based for example on sensitivity tests, qPCR, or the deployment of biosensors).

The transport of pathogens and antibiotic resistance genes (ARGs) in the Gulf of Trieste was also addressed with a Lagrangian modelling approach. Simulations of ARG release from wastewater treatment plants, including during the November 3rd 2023 storm surge, reveal how the general circulation and meteo-marine events affect dispersal. Results identify critical areas, support the interpretation of field data, helping optimize sampling strategies and strengthening integrated monitoring.

Within the Task, we developed a modelling framework to assess current and future invasion risk of benthic invasive alien species in the Mediterranean. The approach builds on *MaxEnt* ecological niche models, but improves their reliability through extensive hyperparameter tuning and an objective, multi-criteria model selection procedure. Site-weighted performance metrics and novel delta metrics are used to reduce sampling bias, diagnose overfitting, and favour models that generalise well across space and time. Explicit uncertainty analyses, including extrapolation-risk mapping and sensitivity of suitability classes to threshold choice, provide spatially and temporally resolved confidence levels for predictions. Annual projections of habitat suitability, tested on the invasive alga *Caulerpa cylindracea*, enable detection of emerging hotspots and long-term trends, supporting prioritisation of monitoring and management actions. The framework is highly modular and transferable, and provides decision-ready maps and indicators for risk-aware planning.

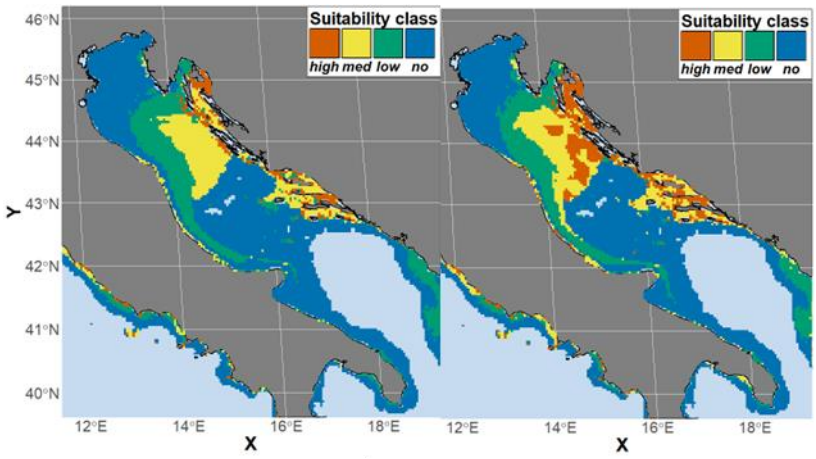


Figure 3 – Extrapolation risk map. Colours towards red indicate where future (2030-2050) conditions deviate significantly from the environmental combinations used to train the models ('strict extrapolation').

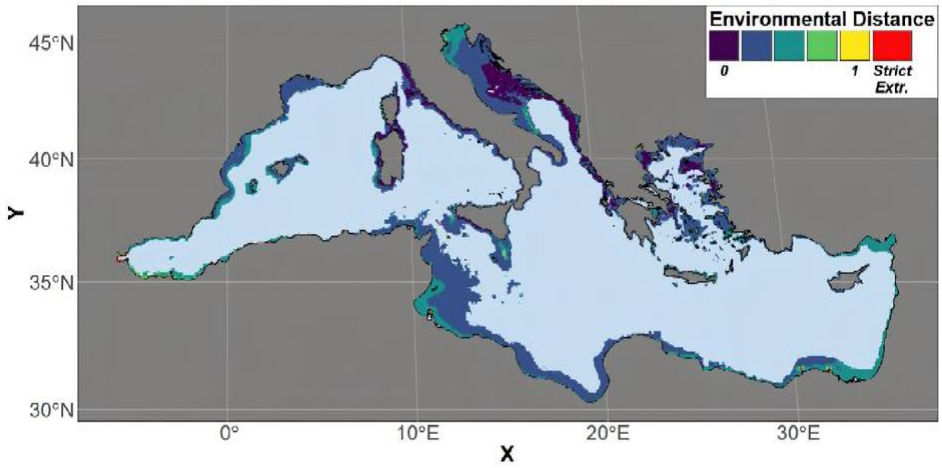


Figure 4 – A detail of the Caulerpa cylindracea's projected suitability for the future (2030-2050). The choice of a conservative (left) or stricter (right) threshold to classify the probability of occurrence to suitability strongly affects the results.

Identification and classification of macro- and microplastics dispersed in terrestrial and marine environment by hyperspectral imaging

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Abstract

The present work illustrates the research activities carried out in the framework of tasks 4.3.1 and 4.3.2 of RETURN project with reference to the development of innovative technologies for microplastic characterization in different environmental matrices. More in details, the methodologies and the corresponding applications developed to improve the identification and classification of macro- and microplastics (MPs) dispersed in terrestrial and marine environments through hyperspectral imaging (HSI) coupled with chemometrics are described. The main objective of the research activity was to develop analytical strategies for the detection of MPs, overcoming the limitations of conventional spectroscopic techniques such as FT-IR and Raman spectroscopy. Polymer identification using these techniques is laborious and time-consuming, however, in recent years, HSI has been proposed as a rapid and effective solution. The main advantage of HSI is the ability to rapidly acquire spectral images by combining classical spectroscopy with digital imaging, enabling the acquisition of the spectral signature of each pixel in the image across different wavelength ranges (e.g., VIS-NIR: 400-1000 nm, near-infrared - NIR: 1000-1700 nm and short-wave infrared - SWIR: 1000-2500). The output data is called hypercube and is characterized by two spatial dimensions and one spectral dimension. The combination of HSI technology with a chemometric approach helps extract meaningful information from the large amount of data obtained with HSI by reducing dimensionality while preserving essential spectral features. Furthermore, using automatic chemometric classification techniques, the characteristic spectra of each pixel can be classified to identify the chemical signatures associated with different types of materials. Therefore, the use of this technology allows for the direct identification and classification of MPs within various matrices (e.g., sand, marine sediments, etc.), thus avoiding complex and time-consuming pretreatment procedures for MP extraction.

To achieve this goal, the main research activities were divided into methodological studies and application of spectral sensing strategies to different case studies. In particular, a methodological study was conducted to define an HSI analytical protocol for the characterization of MPs, testing different configurations: 1) two spatial resolutions (150 and 30 µm), 2) two wavelength ranges (NIR: 1000-1700 and SWIR: 1000-2500 nm) and 3) three different classification models (PLS-DA, ECOC-SVM, NNPR). The obtained results provide a comprehensive guide for selecting appropriate

acquisition settings and data processing methods to optimize the characterization of MPs of different sizes using HSI (Serranti et al., 2024). Furthermore, a custom micro-HSI scanner developed within the RETURN project specifically for the analysis of the MPs was tested. The results demonstrate the capability to classify MPs with a size up to 150-200 µm. The identification of MPs of smaller sizes remains challenging due to reduced spectral quality (Serranti et al., 2025).

Finally, the analytical procedures were applied and tested to several case studies:

- Detection of the presence of micro-bioplastics in the final product of anaerobic digestion process to assess its quality. (Capobianco et al., 2024).
- Microplastic litter classification on marine and coastal areas at laboratory-scale from different sites in Italy and Europe. (Cocozza et al., 2024; Palmieri et al., 2024a; Palmieri et al., 2024b).
- Direct identification and classification of microplastics in sandy beach and marine sediment samples, respectively, without prior extraction. (Rizzo et al., 2024).
- In-situ macroplastic litter classification by ground-based hyperspectral sensor and portable NIR device.
- Microplastic pellets characterization and degradation analysis: the Toconao ship accident case study. (Cocozza et al., 2025; Scarrica et al., 2025).

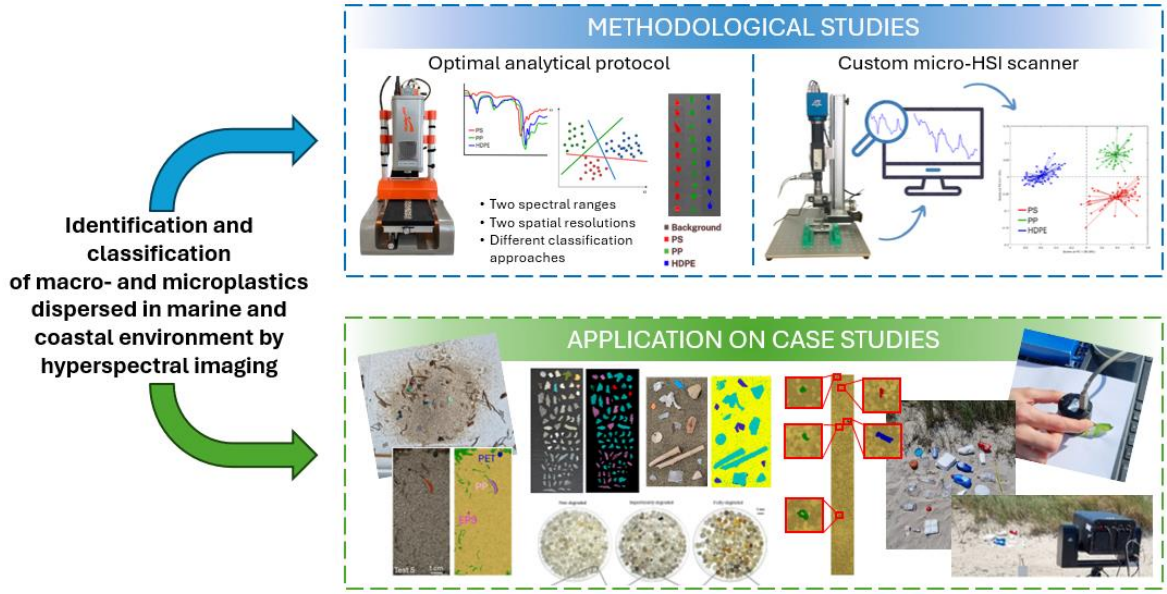


Figure: Graphical representation of the research activities carried out by UNIROMA1-DICMA research group within the tasks 4.3.1 and 4.3.2 of the RETURN project. The case studies are in collaboration with UNIROMA1-DICEA and UNIBA research groups.

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Cutting-Edge Models to Monitor Floating Plastic Debris Along Apulian Coasts

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Abstract

This study takes into account a Lagrangian particle-tracking framework to model the transport, dispersal, and fate of floating plastic debris along the Apulian coast (Ionian Sea). Utilizing the specialized plasticparcels model (Denes and Sebille, 2024), we simulated the pathways of plastic particles based on ocean current data from the Copernicus MEDSEA reanalysis(Escudier et al., 2020; Clementi et al., 2022) and initial particle conditions (density and size) derived from direct manta net and water sample surveys conducted between 2016 and 2024. The model incorporates key processes governing plastic behavior, including advection by surface currents, wind drag, and vertical mixing. Our simulations successfully identify the principal transport tracks and map the spatiotemporal distribution density of plastic particles. The results reveal seasonal and interannual variability in dispersal patterns, highlighting key accumulation zones and pathways from offshore to nearshore environments. In particular, the low-lying coastal areas and barrier dune systems on the Ionian and Adriatic coasts of the Apulia region are highly influenced by plastic accumulation (Figure 1). Furthermore, high densities of plastic debris result in sink processes that affect the soft sediments of the continental shelf and abyssal plain seafloor. This modelling approach provides a robust tool for understanding the dynamics of marine plastic pollution in the region, with implications for targeted mitigation and cleanup strategies.

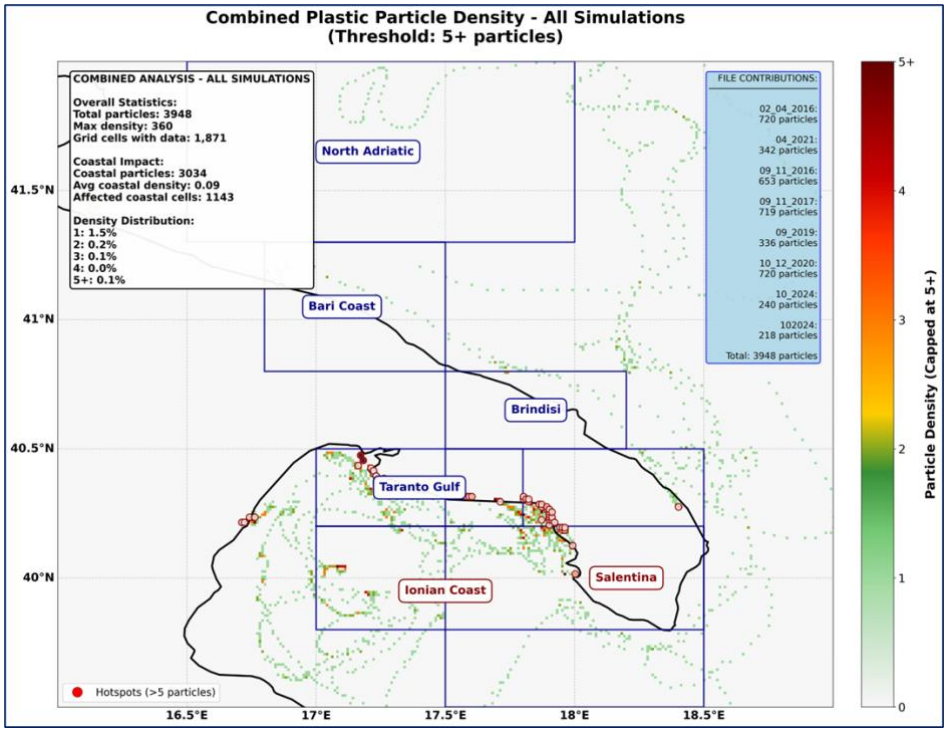


Figure 1 – Results of plastic pollution modelled through plasticparcels for the Apulian region.

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Assessing Pollution and Environmental Risks in the Adriatic Sea through Multi-Hazard Modeling

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Abstract

In the past decade, the ability to simulate the fate and transport of pollutants in marine ecosystems has improved significantly, providing new tools to support hazard and water quality assessments. Coupled models that simulate hydrodynamic transport and properties, pollutant biogeochemistry, and in some cases the dynamics of the lower food web, have proven effective in predicting the spatial and temporal distributions of pollutants and advance scientific understanding (Liubartseva et al., 2025; Melaku Canu et al., 2015; Rosati et al., 2022, 2024).

In RETURN VS4, we developed a suite of models to simulate the fate and transport of priority and emerging pollutants in the Adriatic Sea (oil, mercury, plastics, and pharmaceuticals) under realistic environmental conditions, and integrated model outputs to provide a first-tier multi-risk assessment for the Adriatic Sea (e.g., Figure 1 and Figure 2). The Adriatic Sea is a shallow semi-enclosed basin characterized by high freshwater inflow and strong anthropogenic pressures related to urbanization, maritime transportation, industrial activities, and historical mining (Furlan et al., 2019, Horvat et al., 2014).

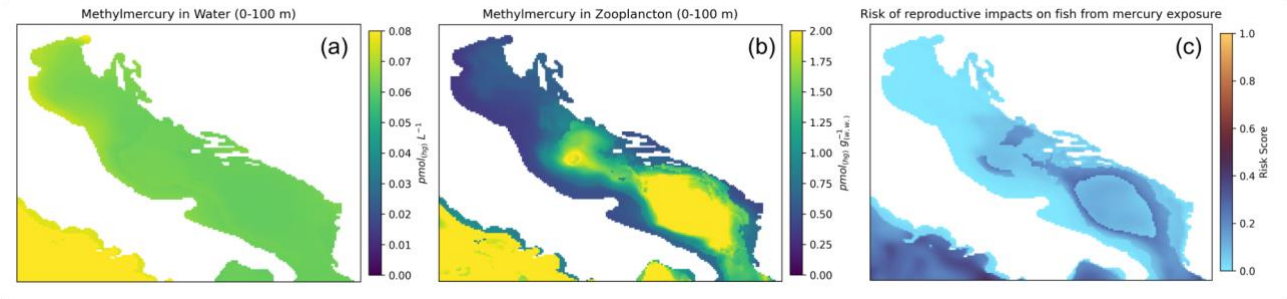


Figure 1 - Modeled distribution of methylmercury in (a) water and (b) zooplankton in the upper 100 m of the Adriatic Sea (annual average) and (c) estimated reproductive risk for planktivorous fish.

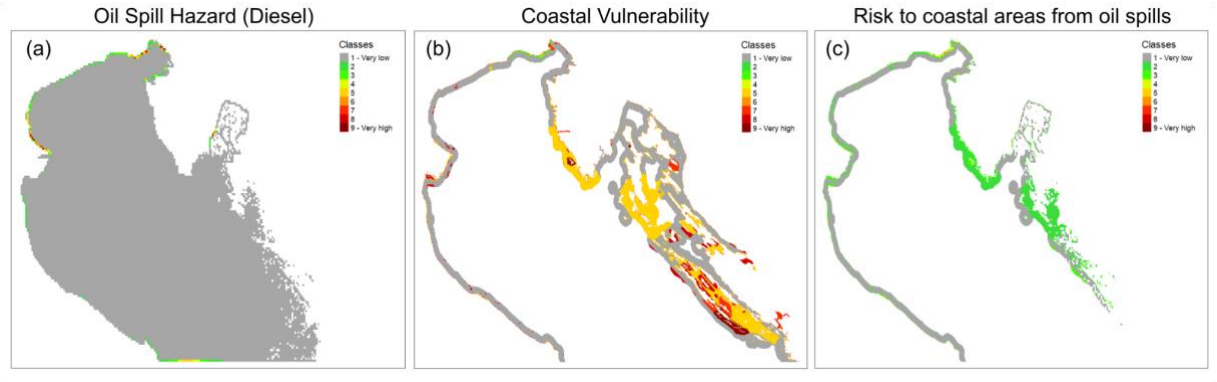


Figure 2 - Modeled (a) distribution of beached oil 150h after oil spill, combined with (b) coastal vulnerability based on environmental and socioeconomic value to estimate (c) risk to coastal areas.

For each pollutant, key sources were identified and their contributions to the marine ecosystem quantified. Oil discharges are primarily associated with the volume of maritime traffic along shipping routes, mercury enters predominantly through riverine inflows and atmospheric deposition, while plastics and pharmaceuticals are introduced via rivers and wastewater treatment effluents. After the release, pollutants are transported by water masses and undergo specific processes – such as microbial or photochemical degradation, sinking, volatilization, and bioaccumulation – depending on their physical-chemical properties and the meteo-climatic conditions.

The modeled spatial distributions of pollutants were combined with ecotoxicological or socio-economic thresholds to provide single and cumulative risk indexes for the study area.

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Physiological and genetic effects of microplastics on model plant species

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Abstract

The widespread occurrence and distribution of microplastics (MPs) in both aquatic and terrestrial environments has become a major global concern. Monitoring MP presence and assessing their impacts on plants deserve special attention, as plants are fundamental primary producers and represent the entry point for MP bioaccumulation throughout food chains. The abundance of these contaminants in soils can reach edible parts of the plants and have effects in nutritional value and quality of fruits and vegetables. It is therefore essential to evaluate the potential risks of human exposure to MPs through the consumption of crops grown on contaminated soils. Aquatic vegetation also plays key ecological roles, providing habitats for numerous organisms and participating in vital processes such as nutrient cycling and water purification. Understanding the effects of MP contamination is important to assess possible ecosystem-level consequences, such as altered symbiosis, nutrient cycling, and interactions between plants and other organisms, including pollinators and pathogens.

The general aim of this work was to monitor the effects of MP pollution on plants. The impacts of MPs on growth, yield, physiology, and epigenetic responses were investigated in both terrestrial and aquatic plant models.

Effects of MPs in terrestrial plants

The effects of polyethylene terephthalate (PET) and polyvinyl chloride (PVC) MPs were investigated under controlled climatic chamber conditions (temperature, humidity, and light). Plants were grown in pots containing soils artificially contaminated with environmentally realistic concentrations of MPs, and several physiological and biochemical parameters were evaluated (Fig. 1a) to investigate different issues.

- Tomato (*Solanum lycopersicum*) was used as model crop to assess MP effects on plant health and fruit quality (Fig. 1b). Photosynthetic parameters, number of flowers and fruits, plant biometry and ionome were evaluated, along with fruit quality. Photosynthetic parameters, flower and fruit number, plant biometry, ionomic composition, and fruit nutritional traits were measured. Results showed that MPs negatively affected crop productivity and fruit quality, reducing the nutritional value of tomatoes.

- The potential effects of MPs on disease resistance mechanisms of plants was explored on the model species *Arabidospis thaliana* (Fig. 1c). Enhanced pathogen susceptibility in agricultural soils, for instance, would have consequences in terms of crop losses and enhanced use of chemical products. The plants grown on soil artificially polluted with PET or PVC MPs were exposed to different pathogens (e.g. *Botrytis cinerea*). Results revealed altered plant responses to biotic stress,

with MPs triggering defense mechanisms against fungal pathogens, suggesting a possible priming effect.

- The impact of MPs on ecological interactions was studied using *Viola tricolor* as a model for plant–pollinator relationships (Fig. 1d). The effects of MPs were investigated on flower characteristics involved in attracting pollinating insects, such as odor emission, flower number and color, and nectar quality. MP-contaminated soils caused several alterations compared with controls, including a reduced number of flowers, changes in the volatile organic compounds (VOCs) emitted, and altered nectar quality. These findings suggested that soil MP contamination may interfere with plant–pollinator interactions.

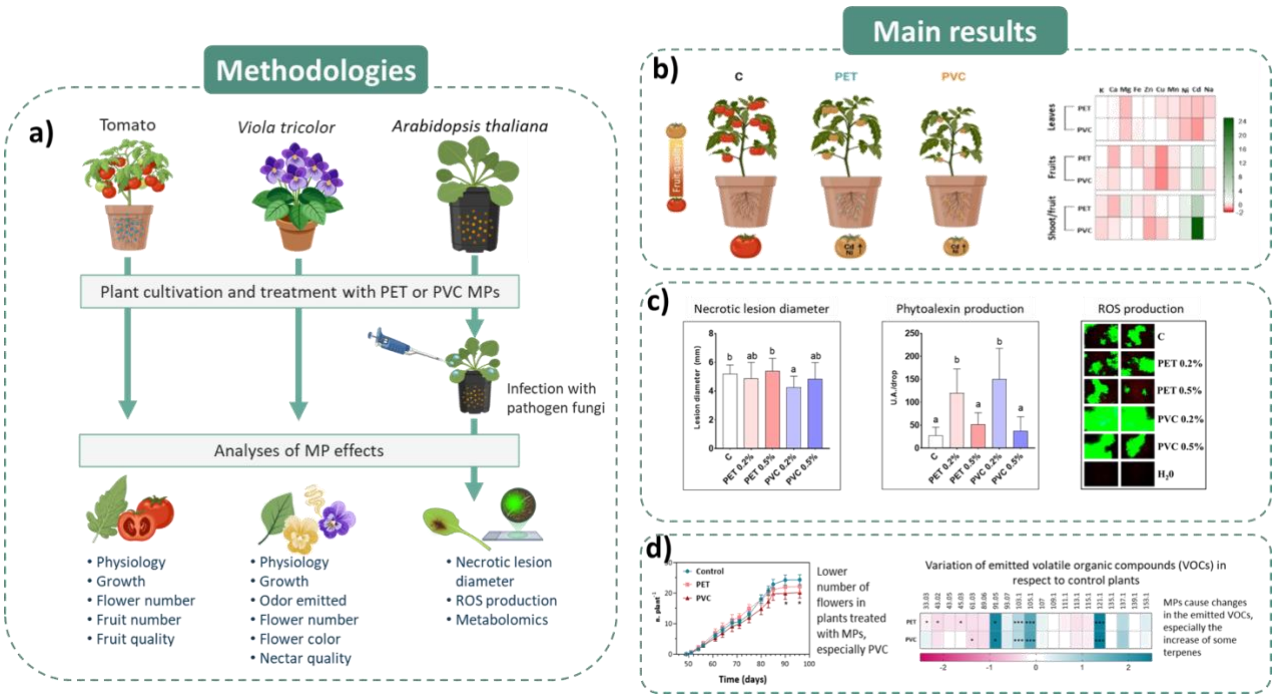


Figure 1 – Graphical representation of the setup and methodologies used in the experiments with terrestrial plants (a) and of the main results obtained (b, c, and d).

Effects of MPs in aquatic plants

Given the ecological importance of macrophytes in maintaining freshwater and coastal ecosystem balance, two different species (*Spirodela polyrhiza* and *Azolla filiculoides*) were used as model aquatic plants to investigate MP phytotoxicity. Novel methods were developed for the preparation and characterization of MPs derived from commonly used plastic materials, resulting in realistic mixtures of micro- and nanoparticles. Water dispersions of PET MPs (~200–300 nm) were produced from plastic bottles through repeated homogenization cycles and used to prepare growth media at environmentally relevant concentrations. These solutions were used to cultivate the water plants in a climatic chamber with controlled conditions of temperature, humidity, and light and to evaluate

the effects of MP at different levels: plant growth, physiology, epigenetics, ecological interactions, MP absorption capacity (Fig. 2a).

- The effects of polyethylene terephthalate (PET) MPs were tested on *S. polyrhiza*. Analyses revealed a decrease in photosynthetic efficiency and starch concentration, as well as alterations in the plant ionomic profile and oxidative status. DNA analyses also showed unusual hypermethylation at 5'-GGGG sites, providing, for the first time, evidence of MP-induced epigenetic modifications in plants (Fig. 2b).

- The aquatic fern *A. filiculoides* was used as an indicator species to evaluate the toxic impacts of PET MPs at the level of ecological interactions, focusing in particular on the symbiotic association between *A. filiculoides* and the nitrogen-fixing cyanobacterium *Trichormus azollae*. Results showed that MPs can have a harmful effect on this symbiotic system, causing a reduction in nitrogen content and in the absorption of essential elements by the plants. Moreover, a decrease in the relative abundance of the N_2-fixing cyanobacteria and an alteration of the symbiont's phenotype were observed in MP-treated plants. The harmful effects on the strict *Azolla–Trichormus* symbiosis suggest possible implications for nitrogen cycling at the ecosystem level.

- In addition, our studies investigated how MPs interact with the floating plant *S. polyrhiza*, with a specific focus on evaluating its potential for application in phytoremediation. Under treatment conditions, a significantly lower number of MP particles was detected in the medium, suggesting particle adsorption by the roots and the underside of the fronds, as confirmed by confocal microscopy analyses. These findings indicate that *S. polyrhiza* has a promising potential for MP removal from water environments.

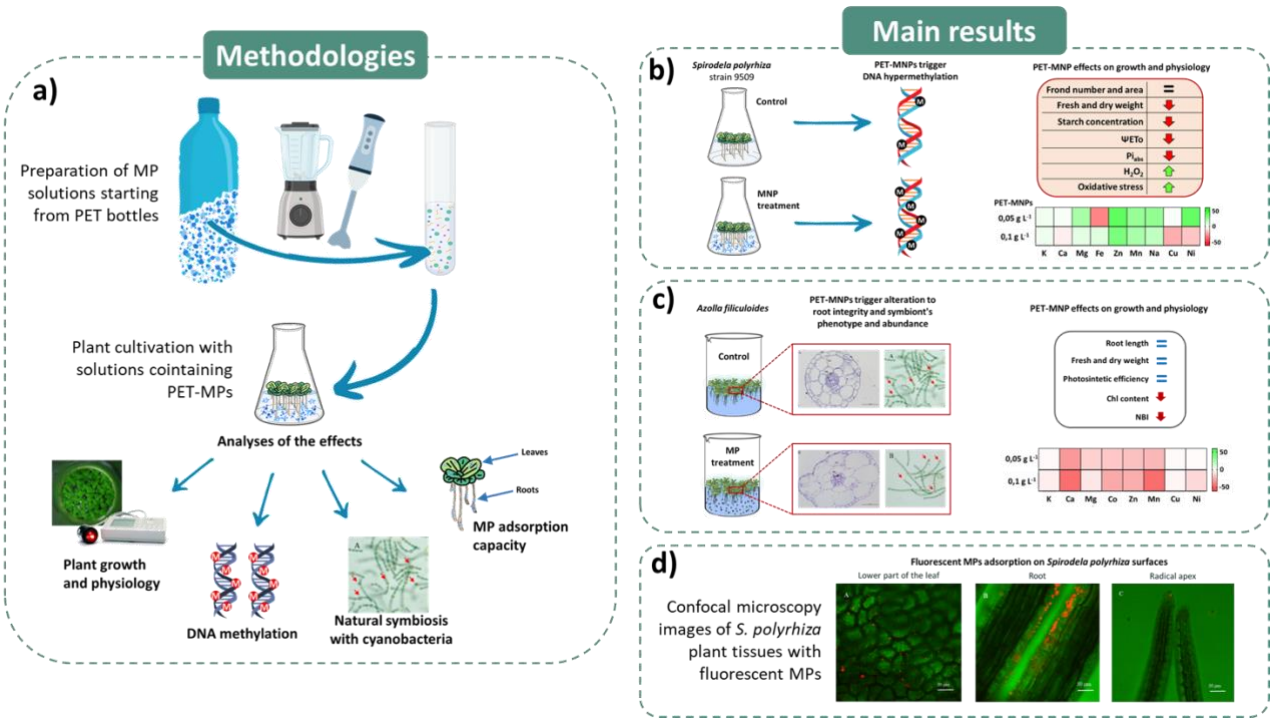


Figure 2 – Graphical representation of the setup and methodologies used in the experiments with aquatic plants (a) and of the main results obtained (b, c, and d).

Our findings reveal multiple effects of MP pollution on both terrestrial and aquatic plants, highlighting potential ecological consequences such as altered symbioses, disrupted nutrient cycling, and impaired interactions between plants and pollinators. Furthermore, the results emphasize possible risks to human health through the consumption of low-quality vegetables grown on contaminated soils.

Micropollutants fate in water environment from sources to humans: integrated risk assessment and targeted mitigation strategies

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Abstract

Micropollutants, also referred to as Contaminants of Emerging Concern (CECs), are increasingly recognized as a critical challenge in water management due to their trace concentrations, complex chemical nature, and uncertain toxicological profiles. These substances - ranging from pharmaceuticals and personal care products to pesticides, herbicides, and industrial chemicals like PFAS and phthalates - enter the aquatic environment through both point sources (e.g., wastewater treatment plants, urban drainage) and non-point sources (e.g., agricultural runoff). The anthropic water cycle, encompassing wastewater reuse, cascade uses in urban settings, and drinking water production, acts as a carrier for these micropollutants, facilitating multiple exposure routes to both the environment and human populations.

Traditional concentration-based monitoring methods, while useful for detecting the presence of micropollutants, fall short in assessing their actual impact. These approaches often overlook the risk posed by chronic exposure, especially under varying environmental conditions such as wet-weather events, which can significantly alter pollutant discharge dynamics. For instance, compounds like Carbamazepine (CBZ) and Diclofenac (DCF) have been detected across multiple compartments of the urban water system - from combined sewer overflows (CSOs) and wastewater treatment plant (WWTP) effluents to surface waters and irrigated crops - highlighting the pervasive nature of these contaminants. Their concentrations, based on literature data, are shown in Figure 1.

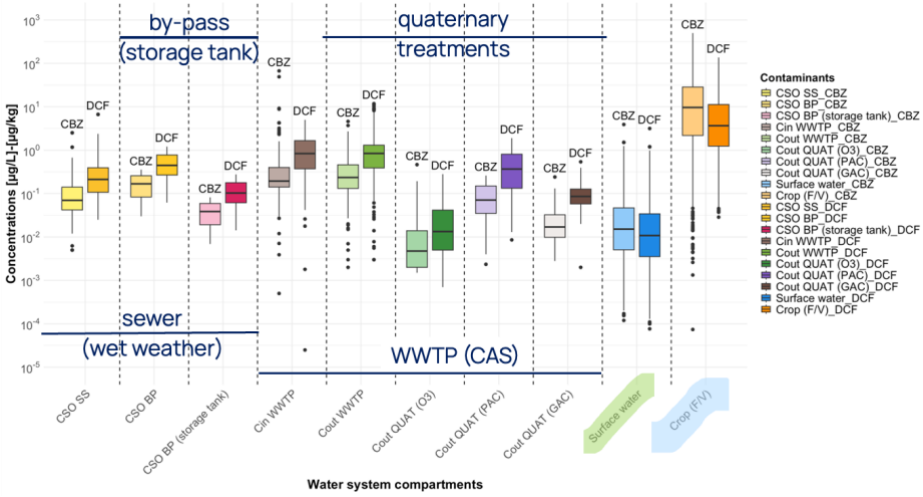


Figure 1 – Carbamazepine and diclofenac concentrations in various sampling points of the integrated urban water system and after potential mitigation actions applied to both by-pass of WWTP and biological effluent to WWTP.

To address these limitations, we propose an integrated risk-based assessment framework that complements concentration data with quantitative risk evaluation. This approach enables:

- apportionment of environmental and human health risks across different water system compartments,
- identification of risk thresholds to guide regulatory and operational decisions,
- prioritization of mitigation strategies, optimizing economic resource allocation for maximum impact.

The framework incorporates stochastic modeling to simulate chronic risk scenarios, particularly under wet-weather conditions, which exacerbate pollutant mobility and exposure. By evaluating both direct and indirect reuse of treated wastewater, the model supports a One Health perspective, recognizing the interconnectedness of environmental, human, and agricultural health.

The effect on terms of concentration reduction of some mitigation strategies are shown in Figure 1: in detail, we explored the effect of storage tanks for by-pass and of quaternary treatments to further polish biological effluents. Key findings of our work include:

- quantitative mapping of CBZ and DCF concentrations across urban water compartments, revealing significant variability influenced by treatment technologies and weather conditions,
- risk ranking of water reuse scenarios, demonstrating that advanced treatment processes (e.g., ozonation, activated carbon) significantly reduce both environmental and human health risks,
- scenario modeling under climate change projections, emphasizing the need for adaptive strategies in urban water management.

The implications we would like to highlight for integrated urban water systems are as follows:

- the transition toward water-wise cities - driven by factors such as urbanization, water scarcity, energy crises, and climate change - necessitates a paradigm shift in how micropollutants are managed,

- integrated monitoring systems that combine chemical analysis with risk modeling is of paramount importance to tackle the interconnected environmental compartments,
- targeted mitigation strategies, including both preventive measures (e.g., source control, green infrastructure) and technological interventions (e.g., quaternary treatments) should be coupled for an effective reduction on micropollutant spread,
- policy frameworks that support dynamic regulation based on risk thresholds rather than static concentration limits are strongly encouraged.

This research provides a comprehensive roadmap for managing micropollutants in urban water environments. By bridging the gap between detection and impact assessment, the integrated risk-based approach offers a robust tool for safeguarding both environmental and human health. The findings advocate for a multi-disciplinary, systems-level strategy that aligns with the principles of One Health and supports the sustainable transformation of urban water systems in the face of emerging global challenges.

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Transport and fate of ARGs in the Gulf of Trieste

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The transport and fate of pathogens and antibiotic resistance genes (ARGs) in the Gulf of Trieste (GoT) is studied by integrating numerical simulations and omics data spanning over one year of samplings. Here, we focus on the first period of the sampling (October - November 2023) that also includes a storm surge event in the study area (November 3, 2023), thus enabling an analysis of the impact of extreme meteo-marine events on the spread of these biological pollutants (BPs).

We integrated a hydrodynamics (mitGCM) and a particle tracking model (LTRANS-Zlev), to predict the spatial and temporal distribution of BPs originating from point sources such riverine inflows (primarily from the Isonzo River) and wastewater treatment plants. The hydrodynamics model of the GoT [1] has a spatial resolution of around 750m and an uneven vertical resolution (from 20 thinner layers of 1 m at the free surface to a thickness at the bottom of about 11 m). Hourly variable fields of currents, wind, temperature, and salinity are obtained from the MITgcm simulations and used to force the LTRANS-Zlev solver [2]. Pathogens and genes are treated as buoyant particles with the same density as water (densities of marine bacteria and sea water are in the same range). BPs particles are advected by the hydrodynamic fields and undergo a degradation process over time, as field observations from other studies indicate that the half-life for DNA and cells in the marine environments spans from <1 day to one week [3], even though such estimation is still debated.

The resulting pollutant distributions are qualitatively evaluated against experimental data in order to assess the modelling approach and its reliability as a prediction tool to evaluate dispersion at present conditions and in climate change scenarios. This integrated approach will allow for better data interpretation, enlightening also the connectivity among sampling sites, and eventually will provide a scientific basis for integrated monitoring strategies and sustainable management of anthropogenic pressures in the Gulf of Trieste, in line with European directives for marine environmental protection.

Keywords: ARGs, MITgcm, Lagrangian particles, Gulf of Trieste

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Objective Multi-Criteria Integration for Marine Hazard and Risk Assessment

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Abstract

Marine multi-hazard assessments often lack objective methods for integrating heterogeneous indicators with incomplete spatial coverage. We present a geospatial multi-criteria decision analysis framework to derive a composite risk index for the Adriatic Sea, constructed from seven normalised layers (pharmaceuticals, microplastics, mercury bioaccumulation, and oil-spill risks).

To achieve this, we combine objective CRITIC weighting (Diakoulaki et al., 1995) with TOPSIS ranking (Hwang and Yoon, 1981; Lai et al., 1994). First, the seven single-hazard risk layers (criteria) are harmonised to a common spatial grid and scaled to [0,1] cost-type scores. CRITIC weights are then calculated on area-weighted fields, combining spatial contrast and inter-criterion correlation; a coverage exponent penalises indicators with limited support while retaining highly informative but patchy datasets. These weights are used in a CRITIC–TOPSIS aggregation, where each grid cell is treated as an alternative and ranked by its distance to the ideal (zero-risk) and closeness to the anti-ideal (unit-risk) points.

To avoid the substantial loss of spatial coverage resulting from the strict intersection of all criteria supports (Figure 1), we introduce a union-of-support TOPSIS index (Figure 2). For each grid cell, the global CRITIC weights are renormalised over the subset of available criteria, and TOPSIS is recomputed, preserving the relative importance structure while using all locally available information. This produces spatially continuous multi-risk patterns that remain consistent with the strictly defined all-hazard index but reveal additional offshore hotspots. Weight-perturbation Monte Carlo experiments (Chen et al.,2022) show that both strict and union-of-support indices are robust to large variations in the CRITIC vector, supporting the use of this framework as an operational, data-driven tool for screening-level marine risk prioritisation under heterogeneous coverage.

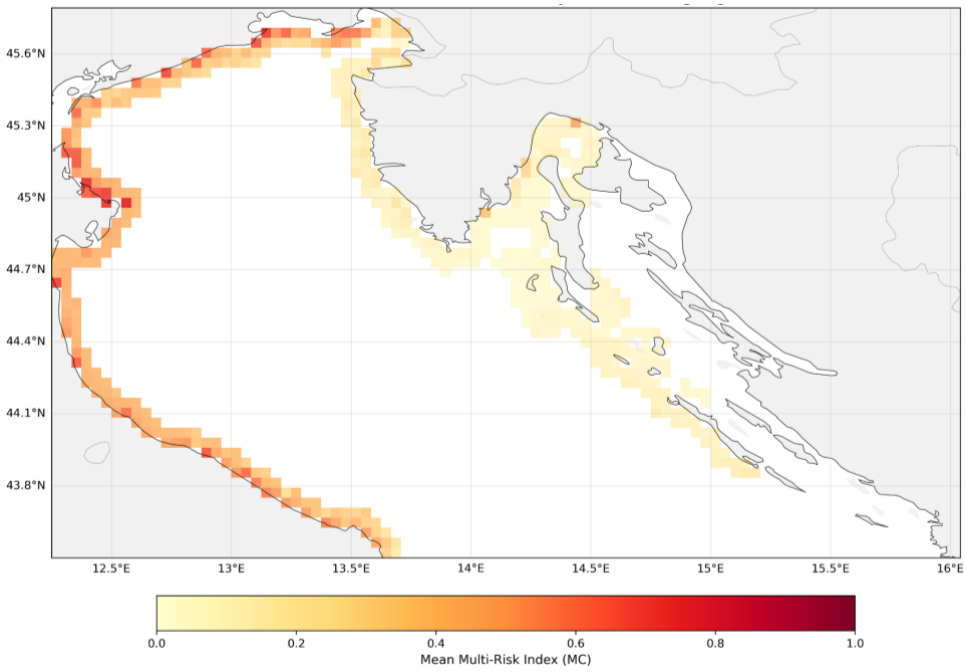


Figure 1 – Strict-support TOPSIS. Index values are computed only for cells with valid values for all criteria.

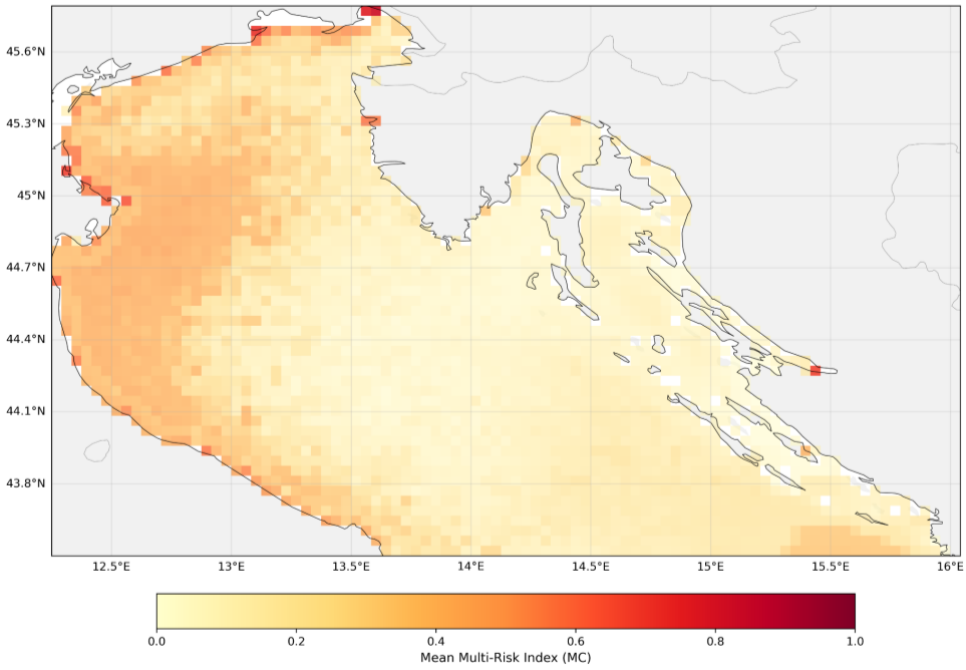


Figure 2 – Union of support TOPSIS. Relaxing the "strict" assumption, index values are computed if at least two criteria are present, by re-normalising the global CRITIC weights over the subset of criteria actually present.

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Multi-risk integrated SWOT–FMEA framework for the risk-based management of dredged marine sediments: results of Task 4.5.3 (Deliverable VS4) of the RETURN Project applied to the case studies of Genoa and Augusta

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Abstract

The management of dredged marine sediments requires decision-making tools that integrate environmental risks, technical and economic constraints, regulatory requirements, and social acceptability. As part of Task 4.5.3 of the RETURN Project, an innovative multi-risk framework was developed and applied based on the structured integration of SWOT (Strengths, Weaknesses, Opportunities, Threats) and FMEA (Failure Mode and Effects Analysis) analyses. This framework was validated on two representative case studies: the commercial port of Genoa (maintenance dredging) and the industrial port of Augusta-SIN (remediation dredging). The objective is to support the selection of management scenarios and treatment sequences that maximize effectiveness, sustainability, and operational robustness along the entire sediment management chain.

The SWOT analysis was conducted through an iterative multi-stakeholder process involving port authorities, the scientific community, and specialized operators. Starting from 87 preliminary factors, the thematic clustering and prioritization process led to the identification of 24 strategic factors. Strengths include consolidated expertise in environmental dredging management, the availability of integrated technologies (biological, chemical, thermal), a regulatory framework, and an extensive database on sediment quality. Weaknesses include heterogeneous contamination, lengthy authorization processes, high costs, a lack of dedicated infrastructure, and challenges in batch traceability. Opportunities include integration into circular economy programs and coastal management plans, access to dedicated financing, and the development of advanced technological solutions, while threats include unregulated emerging contaminants, climate uncertainty, volatile energy costs, and potential conflicts with local communities. The TOWS analysis allowed us to translate these elements into targeted operational strategies, explicitly orienting the intervention priorities.

The FMEA was applied to the six macro-phases of the management chain (planning, characterization, dredging, transportation, treatment, final destination), identifying 45 potential

failure modes that include both operational criticalities and authorization, organizational, and socioeconomic aspects. For each, severity, probability, and detectability were assessed (scale 1–10), with the Risk Priority Number (RPN) calculated (von Ahsen et al., 2022).

The analysis highlighted eight critical failure modes (RPN > 300), primarily associated with unrepresentative sediment characterization, contaminant dispersion during dredging operations, ineffective treatment in the presence of complex mixed contaminants, and cross-contamination risks during transportation. By integrating the results of bench-scale trials on the main treatment technologies (bioslurry, low-temperature thermal desorption, sediment washing), the framework allows for the association of optimized and non-standard treatment sequences with specific risk profiles, translating RPN scores into concrete management trajectories and ensuring a measurable risk reduction (Di Bella et al., 2023; Zhao et al., 2019; Kim et al., 2023; Licitra et al., 2025; Di Trapani et al., submitted). The proposed corrective and preventive actions—statistically robust sampling protocols, continuous monitoring systems, scheduled equipment maintenance, advanced traceability procedures, and specific personnel training—result in a significant reduction in the average RPN and a substantial reduction in priority criticalities.

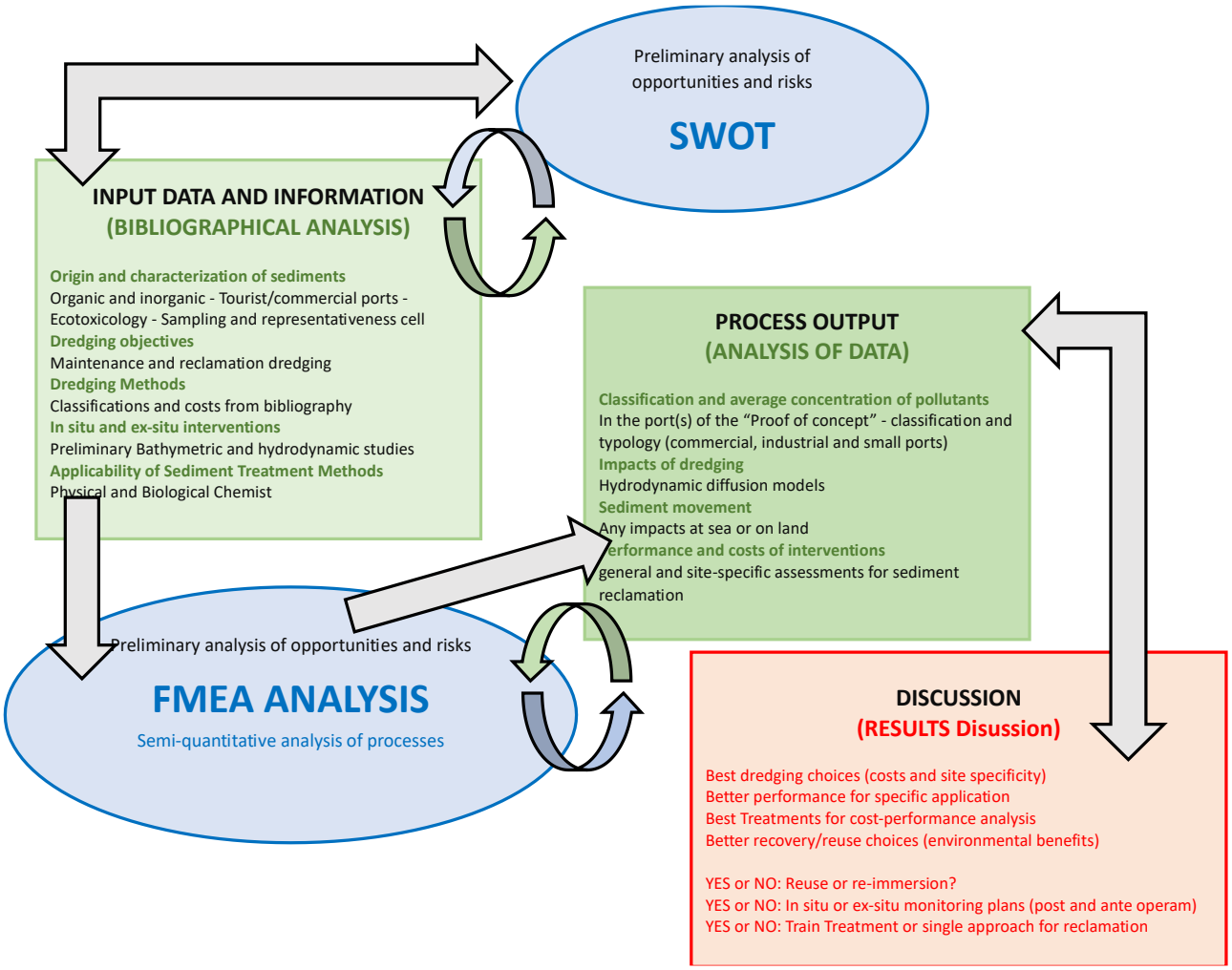


Figure 1 – Schematic representation of the multi-risk decision framework integrating SWOT/TOWS and FMEA analyses applied to the Genoa and Augusta case studies

The SWOT-FMEA integration establishes a three-level decision-making system: strategic, where the SWOT defines the context and key drivers; operational, where the FMEA quantifies risks along the supply chain and supports the prioritization of actions and the selection of treatment pathways; and executive, where the selected solutions are verified through experimental evidence and operational data. Joint application to the Genoa and Augusta cases shows that the framework reduces decision-making uncertainty, improves the consistency between environmental objectives and real-world constraints, optimizes the selection of treatment sequences, and reduces overall dredging project times and costs. The modular and transparent nature of the approach facilitates its transferability to other port contexts and enables its evolution into a dynamic system, updatable with monitoring data for adaptive risk management. Overall, the framework developed in Task 4.5.3 represents a robust operational tool for the risk-based management of port sediments, in line with the circular economy and environmental resilience objectives promoted by the RETURN Project.

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Safe-by-design nanocellulose based materials for water treatment

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Abstract

By carefully planning and conducting transport tests, researchers can optimize the use of nanoparticles in remediation applications, ensuring their effectiveness while minimizing costs and environmental risks.

Besides considering transport phenomena for applications in nanoremediation, a specific focus was on a proper evaluation of the (eco)toxicological impact of specific nanoparticles (cellulose nanofibers), used as building blocks by POLIMI for the design of different families of new sorbent materials.

These studies were devoted to a proper eco-design of the nanostructured materials further applied for water treatment. They consisted in both validating the building blocks (TEMPO-oxidized cellulose nanofibers, TOCNF) and the other components of final nanosponges' formulations, and verifying the best operative conditions to ensure a safe use of the new nanostructured materials.

For these reasons we evaluated the environmental safety of TOCNF by an acute *in vivo* study with marine mussels *Mytilus galloprovincialis* (Rusconi et al., 2024) and sea urchins [Esposito et al., 2024]. Moreover, we optimized the nanostructured sorbent materials, obtained by promoting the cross-linking of TOCNF with branched polyethyleneimine, in order to prevent the release of toxic components in water and to preserve remediation efficiency by removal of heavy metal contaminants (Esposito et al., 2023).

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Robustness and resilience of a combined process, employing waste materials, for the remediation of TCE-contaminated aquifers.

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Abstract

The remediation of contaminated sites increasingly demands sustainable solutions capable of valorizing waste materials from other production chains. Trichloroethylene (TCE)-contaminated aquifers provide an ideal testbed for developing and optimizing integrated abatement systems. While hydraulic containment and water treatment (Pump & Treat) remain widespread approaches for chlorinated solvent plumes, *in situ* biological treatments often face intrinsic limitations, such as short contaminant residence times and the scarcity of nutrients or electron donors (EDs).

To address these challenges, this study investigates a combined process coupling **Biological Reductive Dechlorination (BRD)**—performed by *Dehalococcoides*—with **adsorption onto Biochar (BC)**, a by-product of pine wood gasification for power generation. The BC, characterized by a high carbon content and surface area, acts both as an adsorbent and microbial support. Electron donors for the sequential hydrogenolysis process were provided by the fermentation of **polyhydroxyalkanoate (PHA)-enriched biomass**, produced from **Mixed Microbial Cultures** fed with the fermented Organic Fraction of **Municipal Solid Waste** (OFMSW) in a three-stage pilot-scale process.

Experiments were conducted in a vertical cylindrical reactor (144 cm height, 10 cm diameter) packed with sand and BC (4% w/w) along its length, and PHA-enriched biomass (4% w/w) in the first half section. Over 934 days of operation—treating 5731 L of contaminated water (1433 pore volumes)—the system's **robustness** and **resilience** were evaluated under varying operational conditions.

At the initial hydraulic retention time (HRT) of 39 h, complete TCE removal was achieved through the synergistic action of BRD and adsorption. When the flow rate was increased (HRT ≈ 10 h) and fermentation products (VFAs) were depleted, microbial kinetics slowed, contaminant migration accelerated, and a sequential breakthrough of intermediates occurred, culminating in TCE breakthrough after 460 days. The subsequent reduction of flow rate failed to restore performance, indicating electron donor limitation. Upon feeding lactate as an easily degradable ED source, TCE degradation resumed immediately—without lag phase—demonstrating the system's resilience. Interestingly, the transient accumulation of *cis*-DCE exceeded the molar input of TCE, suggesting desorption and concurrent biodegradation of previously adsorbed TCE.

These results highlight the **efficiency, robustness, and adaptability** of this waste-based combined process, which shows strong potential for scale-up and field application as a **reactive permeable**

barrier or as a **fixed-bed reactor** for *ex situ* treatment of extracted groundwater, possibly integrated with **groundwater circulation wells** to enhance contaminant mobilization in low-permeability zones. The promising results show the efficiency and robustness of this process, which is expected to be further scaled up, with a view to application at real sites as a reactive permeable barrier, or as a fixed-bed reactor in a treatment plant for emitted water, possibly further complemented by recirculating wells for contaminant mobilization in less permeable areas of the aquifer.

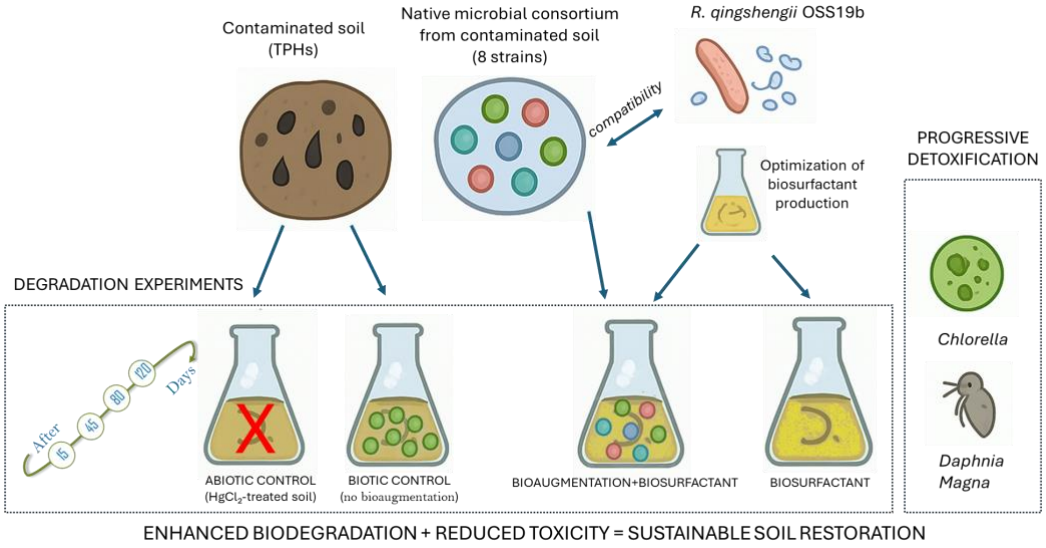
Multidisciplinary Assessment of Soil Bioremediation by Indigenous Hydrocarbon-Degrading Bacteria: Chemical, Microbial, and Ecotoxicological insights

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The research activity aimed to enhance the natural bioremediation potential of a hydrocarbon-contaminated soil through the synergistic application of a native microbial consortium and a biosurfactant specifically designed to increase hydrocarbon bioavailability and microbial activity. The study also included an ecotoxicological evaluation to verify both the environmental safety and the long-term effectiveness of the proposed remediation strategy.



The experimental work built upon previous bioaugmentation trials that identified a consortium of eight bacterial strains, isolated from the same contaminated soil and deposited in the ENEA Microbial Culture Collection (EMCC). These strains were revitalized and characterized for their ability to produce biosurfactants and degrade hydrocarbons. Laboratory assays confirmed that all strains possessed biosurfactant-producing capacity, with *Brevibacterium aurantiacum* RET4 and *Paenibacillus mobilis* R1 showing the highest emulsification and surface activity values. In parallel, growth and degradation tests on minimal media, containing oil as the sole carbon source, demonstrated that the entire consortium was metabolically capable of utilizing hydrocarbons, either through direct assimilation or by inducing dissolution halos, confirming their functional potential for soil bioaugmentation.

In addition to the microbial consortium, a distinct bacterial strain, *Rhodococcus qingshengii* OSS19b, stored in the EMCC but not included in the original bioaugmentation consortium, was evaluated for

its biosurfactant-producing capacity. This strain exhibited the highest emulsifying activity (E24 ≈ 60%), a marked ability to reduce surface tension, and strong hydrocarbon-degrading potential, even surpassing that of the indigenous bacteria used in the bioaugmentation experiments. Compatibility tests carried out by cross-streak assays confirmed that OSS19b could coexist with the consortium strains without any inhibitory interactions, ensuring synergistic cooperation during co-inoculation.

Optimization trials were performed to define the best conditions for biosurfactant production. The optimal growth was obtained in a minimal medium supplemented with 0.2% sodium gluconate at 28°C under shaking conditions. Scale-up experiments conducted in 1 L flasks confirmed that maximum biosurfactant yield was achieved after five days of incubation. Physicochemical analyses revealed a strong emulsifying capacity and surface activity. Since *Rhodococcus* biosurfactants are mainly associated with the cell fraction, centrifugation significantly reduced the emulsifying index (E24 = 29.6%). However, mild sonication, which induced partial cell lysis, restored the emulsification values (E24 = 44.4%) while maintaining a minimal microbial load. The resulting cell suspension, containing both active cells and biosurfactant compounds, was used directly in soil degradation experiments without additional purification steps.

Batch-scale degradation trials were then carried out on hydrocarbon-contaminated soil over a 120-day period. The experimental setup included four parallel conditions: abiotic control ($HgCl_2$-treated soil), untreated biotic control, biosurfactant-only treatment, and combined bioaugmentation with biosurfactant addition. Microbiological, chemical, and ecotoxicological analyses were conducted at regular intervals (15, 45, 80, and 120 days). Bacterial counts indicated sustained microbial viability (10^8–10^{12} CFU/ml) across treatments with biosurfactant. Partial elaboration of chemical data indicated that the addition of the biosurfactant substantially enhanced the biodegradation of total petroleum hydrocarbons (TPHs), particularly affecting the heaviest and most recalcitrant fractions, such as hopanes. These compounds, typically resistant to microbial attack, were degraded up to 90%, demonstrating the effectiveness of the biosurfactant in increasing hydrocarbon bioavailability and supporting microbial metabolism.

To ensure the environmental safety of the treatments, ecotoxicological analyses were performed in parallel using a suite of bioassays on soil eluates. The results revealed a progressive decrease in soil toxicity over time, particularly in the combined bioaugmentation–biosurfactant treatment. A marked reduction in toxicity toward *Chlorella* was observed, suggesting that the treatment not only promoted hydrocarbon degradation but also contributed to the detoxification of the contaminated soil. In contrast, the *Daphnia magna* assays showed temporary increases in toxicity during the early stages of the process, likely linked to the transient release of intermediate degradation products and the higher solubility of hydrocarbons induced by the biosurfactant. These effects gradually diminished as the bioremediation process advanced, leading to a net reduction of ecotoxicological impact by the end of the experiment.

Overall, the results confirmed the synergistic effectiveness of combining an autochthonous microbial consortium with a biosurfactant-producing strain to accelerate the breakdown of the heaviest fraction of petroleum hydrocarbons in contaminated soils. The biosurfactant enhanced the bioavailability of hydrophobic contaminants by reducing surface tension and promoting

emulsification, thereby improving microbial access and degradation efficiency. The concurrent ecotoxicological improvement further validated the environmental sustainability of the approach.

The methodological framework established in this study—including microbial screening, compatibility assessment, optimization of biosurfactant production, and integrated chemical, microbiological, and ecotoxicological monitoring—provides a solid foundation for developing standardized protocols to evaluate the biological treatability of hydrocarbon-contaminated sites. Such a framework can support future feasibility studies and guide the design of site-specific bioremediation strategies, promoting the adoption of biologically based, environmentally safe, and cost-effective approaches to soil restoration.

Framework for an integrated assessment of sustainability and circularity in remediation of contaminated sites

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Abstract

In the context of contaminated sites, the need has emerged to further investigate into the aspects related to their sustainable management and the increasingly urgent necessity to apply less impactful methodologies and technologies that are attentive to the circularity of the resources employed. This urgency also arises from the vulnerability of the national context, which currently sees approximately 17,000 remediation procedures underway [4], involving areas potentially affected by risks to the environment and the surrounding population.

The research work has led to the definition and testing of a Framework that serves as a decision-support tool. Through the use of specific indicators, its purpose is to guide project choices in favour of identifying the best solution, one that allows for the maximization of environmental, social, and economic benefits through a decision-making process shared with the stakeholders [5]. Furthermore, this tool identifies indicators related to the evaluation of circular economy performance, which currently represents one of the major contributions to sustainable development policies [6].

A first phase of the research involved a bibliographic analysis, referring to the European and non-European context, integrated with an evaluation of the different available software. The results of this phase highlighted that Italy is among the few analyzed countries completely lacking regulation and tools for a standardized assessment of remediation sustainability. Therefore, at the procedural level of Italian legislation, no sustainability criteria are imposed for the selection of interventions. Furthermore, techniques such as bioremediation are evaluated in the same way as permanent measures or Dig and Dump (D&D), which are certainly much more impactful. Consequently, the legislation does not favor new technologies that exhibit characteristics of greater sustainability. Furthermore, this research identified the absence of specific studies on the integration of circular economy principles into contaminated site management, which currently represents a significant gap in the scientific literature. Based on this, the main objective of the present research was materialized, which aims at defining a clear, operative, and complete measurement pathway, capable of objectively supporting the development of the strategic model for sustainability and circular economy over time.

The circularity assessment is consistently absent, but for this aspect, reference was made to the main technical standards governing the measurement of circularity in organizations, namely the ISO 59020:2024 [3] and UNI/TS 11820:2022 [2] standards. Subsequently, a careful selection of indicators was carried out to provide a ranking of the best interventions that were measurable at the ex-ante

level—that is, during the design phase—following a SMART criterion [1]: for each indicator, it was verified that the data were Specific, Measurable, Achievable (or Attainable), Relevant, and Time-bound (Temporal). Finally, the framework was validated by applying it to a case study.

The second phase of the research concerned the selection of specific indicators. A set of circularity indicators was identified, consisting of 16 indicators derived from the UNI/TS 11820:2022 standard [2], with 11 for both the ex-ante and ex-post phases and 5 only for the ex-post phase. The indicators derived from the ISO 59020:2024 standard [3] are instead 9, with 4 for both phases and 5 only for the ex-post phase. In the context of sustainability assessment of a remediation project, after identifying objectives for the economic, social, and environmental aspects, it is necessary to define indicators that can measure the achievement of these

objectives. Indicators represent the criteria used to evaluate the various intervention alternatives. The identification of indicators should, in principle, aim for the most complete possible representation of the consequences of each alternative. At the same time, the set of selected indicators must be "economically accessible" (in terms of data and information collection) and as homogeneous as possible in terms of measurement units.

These indicators were tested to identify any critical issues through application to real case studies. The fundamental criterion for validating the indicators and ensuring the reliability of the analysis was found to be data availability, which must be directly or indirectly accessible starting from the drafting of the remediation project. Furthermore, the specificity and completeness of the data are fundamental, as the circularity assessment is based on inventory data related to site management and not on impacts.

Based on the complexity of data retrieval at the preliminary project level (i.e., when the evaluation is made for selecting the best intervention to be developed at the definitive level), following several applicability checks and based on the results derived from application to case studies, a further selection of sustainability and circularity indicators (Table 1) was performed. This was done to obtain a simplified tool useful for defining a framework applicable in a national context and a single decision-making framework aimed at guiding the choice of intervention strategy toward remediation solutions that are not only sustainable but also attentive to the application of circular economy principles.

Table 1 Selection of Sustainability and Circularity Indicators for the identification of the best interventions

	Sustainability Indicators
ENVIRONMENTAL INDICATORS	Mineral resource scarcity (LCA midpoint)
	Solid waste production
	Global warming (LCA midpoint)
	Cumulative Energy Demand (LCA midpoint)
ECONOMIC INDICATORS	Expected duration of intervention
	Construction costs physical capital used in the intervention
	Intervention operating costs
	Increase in land value following reclamation
SOCIAL INDICATORS	Health impacts on workers and residents in communities adjacent to the remediated site
	Equity across genereations and populations
	Negative externalities for residents and stakeholders
	Human capital (i.e., investment in training, experimentation, research and development)
	Circularity Indicators
	(UNI 1) Self-produced secondary material resources reused in the process, compared with total used secondary material resources
	(UNI 18a-18b) Disposed urban and/or special waste compared to total generated waste
	(UNI 24a-24b) Urban and/or special waste treated at local valorization facilities compared to total treated waste
	(UNI 32) Generated by-products compared to total generated production waste

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Drivers of spatial variability in post-fire forest regeneration

Francesco Atzeni [1,2], Flavio Taccaliti [1*], Davide Marangon [1], Federico Colle [3,4,5], Federico Ghiggini [3,4], Emanuele Lingua [1]

(1) Università degli Studi di Padova, TESAF Department; (2) Università Politecnica delle Marche, D3A Department; (3) Università degli Studi di Genova, DIBRIS Department; (4) CIMA Research Foundation, Savona, Italy; (5) Institute of Atmospheric Sciences and Climate, CNR-ISAC, Turin, Italy; *flavio.taccaliti@unipd.it

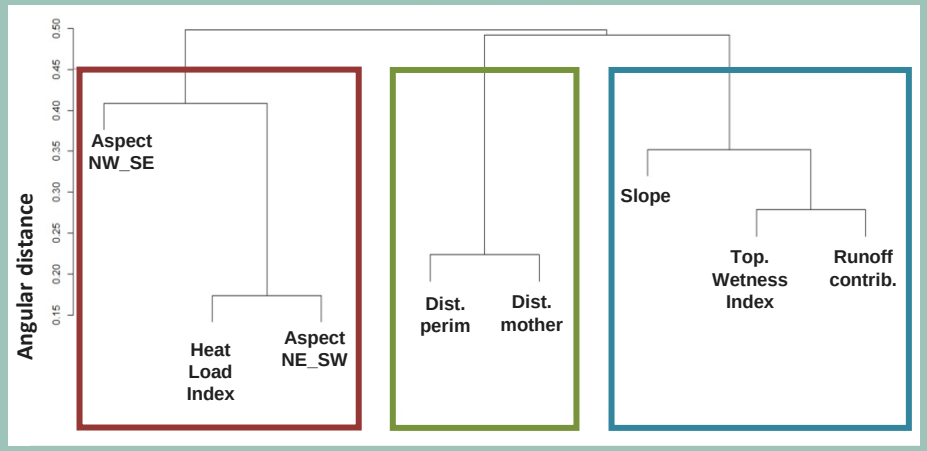
Field-collected location of *Pinus halepensis* Mill. regeneration were combined with environmental variables derived from UAV imagery[†].

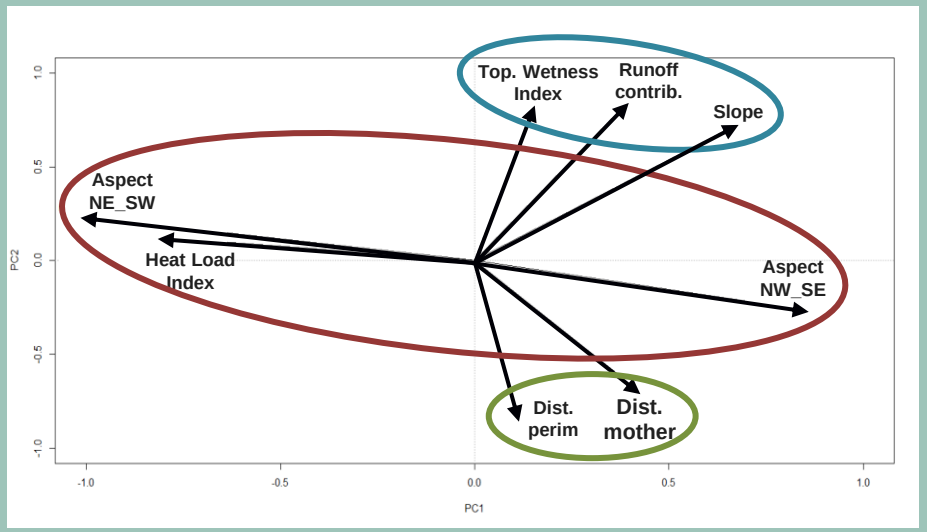
Predictors were grouped through **angular-distance clustering** into three main sets:

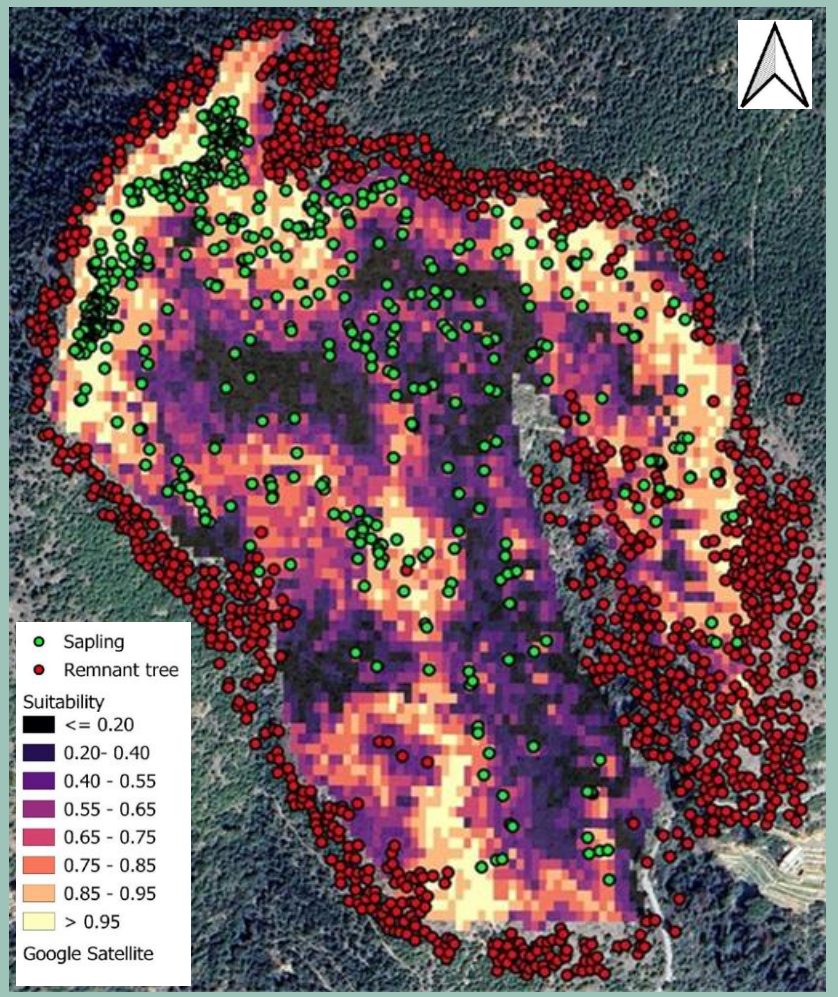
- **Radiation** (aspect, heat load index)
- **Distance** (from the edge, from remnant mother tree)
- **Topography** (runoff contribution, slope, topographic wetness index)

A **Random Forest** calibrated with ecologically-weighted pseudo-absences based on *Heat Load Index*, *Distance to mother trees* and *Topographic Wetness Index* produced an **ecological suitability map** with good sensitivity (0.769) and specificity (0.845) (test set n = 500 pixels)

(†) Thanks to Giacomo Fagugli, Umberto Morra di Cella, and Flavio Pignone from CIMA Research Foundation for the UAV data collection







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DRONERUN - UAV Fast Software Development in the AI Age

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1. Introduzione e Contesto

• Nonostante le crescenti capacità degli UAV, la loro integrazione nella ricerca scientifica rimane limitata (Kemarau et al., 2024).
• Divario dovuto a:
  - **Elevate Barriere Tecniche;**
  - **Lunghi Cicli di Sviluppo** (Pal et al., 2024).
• Sfide future (monitoraggio, soccorso) richiedono IA complessa e controllo **real-time on-the-edge.**

2. Obiettivi del Progetto

• **Ridurre il Time-to-Prototype**: Validare un flusso di lavoro per ridurre i tempi dalla concezione al test reale.
• **Validare una Metodologia**: Usare il **Model-Based Design** (**MBD**) per unificare progettazione, simulazione e implementazione.
• **Creare Basi per la Ricerca**: Fornire una metodologia accessibile.

3. Selezione Piattaforme SW e HW

• **Opzioni Valutate**: Unreal/AirSim (curva C++ ripida), Gazebo/ROS (integrazione non nativa).

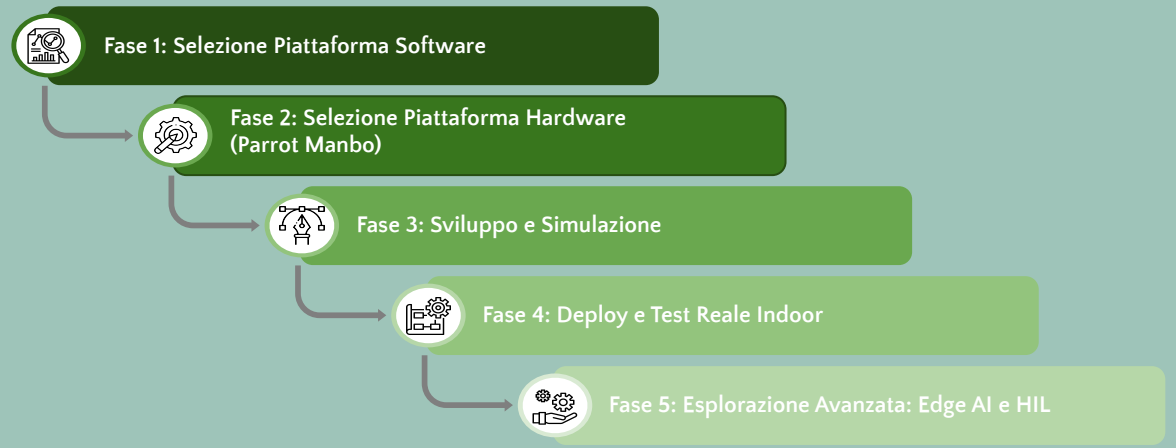
• **Soluzione Adottata**: MATLAB & Simulink
  - Ambiente Unificato
  - Generazione Codice Automatica
  - Validazione HIL (NVIDIA Jetson e Pixhawk 6C)

4. Sviluppo e Risultati

È stata implementata un'applicazione di volo autonomo per validare l'intero workflow:
• **A. Simulazione (Antincendio):** Validazione logica di volo autonomo con SIMULINK/MATLAB (Algorimo:Scanning → Identificazione → Rifornimento → Intervento).

• **B. Deploy e Test Reale (Parrot Mambo):** Il modello Simulink è stato convertito in codice C (Simulink Coder) e caricato direttamente sul processore del Parrot Mambo ed eseguita. Risultato: Conferma con successo dei risultati della simulazione.

• **C. Test Avanzato (AI in HIL):** Validazione architettura ibrida con **NVIDIA Jetson Nano e flight controller Pixhawk 6C** per rilevamento ostacoli e aggiornamento dinamico traiettoria.



5. Conclusioni

• **Workflow Validato**: L'approccio MBD ha mostrato un'elevata coerenza tra simulazione e test reali. I risultati sono attendibili in ambiente fisico.

• **Time-to-Prototype Ridotto**: L'ecosistema integrato MATLAB/Simulink e la generazione automatica di codice hanno ridotto drasticamente i tempi e la complessità del ciclo di sviluppo.

• **Base per la Ricerca**: E' stata creata una metodologia solida e accessibile, trasferibile alla comunità scientifica per accelerare lo sviluppo di applicazioni robotiche autonome.

• **AI READY**: I test HIL con NVIDIA Jetson Nano e il flight controller Pixhawk 6C hanno confermato la **predisposizione dell'architettura per future implementazioni di Edge AI complesse**.

Metodologia: Il Workflow Integrato Model-Based Design (MBD)



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MACRO AND MICRO FOULING COMMUNITIES ON BIODEGRADABLE AND CONVENTIONAL PLASTICS

M.Graziano[1], M.Celussi[1], Elisa Banchi[1], S. Giacobbe[2], S. Manzo[3], M. D'Alessandro[1]

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INTRODUCTION – Floating and submerged plastic debris provide new artificial substrates that can be rapidly colonized by microorganisms (the plastisphere) and macrofouling organisms [1]. These biofouled plastics form a complex community capable of altering local biodiversity and can act as vectors for the spread of non-indigenous species [2]. The aim of this study is to compare micro- and macrofouling communities colonizing two conventional (PP, PE) and two biodegradable (Mater-bi and PLA) plastics (Fig. 1) in the marine environment at six coastal sites of the Aeolian Archipelago (Sicily, Central Tyrrhenian Sea), selected for their contrasting environmental conditions in terms of pH, temperature, and levels of anthropogenic activity. (Fig.2).

Fig 1. MCs recovered at Baia di Levante after three months of deployment.



Fig. 2. Sampling sites



Fig. 3. Stainless steel cylinders deployed

MATERIAL AND METHODS – For three months at each site, stainless steel cylinders (Fig. 3) were deployed containing macro-containers that were hand-microperforated (1 mm) to ensure water circulation and held microplastic fragments of the same polymer. For each polymer, four macro-containers (MCs) were deployed, resulting in a total of 36 macro-containers per cylinder. For macrofouling analysis, samples were carefully examined under a stereomicroscope, and encrusting organisms were identified to the lowest possible taxonomic level.

For microbiological analyses, microbial communities from the surrounding seawater (T0) and those forming the plastisphere (T1, after 3 months) were compared. Seawater was collected and filtered in situ at the start of the experiment, while microfouling biofilms developing on the microplastics were analyzed after three months of exposure. The microbial communities were investigated using DNA metabarcoding, targeting the 16S gene, on seawater (T0, Tf; filtering 3 L through 0.2 µm membrane filters) and on plastic pieces (Tf; 5 fragments). DNA extraction was carried out from membrane and plastics using the Dneasy PowerWater kit (Qiagen). The supplier's instructions were followed with slight modifications aimed at increasing the DNA yield and quality [3] and DNA was quantified with a Qubit fluorimeter (Thermo Fisher Scientific). For the DNA metabarcoding analysis, the V4-V5 region of the 16S rRNA gene was amplified using 515-Y (5'-GTGYCAGCMGCCGCGGTAA-3') and 926R (5'-CCGYCAATTYMTTTRAGTTT-3') primers [4]. Libraries were prepared following the 16S Metagenomic Sequencing Library Preparation protocol and run on an Illumina Novaseq 6000 System for a read length of 2 × 250 bp at the Institute of Applied Genomics (IGA), Udine, Italy.

RESULTS AND DISCUSSIONS – A total of 93 macrofouling specimens were recorded. Polychaetes represented the dominant taxonomic group (59.3% of the total assemblage). The lowest values of abundance (N) and Shannon diversity (H') observed at Baia di Levante (pH 7.51 ± 0.44) and at Lipari Porto highlight the role of acidification and anthropogenic pollution as key stressors threatening marine biodiversity (Fig. 4). The cryptogenic polychaete *Simplaria pseudomilitaris* was the most abundant species (30 specimens), while *Neodexiospira pseudocorrugata* was the most frequent. The non-indigenous bivalve *Pinctada radiata* occurred at all sites except the control site Valle Muria, and was found exclusively on biodegradable plastics, 90% on Mater-bi, both inside and outside the containers, with an average shell length of 8.6 ± 4.7 mm (Fig. 5; Fig. 6). Overall, Mater-bi was the most colonized polymer, hosting 40.6% of the total macrofaunal assemblage. These findings confirm the role of plastics as substrates for the recruitment and growth of non-indigenous species [2].

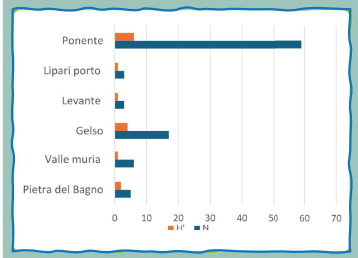


Fig 4. Biodiversity indices at the sampling sites.

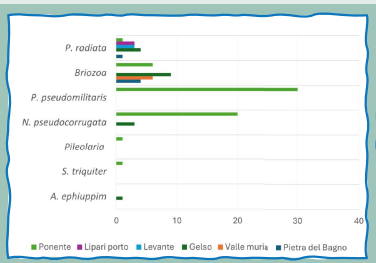


Fig 5. Abunbances of species in sampling sites

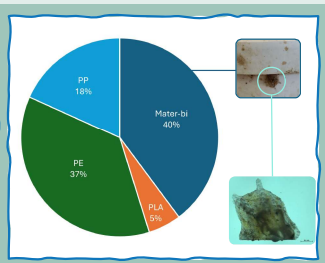


Fig 6. Fouling percentages on different plastic polymers and close-up of *P. radiata* settled on a Mater-bi macro-container (right).

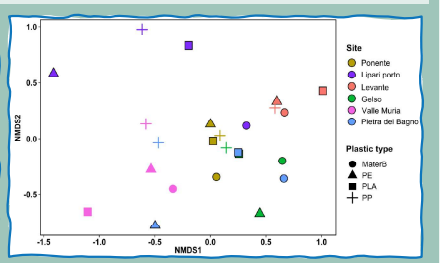


Fig 7. NMDS plot (stress = 0.19) showing Bray–Curtis dissimilarity in community composition of plastic samples.

The taxonomic composition of plastic samples differed significantly from that of seawater, as determined by permutational multivariate analysis of variance (PERMANOVA). *Synechococcus* and *Pelagibacterales* Clade Ia were the most abundant taxa at the genus level in seawater. Baia di Levante showed a higher proportion (~12% vs ~0.5% at the other sites, on average) of the chemolithoautotrophic, sulfur-oxidizing bacterium *Thiomicrorhabdus*, which is typical of hydrothermal vent communities.

On the contrary, plastic pieces were characterized by the presence of particle-associated bacteria, such as members of the *Chitinophagales* order, the *Saprospiraceae* family and the *Woeseia* genus. Focusing on plastic samples, non-metric multidimensional scaling (NMDS) plots using Bray-Curtis dissimilarity matrices showed that samples were mainly grouped by site (Fig. 7). This was confirmed by PERMANOVA, which indicated that both sampling site and plastic type had a significant effect ($p < 0.001$) on prokaryotic community structure. The highest proportion of variance explained was by site (35%), which was greater than that explained by plastic type (16%).

These results suggest that the environmental context has a greater influence than the physicochemical properties of plastics on the composition of plastic-associated prokaryotic communities. Overall, these data further highlight the importance of hydrothermal sites as natural laboratories for investigating the combined effects of ocean acidification and multiple stressors on marine biotic communities [2].

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2. **Pauli Nora-Charlotte, Petermann Jana S., Lott Christian and Weber Miriam (2017).** *Macrofouling communities and the degradation of plastic bags in the sea: an in situ experiment.* R. Soc. Open Sci.4170549 http://doi.org/10.1098/rsos.170549
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Atlante geochimico dei sedimenti fluviali dei principali corsi d'acque del Bacino del Fiume Sarno.

Guarino A.[1], Iannone A. [1], Parrella L. [2], Manzo S. [2], Schiavo S. [2], Crovato C. [2], Montereali M. [2], Caiazzo L. [2], de Cassan M. [2], Caprioli. R. [2], Stefano A. [1]

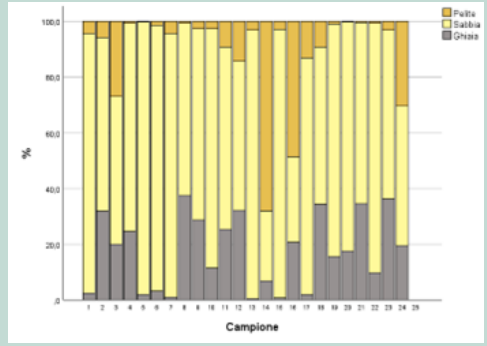
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[2] Dipartimento Sostenibilità, circolarità e adattamento al cambiamento climatico dei Sistemi Produttivi e Territoriali Divisione Protezione e valorizzazione del territorio e del capitale naturale

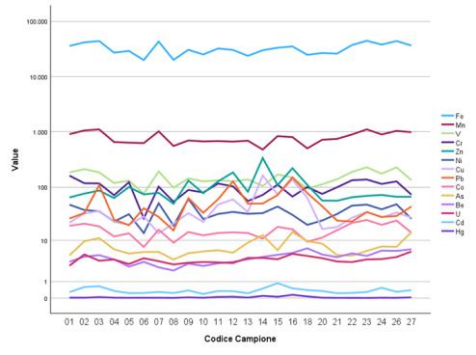
- 24 campioni di sedimento fluviale
  - prelevati al centro dell'alveo
  - 5 aliquote di materiale
  - tratto fluviale lungo 10-20 m
  - passante Φ < 2 mm
  - peso finale di ca. 2.5 kg



- Analisi granulometriche
- 14 elementi potenzialmente tossici e metalli (PTE+)
- 28 idrocarburi policiclici aromatici (IPA)
- 30 policlorobifenili (PCB)
- 19 pesticidi organoclorurati (OCP)
- 6 composti organostannici (OTIN)

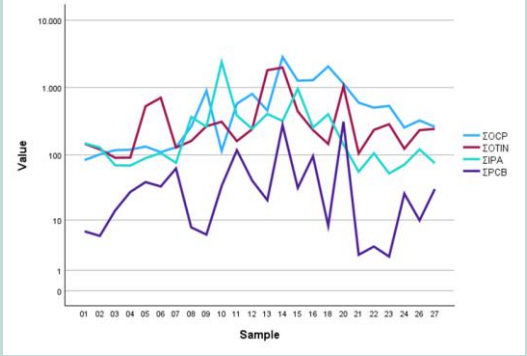


- I metalli mostrano una distribuzione variabile, evidenza della coesistenza di componenti naturali e contributi locali di diversa origine, coerentemente con il contesto fortemente antropizzato del bacino.



- Forte presenza di Fe e Mn, di origine prevalentemente geogenica.
- V, Co e Be in parte seguono l'andamento di questi elementi di origine naturale.
- U e Hg presentano un andamento più uniforme.
- Zn, Cu, Cr, Pb, Ni, Cd, As mostrano andamenti più variabili e picchi localizzati.

- Ogni gruppo è associato a utilizzi diversi (OCP ambito agricolo, OTIN attività industriali e nautiche, IPA processi di combustione, PCB impieghi industriali).



- OCP (ca. 600 µg/kg) > OTIN (ca. 400 µg/kg) > IPA (ca. 300 µg/kg) > PCB (ca. 50 µg/kg)
- Trend comune: tra i campioni dell'area di piana le concentrazioni sono più elevate.
- Suggerisce che i tratti di pianura agiscano come zone di accumulo perché è favorita la deposizione dei sedimenti fini e il sequestro dei contaminanti.

- Le aree centrali e settentrionali presentano i maggiori livelli di contaminazione, in linea con la localizzazione storica delle principali fonti industriali e urbane.
- La distribuzione dei contaminanti riflette sia processi idrodinamici di trasporto e deposizione dei sedimenti, sia l'interazione tra sorgenti puntuali e diffuse.

BOOK OF ABSTRACTS

Return



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