How to recover from extreme events and anthropogenic impact? Knowledge and best practices from thirteen case studies

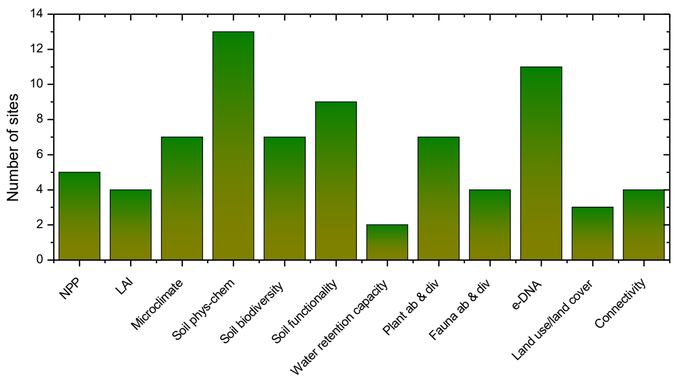
Chiara Baldacchini[1,*], Alessio Giovannelli[2,3,*], Francesca Adducci[3,4], Federico Ardenti[5], Giacomo Baldesi[3,6], Sara Barberini[7], Alessandro Bizzarri[8], Alessandra Bonetti[2], Ernesto Renato Bovio[9], Francesca Bretzel[3,10], Fabiana Canini[1], Elisa Carrari[8], Pietro Castellucci[8], Pier Mario Chiarabaglio[11], Gianpasquale Chiatante[1], Gherardo Chirici[8], Marco Ciolfi[12], Claudia Cocozza[8], Anna Corli[3,6], Marta Cotti Piccinelli[1,13], Luigi Paolo D'Acqui[2], Ettore D'Andrea[3,12], Miriam Di Blasi[14], Sara Di Lonardo[2,3], Francesco Drosera[15], Giovanni Emiliani[2], Andrea Fiorini[16], Saverio Francini[17], Maria Genovese[14], Martina Grattacaso[2], Emanuele Lingua[9], Alberto Maltoni[8], Davide Marangon[9], Barbara Mariotti[8], Marco Carlo Mascherpa[10], Simone Mereu[3,18,19], Lucia Mondanelli[8], Andrea Mondoni[3,6], Antonio Montagnoli[20], Lidia Nicola[6], Simone Orsenigo[3,6], Mattia Pallanza[3,6], Marco Pellegrini[21], Giuliana Pincelli[22], Roberto Pini[10], Edoardo Puglisi[23], Negar Rezaie[2,3], Irene Rosellini[10], Maurizio Sarti[12], Cristiana Sbrana[24], Andrea Scartazza[3,10], Manuele Scatena[10], Flora Giulia Simonelli[9], Costantino Battista Sirca[3,19,25], Tommaso Sitzia[3,9], Donatella Spano[3,19,25], Eliana Lanfranca Tassi[10], Solveig Tosi[3,6], Silvia Traversari[3,10], Maria Laura Traversi[2], Giovanni Trentanovi[2], Francesca Vannucchi[3,10], Laura Zucconi[1], Carlo Calfapietra[3,12]

*[1] Department of Ecological and Biological Sciences, University of Tuscia, Viterbo, Italy; [2] National Research Council, Research Institute on Terrestrial Ecosystems (CNR-IRET), Sesto Fiorentino (FI), Italy; [3] National Biodiversity Future Center (NBFC), Palermo, Italy; [4] National Research Council, Institute of Bioeconomy (CNR-IBE), Roma, Italy; [5] CERZOO Research Station, Piacenza, Italy; [6] Department of Earth and Environmental Sciences, University of Pavia, Pavia, Italy; [7] National Research Council, Institute for Sustainable Plant Protection (CNR-IPSP), Sesto Fiorentino (FI), Italy; [8] Department of Agricultural, Food, Environmental and Forestry Sciences and Technologies, University of Florence, Italy; [9] Department of Land, Environment, Agriculture and Forestry, University of Padova, Legnaro (PD), Italy; [10] National Research Council, Research Institute on Terrestrial Ecosystems (CNR-IRET), Pisa, Italy; [11] Consiglio per la Ricerca in Economia e Agricoltura, Casale Monferrato (AL), Italy; [12] National Research Council, Research Institute on Terrestrial Ecosystems (CNR-IRET), Porano (TR), Italy; [13] Infrastrutture SpA; [14] Enel Green Power SpA; [15] Regione Toscana; [16] Department of Sustainable Crop Production, Università Cattolica del Sacro Cuore, Piacenza, Italy; [17] Department of Science and Technology of Agriculture and Environment, University of Bologna, Bologna, Italy; [18] National Research Council, Institute of Bioeconomy (CNR-IBE), Sassari, Italy; [19] Foundation Euro-Mediterranean Centeron Climate Change (CMCC), Sassari, Italy; [20] Department of Biotechnology and Life Science, University of Insubria, Varese, Italy; [21] Studio forestale Pellegrini, Asiago, Italy; [22] Parco Naturale Adamello Brenta; [23] Department of Sustainable Food Process, Università Cattolica del Sacro Cuore, Piacenza, Italy; [4] National Research Council, Institute of Agricultural Biology and Biotechnology (CNR-IBBA), Pisa, Italy; [25] Department of Agricultural Sciences, University of Sassari, Sassari, Italy; * (presenting authors)*

Thirteen Open Air Laboratories (OALs) were set up and monitored under Spoke 4/Activity 4.5 of the National Biodiversity Future Center (NBFC). These OALs represent case studies addressing the main ecological and environmental threats affecting Italy, including **natural disturbances** (e.g. storm winds in mountain areas, flooding in riparian zones), **anthropogenic pressures** (e.g. agriculture, forest management, energy production), and **combined impacts** such as forest fires.

In some OALs, **Ecosystem Restoration (ER)** and **Nature-based Solutions (NbS)** were implemented, while others were used to monitor **spontaneous regeneration** after extreme events. The OALs cover different terrestrial biomes across the national territory, from Alpine area to the Po Plain, Sardinian mountains, and the central Apennines. Six OALs are included in the Spoke 4 Broad Area Sites (BASs), and seven participate in the Biodiversity and Ecosystem Function Network (BioFUNet) of NBFC.

Within the thirteen OALs, biotic and abiotic parameters relevant for biodiversity were monitored using **shared impact evaluation frameworks** focused on biodiversity dynamics in the soil-plant continuum. These frameworks are coherent with established international standards, such as the GEOBON Essential Biodiversity Variables and the European NbS Impact Evaluation Framework, ensuring comparability and replicability across sites.



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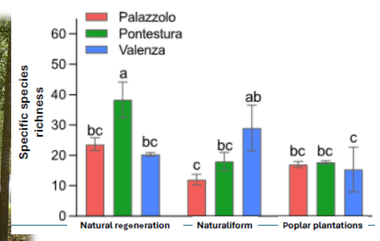
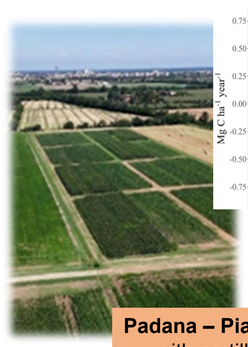
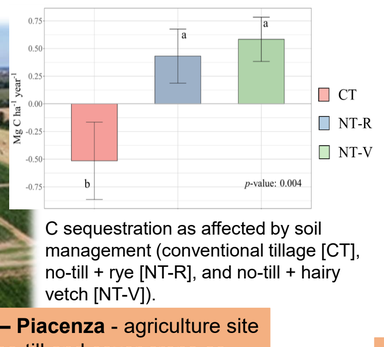


Species richness as a function of management. Corli et al. (2025) Forest Ecology and Management 595, 123000.

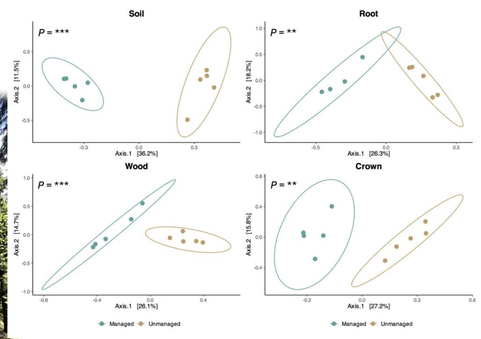
Po Vercellese - riparian sites under floodplain and human impact, where vascular plant diversity, stand structure, and soil have been monitored in cultivated, semi-natural, and natural poplar stands, with semi-natural showing the best trade-off.





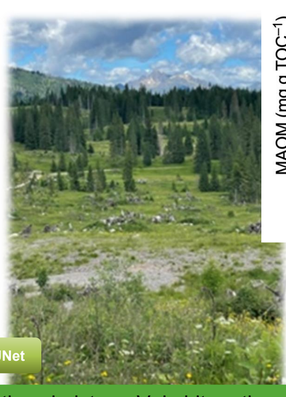
C sequestration as affected by soil management (conventional tillage [CT], no-till + rye [NT-R], and no-till + hairy vetch [NT-V]).

Padana – Piacenza - agriculture site with no-till and cover crops as regenerative strategy to enhance soil quality and sustain crop production; environmental performances were driven mostly by quantity of biomass input rather than quality.



Bray Curtis beta-diversity for fungi, with PERMANOVA P-values (**, P < 0.01; ***, P < 0.001). Traversari et al. (2025), STOTEN 1001, 180432.

Adamello-Brenta - forest structure, soil traits, endophytic and soil bacteria and fungi were compared in managed (i.e., thinning) and unmanaged alpine Norway spruce stands. Specific taxa featuring the different forest management have been identified.



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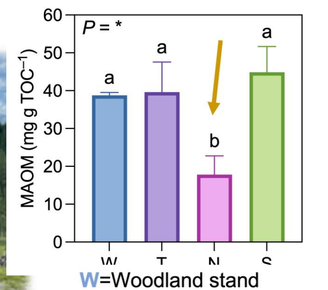
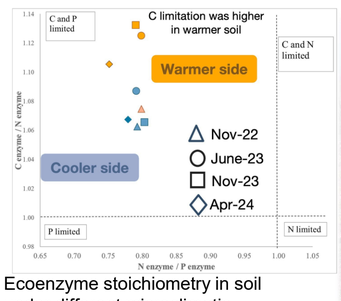


Soil carbon sequestration in post-Vaia sites.

Asiago - in 2018, the windstorm Vaia hit north-eastern Italy, affecting about 45 kha of forest areas and causing more than 12 million m^3 of timber loss; a study was conducted to assess the effect of the windstorm on biodiversity and soil health, as well as to evaluate the proper restoration action with seedlings of different species for the recovery of forest ecosystem and related ecosystem services.

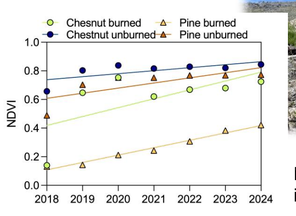


Ecoenzyme stoichiometry in soil under different microclimatic conditions in La Verruca.

BioFUNet

Monte Pisano - La Verruca - a burned Mediterranean area was used to test different container types for cork oak seedlings; plant growth and physiology and soil health were monitored, revealing that the largest seedlings showed the best establishment and performance, and that microclimatic variables affect planting success.
Monte Pisano – Montemagno - in chestnut and pine forests, soil health was monitored over time in burned areas under natural regeneration and compared to unburned areas as control; soil enzymes, stable N isotopes and mycorrhizal colonization were suitable indicators for monitoring soil recovery.
Monte Pisano – Vicopisano - above and below ground biomass, soil health, and biodiversity were monitored over time in a pine forest under natural regeneration within the NBFC "Gruppo Incendi".

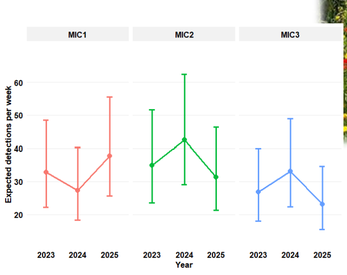
BioFUNet



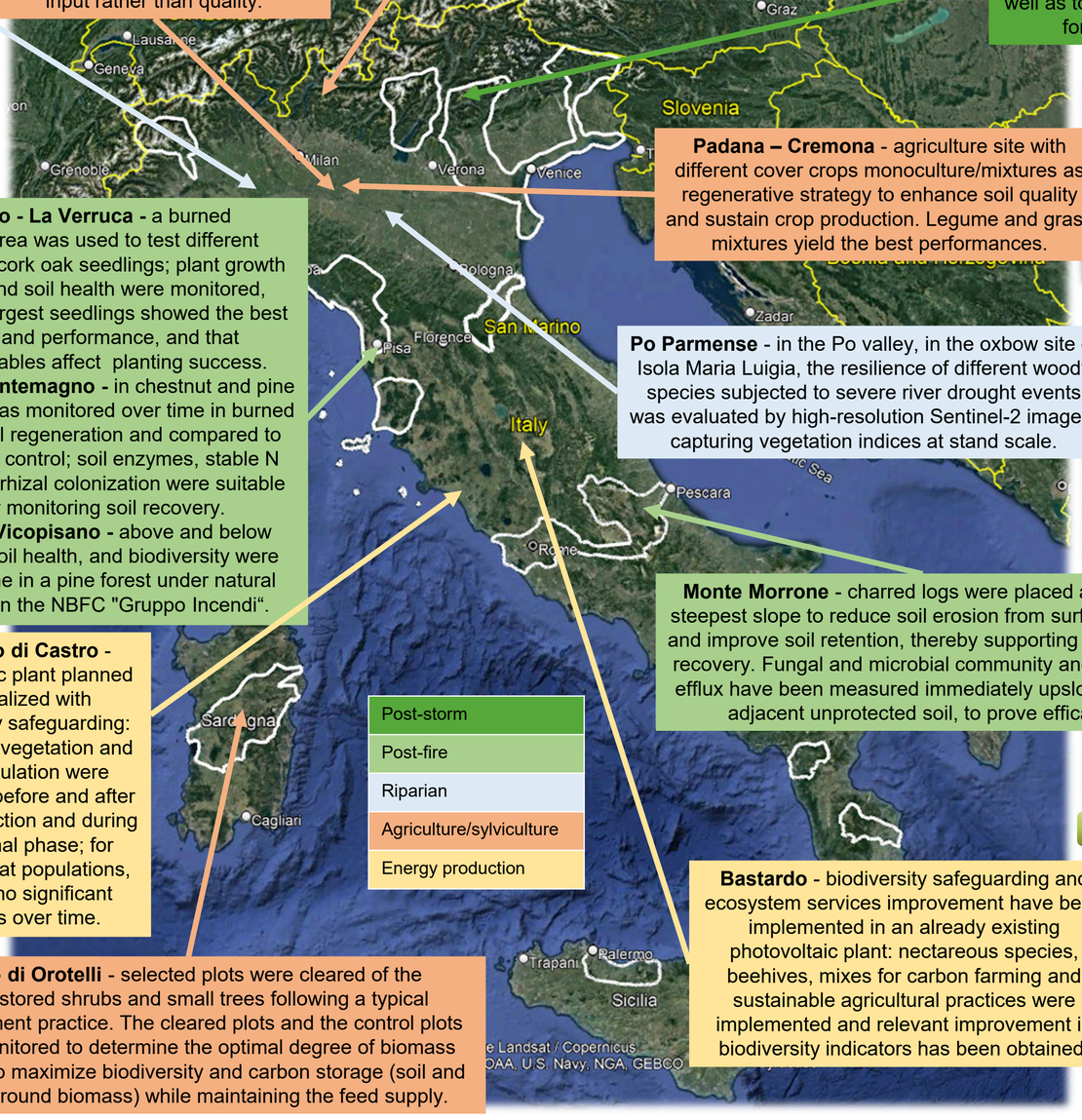
NDVI times series in Montemagno.

BioFUNet

Montalto di Castro - photovoltaic plant planned and realized with biodiversity safeguarding: soil health, vegetation and bats population were monitored before and after the construction and during operational phase; for instance, bat populations, showed no significant changes over time.

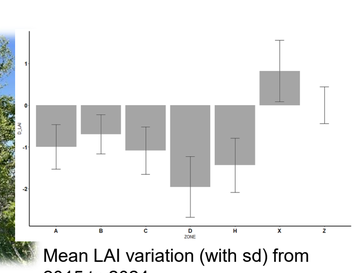


Estimated marginal means (±95% CI) of weekly bat detections before (2023), during (2024) and after (2025) plant construction.



Monte Morrone - charred logs were placed along the steepest slope to reduce soil erosion from surface runoff and improve soil retention, thereby supporting vegetation recovery. Fungal and microbial community and soil CO_2 efflux have been measured immediately upslope and in adjacent unprotected soil, to prove efficacy.

Po Parmense - in the Po valley, in the oxbow site of Isola Maria Luigia, the resilience of different woody species subjected to severe river drought events was evaluated by high-resolution Sentinel-2 imagery capturing vegetation indices at stand scale.



Mean LAI variation (with sd) from 2015 to 2024.

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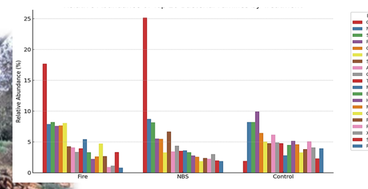
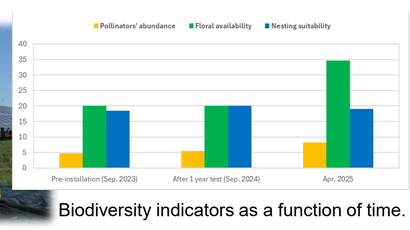


Relative abundance of top 20 bacterial families by treatment..

Bastardo - biodiversity safeguarding and ecosystem services improvement have been implemented in an already existing photovoltaic plant: nectareous species, beehives, mixes for carbon farming and sustainable agricultural practices were implemented and relevant improvement in biodiversity indicators has been obtained.



Biodiversity indicators as a function of time.

Agro di Orotelli - selected plots were cleared of the understored shrubs and small trees following a typical management practice. The cleared plots and the control plots were monitored to determine the optimal degree of biomass removal to maximize biodiversity and carbon storage (soil and above ground biomass) while maintaining the feed supply.

BioFUNet

Monitoring of **natural recovery** following extreme events enabled to:

(a) map vegetation recovery as a function of fire impact,

(b) identify optimal management practices for poplar plantations to enhance biodiversity restoration in riparian sites,

(c) characterise fungal and bacterial taxa in soils and plants from managed and unmanaged forest stands.

The monitoring of **ER and NbS** allowed to:

(a) evaluate the effectiveness of restoration actions using seedlings of different species for forest recovery and related ecosystem services in areas impacted by the 2018 Vaia storm,

(b) assess soil and plant recovery performance through species selection and the placement of charred logs to mitigate soil erosion on post-fire slopes,

(c) evaluate the resilience to of afforested species to flooding and drought in the Po river valley and the restoration potential of Vicia species and poplar intercropping,

(d) identify best practices for ER in post-agricultural and sylvicultural sites

(e) define strategies to integrate NbS approaches within ground-mounted photovoltaic plants.

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