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Bioremediation as an effective tool for a clean environment

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Bioremediation: potential benefits, challenges and how they are addressed in the NYMPHE project

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Chemical pollution – a major ecological problem

Large variety of:

- chemicals
  (hydrocarbons and their derivatives, pharmaceuticals and personal care products, (micro)plastics, pesticides, fertilizers, heavy metals, ...)

- contamination sources
  (industries, transportation, agriculture, cities, wastewaters, mining, ...)

- affected environmental matrices
  (soils, groundwater, surface water and sediments in terrestrial and marine environments, air)

→ harm to human health and the environment (biodiversity, ecosystems functions and services)
Bioremediation – a promising and sustainable approach to tackle environmental contamination

Bioremediation: a process that uses living organisms, mainly microorganisms such as bacteria and fungi, and plants, to degrade or detoxify contaminants

- Reduce the amount of pollutants released to nature (e.g., WW treatment)
- Degrade/remove the released pollutants that have accumulated and persist in contaminated environmental matrices

Benefits compared to physico-chemical approaches:
- bioprocess taking place under “mild”, life-compatible conditions (ambient T, no highly reactive chemicals or solvents)
- no or minimal alteration of the physical, chemical and biological features of the treated matrix
- nature-based approach that can promote biodiversity recovery and the revitalization of the site after remediation
Bioremediation – main actors and strategies

<table>
<thead>
<tr>
<th>ENZYMES</th>
<th>MICROORGANISMS (bacteria, algae, fungi)</th>
<th>PLANTS/HOLOBIONTS</th>
<th>ANIMALS (clams, earthworms)</th>
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<td>The catalysts that make reactions happen rapidly in biological systems. They can be very substrate-specific or promiscuous.</td>
<td>High metabolic versatility, fast growth, fast natural evolution/adaptation. They are ubiquitous - inhabit all environmental niches and higher organisms in the form of complex communities</td>
<td>Natural ability to “extract” and process chemicals (nutrients) from soil/water, in close cooperation with bacteria</td>
<td>Clams can act as biofilters and/or adsorb pollutants. Earthworms can promote soil aeration and microbial activities</td>
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- Control of environmental conditions and supplementation of the suitable nutrients to promote the activity of degrading (micro)organisms (*biostimulation*)
- Introduction of specialized degrading microorganisms (*bioaugmentation*)
Bioremediation – main bottlenecks...

- Biologics performance
  - Lack of competitiveness
  - Long acclimation period
  - Insufficient enzymes

- Pollutants
  - Multiple contaminations
  - Low concentration/bioavailability

- Environment/matrix
  - Physico-chemical parameters
  - Lack of electron donors/acceptors

- Complex reality of polluted sites

...and how they are addressed in the EU project NYMPHE

- Associations of multiple biologics
- Toolbox to improve bioremediation efficiency of biologics
- Model-based microbiome management

- “nature-inspired” & “reality-tailored” system approach

NYMPHE
Nymphe General Objective

To develop bioremediation / revitalization strategies based on bioremediation systems consisting of assemblies of multiple biologics, assess them from technical, environmental, economic and societal perspectives for the revitalization of polluted environments, and showcase them at 4 real contaminated sites and 1 site for confined tests with genomically edited organisms, with the ambition of removing at least 90% of the main pollutants of the four polluted sites and improve their biodiversity status.
Sites & target polluted matrices in Nymphe

**IGB site - Hyporheic zone (HZ)** (Hoppegarten-Berlin, DE): River Erpe sediment and surface water contaminated with **pharmaceuticals**

**CENVIS site** – (Leopoldov, SK) site used as **facility enabling the “confined use” of genomically edited biologics** to remediate the contaminated matrices of ER, CHQ and IGB sites

**METFI site** – Municipal WW (IMDEA Water, Alcala, ES): Municipal WW with **pharmaceuticals** (antibiotics) and **microplastics (MPs)**

**ER site - Industrial site** (Ferrara, IT): groundwater (GW), aquifer sediments, and soil matrices contaminated with **Petroleum Hydrocarbons (PHC)** and **chlorinated aliphatic hydrocarbons (CAH)**, heavy metals (HM)

**CHQ site - Agricultural field** (Falassarna, GR): soil contaminated with **microplastics (MPs)** and **pesticides**
The Nymphe approach

**SELECTION, ISOLATION, CHARACTERIZATION OF THE BIOLOGICS FOR BIOREMEDIATION**

- **ENZYMES**
- **MICROORGANISMS** (bacteria, algae, fungi)
- **PLANTS/HOLOBIONTS**
- **ANIMALS** (clams, earthworms)

**Set of biologics** suited for high-performance degradation of pollutants “characteristically” occurring at the 4 sites

**Multi-component systems** based on the rational assembly of a large set of biologics at laboratory scale using real contaminated matrices from the Nymphe sites

**SYSTEMS ASSEMBLY, REINTRODUCTION IN CONTROLLED ENVIRONMENT (lab scale) AND MODELLING (microbiomes, natural ecosystems)**

Environmental and holobiont-associated microbiome modelling for each multi-component system: keystone species and metabolic activities that need to be either enhanced/complemented or suppressed to boost bioremediation.
The Nymphe approach

**PLATFORMS FOR THE IMPROVEMENT/ENLARGEMENT OF THE BIOLOGICS**

**STRATEGIES FOR IMPROVEMENT AT SYSTEMS LEVEL**
(complementary pathways, microbiome control, community assembly)

- Model-based microbiome modulation strategies and modulators for systems improvement
- Artificial communities with complementary pathways
- Microbial electrochemical technologies (METs)
- Tools for stable community assemblies (complementary auxotrophies & surface display of adhesins)

**NATURAL IMPROVEMENT OF SINGLE TOOLS**
(accelerated evolution)

- AI- and Membrane Bioreactor (MBR)-guided accelerated natural evolution of microbial degraders
- Molecular devices for controlled genomic variability

**ENGINEERED IMPROVEMENT**
(in silico, gene editing, synthetic biology)

- Tools for spatial control of distribution of biodegraders (3D-bioprinting, biological granules with scaffolding between members)
The Nymphe approach

- Innovative integrated evaluation tool (IIET) for conclusive environmental quality and risk assessment of the treated matrices (chemical, ecotox, microbiome functions and biodiversity)

- Mathematical model that forecast the environmental impact of bioremediation, to evaluate the revitalization status in relation to Natura 2000 ecological requirements

- Benchmarking against strategies in use

BIOLOGICS (native and improved) FOR BIOREMEDICATION

- PHC and CAH
- HM
- Pharmaceuticals
- (micro)plastic & plasticizers
- Pesticides

Industrial soils

Agricultural soils

Hyporheic zone

Municipal wastewater

ASSESSMENT

- TECHNICAL (chemical & ecotox)
- ENVIRONMENTAL (Ecological, Life Cycle & Risk assessments)
- ECONOMICAL (Lyfe Cycle Cost & cost-effectiveness analyses)
- SOCIETAL

PILOT/FIELD TESTS IN THE NYMPHE SITES FOR BIOREMEDICATION/REVITALIZATION
Nymphe main expected results and impacts

Efficient bioremediation / revitalization strategies fully assessed at pilot / field scale

- Set of appropriate systems of biologics for «typical» polluted sites (industrial, agricultural, HZ, municipal WW)
- Microbiome management strategies able to improve stability and efficiency of bioremediation
- Tools for biologics and systems improvement, including genomically edited organisms
- Innovative Integrated Environmental Tool (IIEET) & Ecological assessment toolbox (EA) for the bioremediation projects

ENVIRONMENTAL, TECHNOLOGICAL, ECONOMIC, SOCIETAL IMPACTS

- Better perspective of revitalization, biodiversity and ecosystem services recovery
- New products and services for bioremediation
- Replication/multiplication of bioremediation actions
- Growth in the bioremediation sector and new jobs
Thank you for your attention!