Phy2SUDOE

European Regional Development Fund

Advancing in the application of innovative phytomanagement strategies in contaminated areas in the SUDOE area

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Dear reader,

I am pleased to present Phy2SUDOE, a European project aimed at the research of phytomanagement techniques for the recovery of degraded areas. Phy2SUDOE has consolidated the network of phytomanaged sites formed in the previous project we developed in this field, called Phyto-SUDOE, and to extend it with new pollution cases and innovative phytomanagement strategies. In addition, the conservation of endemic biodiversity has been enhanced in some sites that host biota of conservation and biotechnological interest, while the biodiversity of species adapted to pollution has been promoted.

In short, in Phy2SUDOE we have demonstrated the ability of phytomanagement to combine the reduction of pollutant concentrations, the conservation of biodiversity and the generation of valuable ecosystem products and services. But probably the most important outcome of the project is that it sees contaminated soil not as a problem, but as an opportunity to create economic and ecological value in the SUDOE area.

I would like to thank all partners and collaborators for their participation and support, which made Phy2SUDOE a success.

Carlos Garbisu
Project coordinator (NEIKER)

Phy2SUDOE is a European project that formed a network of sites, contaminated by metal(loid)s, and/or organic compounds, on which were implemented phytomanagement strategies for site restoration and valorization.

Project objectives:

1. Consolidate the network of sites formed in the previous Phyto SUDOE Project.
2. To extend this network with new pollution cases (soils polluted with organic compounds or mixed pollution) and innovative strategies of phytomanagement based on the mixture of plant species.
3. To enhance the conservation of endemic biodiversity in some sites hosting biota of conservation and biotechnological interest, while promoting biodiversity through the implementation of phytomanagement strategies.
4. Valorise sites contaminated by metal(loid)s and/or organic compounds through phytomanagement strategies aimed at generating products and ecosystem services on these sites while minimising the environmental impact that the pollutants may cause.

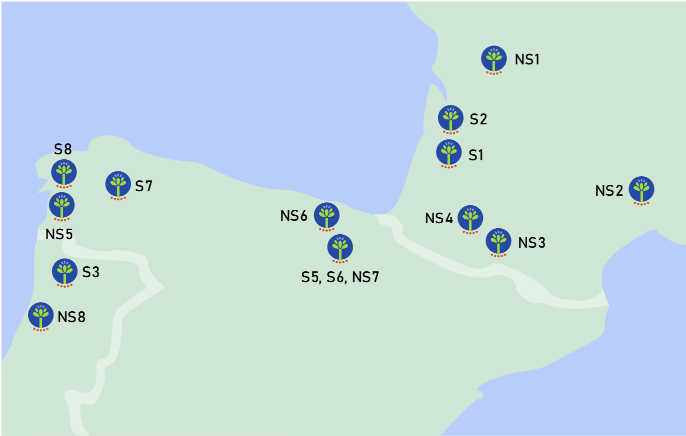
Project partners

1. NEIKER
2. CSIC
3. USC
4. UPV EHU
5. CEA
6. INRAE
7. CHARENTE
8. FERTIL'INNOV
9. UCP-CRP
10. CLOVERSTRATEGY

Associated partners: INHOBE, Gernika-Lumo Town Council, Vitoria-Gasteiz Town Council, Strategic Minerals Spain, Alava Development Agency S.A., Departmental Council 64, XYLOFUTUR competitiveness cluster, Ets LYONNET, Bordeaux Métropole - Green Spaces Department, Municipality of Bordes, Econick, Association of Municipalities Parque da Serras of Porto, EDM – Mining Development Company, Celorico de Basto Town Council.

The application of innovative phytomanagement techniques for the management of contaminated sites requires **pilot and demonstration actions** at local, regional and national levels, covering as many different areas as possible.

Phy2SUDOE builds on an already established **transnational network of sites** (PhytoSUDOE Network) which has been completed with 8 new sites to increase the number of scenarios covered. The network sites cover a **wide range of soil-climatic conditions**, degradation types and phytomanagement alternatives.



PhytoSUDOE site network (S1-S8)
S1. ST MÉDARD D'EYRANS (Gironde, FR). Brownfield, Cu/PAH (INRAE).
S2. CHABAN-DELMAS (Gironde, FR). Urban brownfield, metal(loid)s/PAHs/aliphatic hydrocarbons (INRAE).
S3. BORRALHA (Montalegre, PT). Mining area, Ag/W/Cu/Pb (UCP-CRP, LNEG).
S5. ARIÑEZ (Vitoria-Gasteiz, Basque Country, ES). Peri-urban brownfield, As/Pb/PCB/PAH/acetone/hydrocarbons (UPV, NEIKER, CEA).
S6. MENDIGURENTXO (Vitoria-Gasteiz, Basque Country, ES). Peri-urban brownfield, trace metals (UPV, NEIKER, CEA).
S7. PEDRAFITA (Galicia, ES). Mine tailings, Cd/Zn/Pb (CSIC, USC).
S8. TOURO (Galicia, ES). Mine tailings, Cu (CSIC, USC).

New Phy2SUDOE sites (NS1-NS8)
NS1. DURANDEAU (Charente, FR). Brownfield (Angouleme), mixed pollution (Charente).
NS2. LES AVINIÈRES (Gard, FR). Mining area, Pb, Zn, Cd, Ni (Fertil'Innov).
NS3. SENTEIN (Ariège, FR). Mining area, Pb, Zn (INRAE).
NS4. BORDES (Pyrénées-Atlantiques, FR). Former landfill (INRAE, CD64).
NS5. BANDEIRA (Galicia, ES). Quarry, Ni, Cr (CSIC, USC).
NS6. GERNIKA (Basque Country, ES). Mixed pollution from uncontrolled sewage sludge disposal (UPV).
NS7. ZUMABAKOTXA (Vitoria-Gasteiz, Basque Country, ES). Peri-urban industrial zone with mixed pollution (CEA).
NS8. ESTARREJA (Aveiro, PT). Industrial area, mixed pollution (UCP-CRP, CloverStrategy).

Within the Phy2SUDOE project, tools for the improvement of phytomanagement have been applied:

Amendments

Compounds that are added to the soil to improve its physical, chemical and/or biological properties, favouring plant growth (e.g., organic matter amendment through the addition of compost).

Bioaugmentation

It consists of the inoculation of plants with micro-organisms that can enhance plant growth or tolerance to contaminants, or influence the accumulation of metal(loid)s or the degradation of organic pollutants. In the case of Phy2SUDOE, growth-promoting bacteria (endophytes and rhizophytes) and mycorrhizal fungi have been used.

Different plant species and cropping patterns have also been tested:

Tree plantations

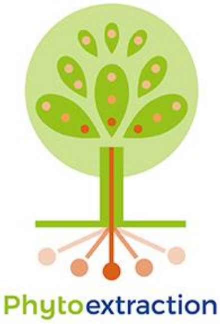
Trees with proven phytoremediation capacity such as poplars and willows (among other species) have been cultivated. In general, fast-growing, and contaminant-tolerant tree species have been used.

Agricultural crops

In most Phy2SUDOE plots, herbaceous species (rape, grasses, alfalfa, etc.) or high biomass species (e.g., sunflower, tobacco, and winter barley) have been grown in rotation systems.

Intercropping

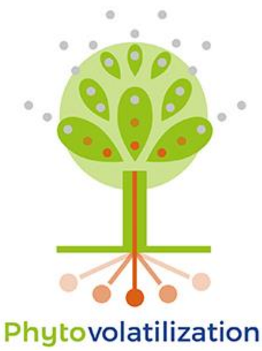
To enhance phytoremediation, forest plantations have been intercropped with agricultural crops in some plots, including legumes or plants associated with nitrogen-fixing micro-organisms (e.g., *Salix/Populus* with *Alnus*).



The plant absorbs the contaminants (mainly metal(loid)s) through the roots and accumulates them in large quantities in the aerial biomass, removing the contaminants through harvesting. When the metal(loid) can be recovered from the biomass (bio-ore) for economic benefit, the process is called phytomining.

Plants can sequester or immobilise contaminants through different mechanisms in the root and/or its zone of influence. This process limits the contaminants' migration and bioavailability and significantly reduces the potential adverse effects on the environment and their transfer to the food chain.

Plant roots release certain compounds (exudates) into the surrounding soil (rhizosphere), stimulating rhizosphere micro-organisms' survival, growth and activity that degrade organic pollutants. Efficiency can be increased by incorporating micro-organisms that can degrade organic pollutants or increase their bioavailability (bio-augmentation) and/or by adding compounds that stimulate plant-micro-organism symbiosis processes (biostimulation).



Some plants take up pollutants (such as selenium or some organic xenobiotics) and release them in a less toxic form into the atmosphere through transpiration. Within the plant, the pollutant is transformed or degraded before being released.

Phytomanagement of contaminated soils aims to **mitigate the risk of contaminant transfer** through different strategies of manipulation of the soil-plant system. It produces biomass of high value and/or ecological interest and **improves soil ecological functions** and the provision of ecosystem services. Long-term trials are essential to evaluate the success of the adopted strategies.

Winter barley (left), Kernza (centre) and vetiver (right). © Mench / INRAE

Working Package 1 (GT1) has focused on maintaining and monitoring the network of degraded or polluted sites managed by the PhytoSUDOE Network. Infrastructure maintenance tasks have been carried out at the sites.

Contamination sampling at site S5b. © David Sedan / DINAM

In areas with high climatic constraints, such as **St. Médard d'Eyrans** (FR), **Ariñez** (ES) and **Mendigurentxo** (ES), tree species have been replaced. To evaluate the long-term success of the phytomanagement strategies adopted, the following have been monitored:

Employment plan worker clearing adventitious vegetation. © Lídia Mingoranc / CEA

1. Physicochemical, biological, and biochemical properties of soil.
2. Contaminant levels (total and bioavailable fractions) in the soil.
3. The transfer of pollutants to plants.
4. Crop survival and nutritional status.

Results

In general, **phytomanagement has been shown to favour the recovery of soil functions** and the provision of ecosystem services. A **gradual improvement of numerous soil indicators** has been observed, such as an increase in organic matter and carbon sequestration, a decrease in the concentration of organic pollutants and the bioavailability of metal(oid)s, an improvement in enzymatic activities, and a significant increase in biodiversity (microbes, plant and invertebrate species).

Bormuellera tymphaea (Ni-hyperaccumulators) at the Bandeira site. © Rodriguez et al / CSIC

The objective of GT2 was to assess the pollutant linkages at the sites, the feasibility of phytotechnological solutions and the remediation and/or phytomanagement strategies implemented.

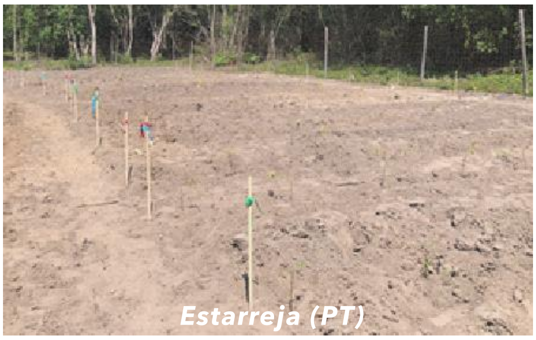
Results

GT2 has expanded the network of phytomanaged sites in the SUDOE region and has demonstrated **the effectiveness and limits of phytotechnologies for remediating contaminated soils** in 8 sites. These include mining, peri-urban and industrial areas, to extend the range of future uses (peri-urban green belts, parks, industrial crops, etc.). Phytomanagement induced **changes in soil bacterial community diversity**, improving soil properties related to fertility and the provision of other ecosystem services.

On-site plots were established at some sites (e.g., Les Avinières) to confirm the **effectiveness of compost application** and to optimise the assemblage of plant and microbial species used for phytostabilization. Populations of useful bacteria adapted to exposure to pollutants were preserved in the untreated areas.

Plant community at the phytomanaged trial in August 2022. © La Charente County / Jardins de l'Angoumois / INRAE Mench

5 months after phytostabilization © La Charente county / Jardins de l'Angoumois / INRAE Mench



Deployment of bait-lamina and field trial at the Esterreja site. © UCP

Phytomanagement trial at the Gernika site. © Soto / UPV

Phytostabilization improves soil properties such as organic matter, total nitrogen, and microbial biomass. Monitoring of grassland composition, seed banks and soil microbial communities shows a **clear rehabilitation and increase in soil quality and biodiversity**, linked to the phytostabilization of metals and dissipation of residual organic compounds.

The sites depend on the administrations and companies that have been part of the project, which facilitates the transfer of results. Overall, **the feasibility and efficiency of sustainable solutions based on phytotechnologies** to clean up these marginal lands and put them on the path to a new (socio)ecosystem with enhanced ecosystem services has been demonstrated.

Phytomanaged plots at the Zumabakotxa site. © Vilela et al / CEA

GT3 aimed to **describe and preserve biodiversity on contaminated sites in mining areas**. In addition to having intrinsic and conservation value, this biodiversity can be used in biotechnological applications.

Silene uniflora (metal(loid) accumulator. © Beatriz Rodríguez-Garrido / CSIC

Studies of plants, micro-organisms and macroinvertebrates adapted to high concentrations of metal(loid)s (e.g., Zn, Pb, Cu, As and Cd) have been carried out at 4 sites of the Phy2SUDOE network: Bandeira (ES), Borralha (PT); Sentein-Bulard, (FR), and Lanestosa (ES).

Results

The botanical study has identified **more than 250 species of metallophyte plants**. Each site's most representative and/or endemic metallophytes have been collected to identify their metal tolerance mechanisms. Several have been shown to be metal (hyper) accumulators or metal excluders, being of particular interest for phytoremediation and phytomanagement approaches. Species of conservation interest have also been identified, and their seeds were conserved in the Olarizu Germplasm Bank (ES).

Helictrotrichon cantabricum (endemic species to Spain and France; metal(loid) excluder. ©CEA

As for **microorganisms**, more than 150 bacterial strains have been isolated from the soil and characterised according to their tolerance to metals and their plant growth-promoting traits, such as phosphate solubilisation capacity. Some of these strains were studied on different mining soils and plants, showing **good performance in promoting plant growth and establishment**. The most promising plant growth-promoting bacteria are conserved in Neiker (ES) and UCP-CRP (PT).

Regarding **macroinvertebrates**, earthworms, slugs, grasshoppers, and snails, which serve as environmental sentinels in contaminated areas, have been collected. Their tissues have been processed and conserved in the Environmental Biospecimen Bank of the Bay of Biscay (ES).

All these collections have become **repositories of indigenous specimens of interest** to local/regional/national administrations and research institutions, whose use can be extended to the search for new lines of research and recovery activities at other sites with similar pollution problems.

Erica arborea metal(loid) excluder. ©UCP

GT. T1 – Project Management

The management tasks have been coordinated by NEIKER, with the help of the leaders of the Working Groups.

1. Administrative management and day-to-day coordination of the project.
2. Political and technical decision-making.
3. Internal communication system.
4. Internal organisation for the preparation of performance reports.
5. Financial management of the project.

GT. T2 – Communication

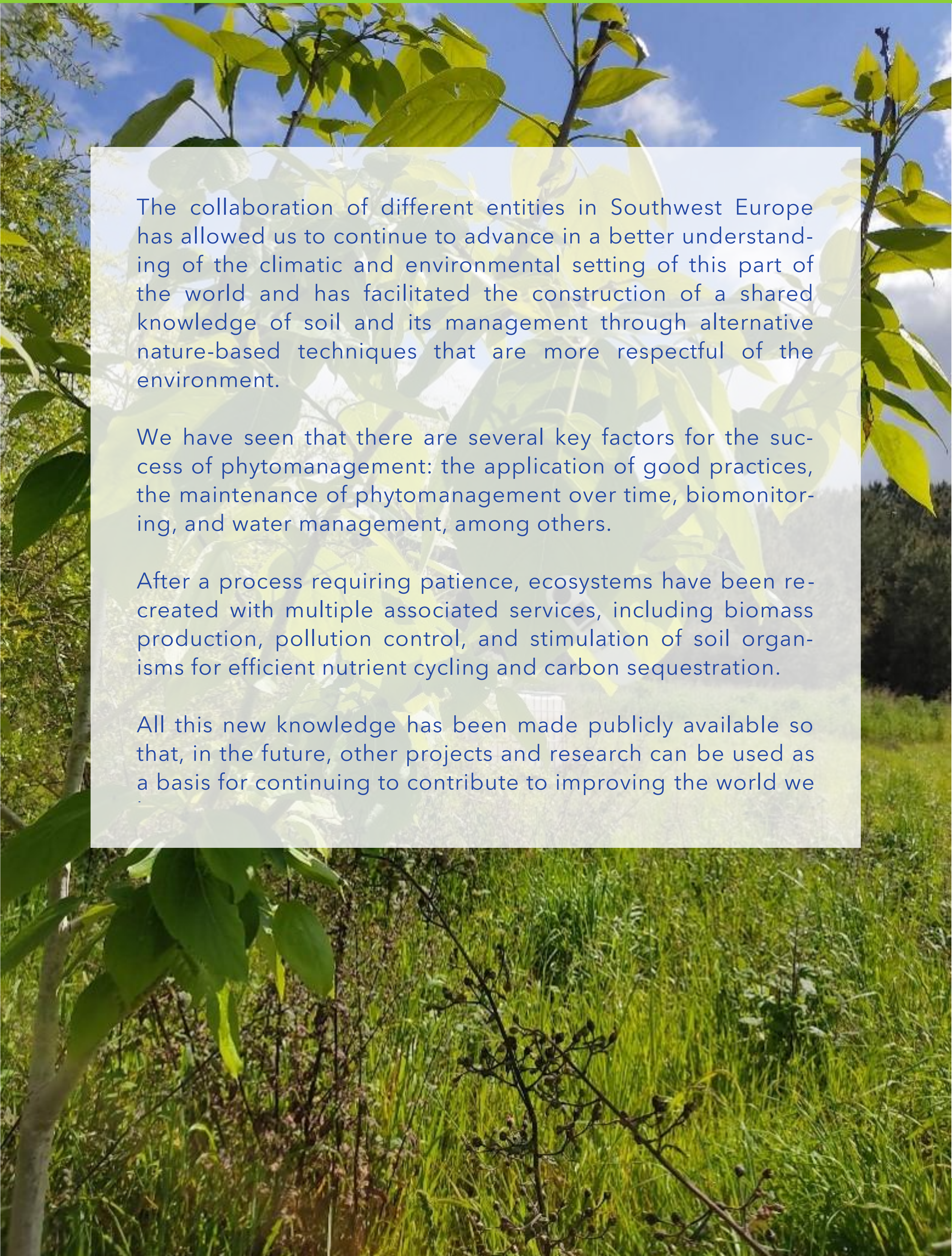
The partner responsible for communication (CEA) has carried out various dissemination actions:

1. Creation and updating of the project website.
2. Creation and updating of social network profiles (Twitter, Face-book).
3. Four informative newsletters
4. Three stakeholder workshops.
5. Video summary of the project.
6. Dissemination of scientific publications.

GT. T3 – Monitoring and Evaluation of the project

In this WG the tasks have been:

1. Measure the progress of the project and its deliverables.
2. To monitor and evaluate the project.
3. Project risk management and quality control.



The collaboration of different entities in Southwest Europe has allowed us to continue to advance in a better understanding of the climatic and environmental setting of this part of the world and has facilitated the construction of a shared knowledge of soil and its management through alternative nature-based techniques that are more respectful of the environment.

We have seen that there are several key factors for the success of phytomanagement: the application of good practices, the maintenance of phytomanagement over time, biomonitoring, and water management, among others.

After a process requiring patience, ecosystems have been recreated with multiple associated services, including biomass production, pollution control, and stimulation of soil organisms for efficient nutrient cycling and carbon sequestration.

All this new knowledge has been made publicly available so that, in the future, other projects and research can be used as a basis for continuing to contribute to improving the world we

Phy2SUDOE

Final Report

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The PhytoSUDOE project (SOE4/P5/E1021) has been funded by the European Regional Development Fund (European Commission) through the 4th Interreg Sudoe Programme.