Ecological adaptation of native plant communities to abandoned mines soil of Sardinia

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Introduction

Abandoned mining sites are highly contaminated environments due to the accumulation of potentially toxic elements (PTEs) and rare earth metals (REEs) due to their release from mining residues of past mining activities. The presence of PTEs and REEs represents a global environmental concern, as these elements can accumulate in soil and groundwater, causing toxic effects on flora, fauna, and human health. The mobility and bioavailability of PTEs and REEs are strongly influenced by soil physicochemical factors, making their control and mitigation complex without targeted interventions.

In this context, the use of native Sardinian plant species represents a sustainable strategy for the ecological rehabilitation of contaminated areas. Endemic plants exhibit morphological and physiological adaptations that make them particularly suitable for the phytoremediation of PTEs and REEs, helping to reduce their bioavailability and promote environmental restoration. These species therefore represent key resources for sustainable remediation interventions, improving soil quality and promoting the renaturalization of local ecosystems.

Materials and Methods

This study investigated the relationship between soil physico-chemical characteristics and the dominant plant communities across 14 abandoned mining sites from 6 mining districts in Sardinia (Italy) Fig. 1, aiming to identify ecological patterns of native species adaptation to soil environmental stresses. For each site, representative species were recorded and soil physico-chemical parameters measured. Spearman's correlation and Principal Component Analysis (PCA) were applied to explore associations between soil variables and species abundance, revealing dominant ecological gradients and plant behaviours.

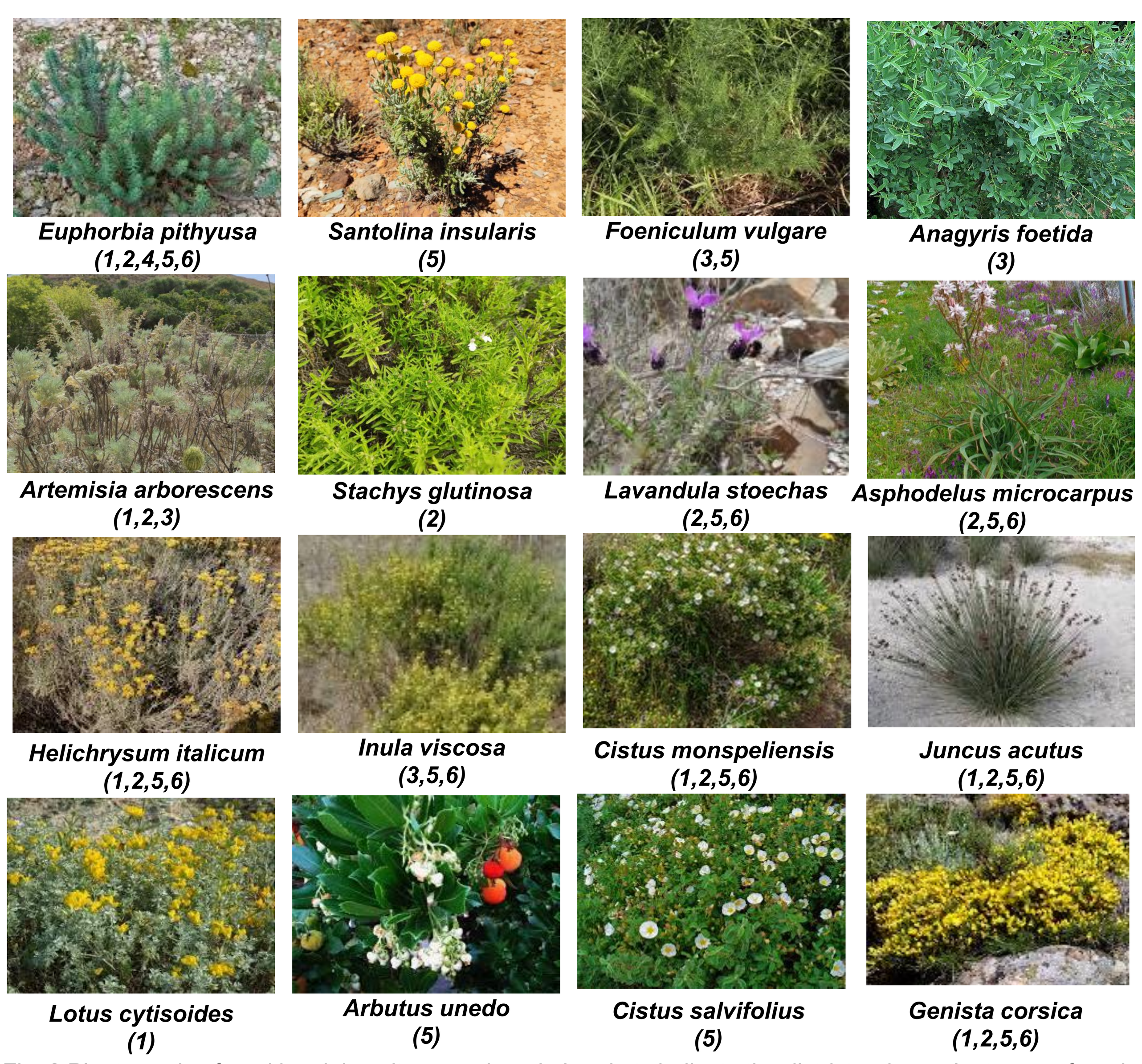

Fig. 2 Plant species found in mining sites, numbers in brackets indicate the districts where plants were found.

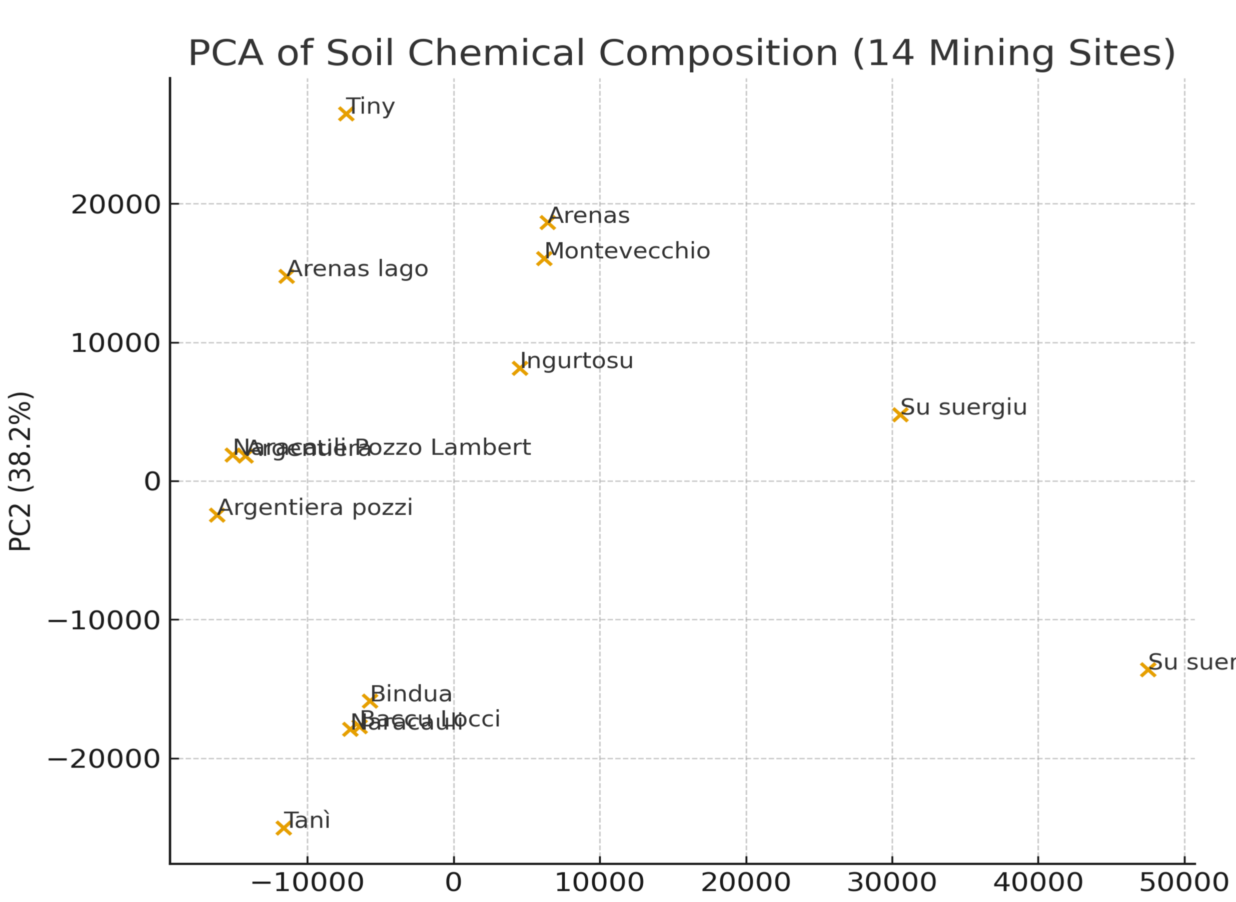

Fig. 3 Principal Component Analysis (PCA) of soil chemical composition from 14 mining sites Sardinia.

Fig. 1 Map of the mining districts and mining sites (n= number od mining sites for each district)

Results

A total of 16 species (Fig. 2) from 9 families were recorded: Asteraceae (*Artemisia arborescens*, *Helichrysum italicum*, *Inula viscosa* and *Santolina insularis*), Fabaceae (*Anagyris foetida*, *Genista corsica* and *Lotus cytisoides*), Cistaceae (*Cistus monspeliensis* and *Cistus salvifolius*), Lamiaceae (*Lavandula stoecas* and *Stachys glutinosa*), Apiaceae (*Foeniculum vulgare*), Asphodelaceae (*Asphodelus microcarpus*), Ericaceae (*Arbutus unedo*), Euphorbiaceae (*Euphorbia pithyusa*) and Juncaceae (*Juncus acutus*).

The PCA analysis (Fig. 3) revealed two dominant ecological gradients: i) PC1 represented soil mineral richness and ionic content, showed high positive loadings for electrical conductivity (EC) and most rare earth elements (REEs), and negative loadings for sand content, distinguishing fine, element-rich soils from sandy, nutrient-poor soils. ii) PC2 shows positive loadings for Organic C, TN, and C/N, and negative loadings for pH, distinguished organic-matter-rich, more acidic soils from mineral-rich, basic soils.

Two main ecological groups emerged from the analyses: i) pioneer-species such as *H. italicum* and *E. pithyusa*, associated with sandy, acidic and nutrient-poor soils, exhibiting positive correlations with sand and negative correlations with electrical conductivity (EC), organic C, and total nitrogen; ii) species which prefer fertile or saline soils with higher EC, organic matter, and nutrient content such as *A. arborescens*, *A. microcarpus* and *J. acutus* linked to clay-rich and poorly drained substrates, typical of coastal or marshy habitats.

A. microcarpus, *A. arborescens*, *I. viscosa*, and *J. acutus* exhibit positive correlations with Fe, Cu, Ni, Pb, Zn, and light REEs (La, Ce, Nd) concentrations, indicating tolerance to metalliferous soils, whereas *H, italicum*, *E. pithyusa*, and *L. cytisoides* were associated with less contaminated soils. Other species (i.e. *C. monspeliensis* and *L. stoechas*) exhibited weak or neutral correlations, suggesting ecological plasticity (Fig. 4).

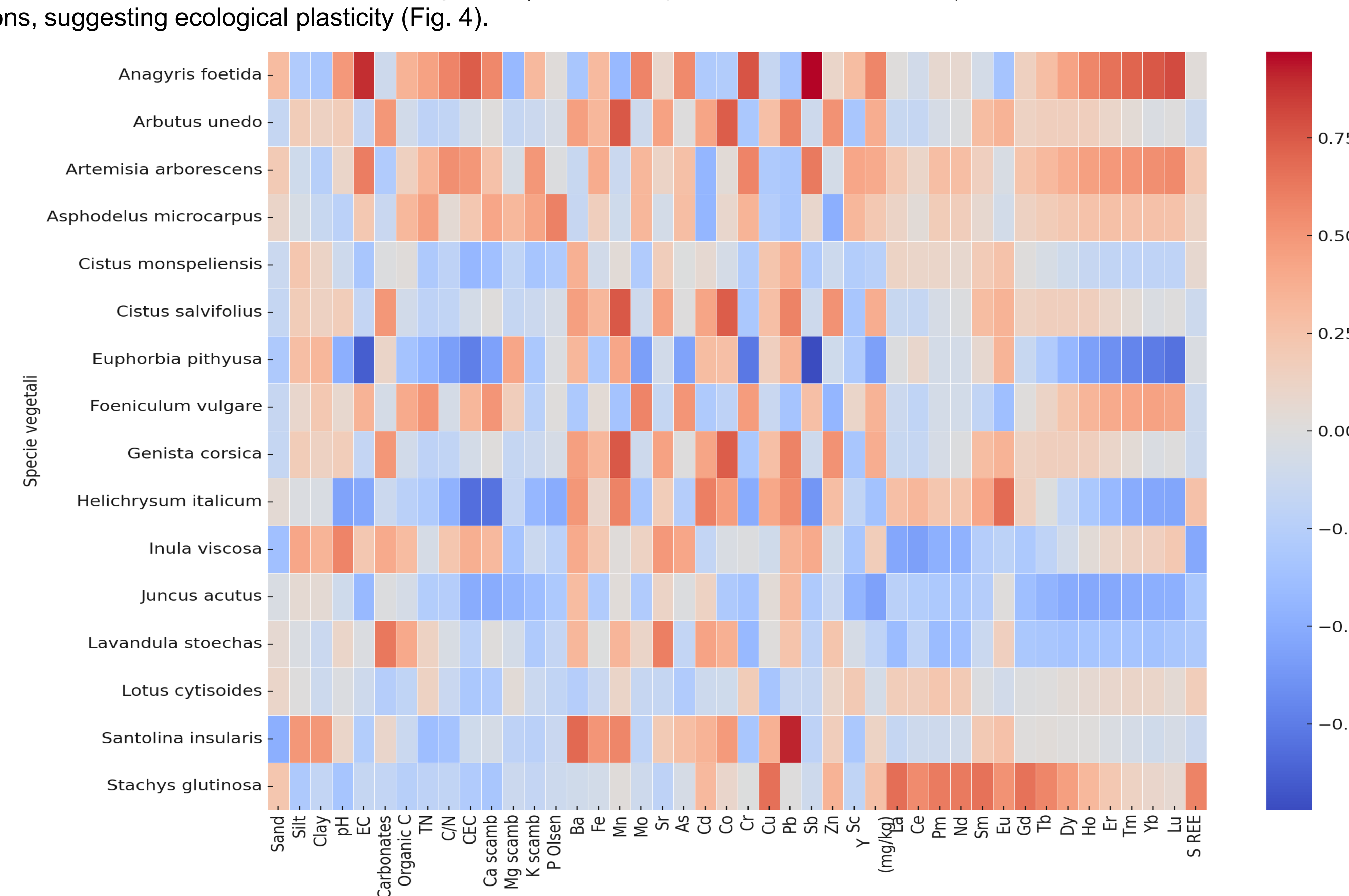

Fig. 4 Heatmap showing the correlation between soil physicochemical properties, potentially toxic elements (PTEs), rare earth elements (REEs), and plant species collected from Sardinian mining sites. Red and blue indicate positive and negative correlations, respectively.

Conclusion

Overall, the study demonstrates that soil characteristics strongly shapes plant community patterns in Sardinian mining sites. Several native species (i.e. H. italicum, S. insularis and E. pithyusa) show promising potential as bioindicators of degraded lands, while others (i.e. *A. arborescens* and *I. viscosa*) can be more suitable for phytoremediation. Finally, several aromatic species were recorded (i.e. *A. arborescens*, *H. italicum*, *I. viscosa*, *L. stoecas, S. insularis* and *S. glutinosa*) providing potential for economic valorization of these degraded lands.

Acknowledgements. This research was supported by:

- Young Researchers Mobility Program 2024. Funding under Regional Law No. 7 of August 7, 2007, "Promotion of Scientific Research and Technological Innovation in Sardinia." Activity Program for 2024. Submission of proposals to support the international mobility of young researchers currently working at the University of Sassari.
- European Union – Next Generation EU, Mission 4, Component 1, CUP B53D23007610006, Project PRIN-MUR 2022Y4J7AN - EUREECA - Rare Earth Elements in Urban and Mining Areas: an Emerging Concern for Soil (and Human) Health.

2nd International Symposium on Biodiversity and Ecosystem Functions under Global Change
12 – 14 November 2025
Alghero (Sardinia – Italy)