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SPECIAL FEATURE PREFACE

Ultramafic Ecology: Proceedings of the 10th International Conference on Serpentine Ecology

Recent advances in the study of serpentine plants and ecosystems: Perspectives from the 10th International Conference on Serpentine Ecology, France: Part II

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Abstract

The 10th International Conference on Serpentine Ecology was held in Nancy, France on June 12–16, 2023. The main goals of the conference were to create a platform for the exchange of ideas and experiences and to promote scientific dialogue among scientists from numerous fields who share expertise in the study of ultramafic habitats worldwide. The proceedings of the conference are being published as two Special Issues of *Ecological Research*, of which this is the second. In this article, we present the major topics and provide some highlights of the contributions to the 10th International Conference on Serpentine Ecology.

KEYWORDS

geoecology, hyperaccumulator, metallophyte, phytomining, ultramafic

1 | INTRODUCTION

Since the first conference in 1991, the International Conference on Serpentine Ecology (ICSE) has been growing as a multidisciplinary group of scientists who study and aid in the conservation of serpentine biota. The 10th ICSE was held in France on June 12–16, 2023, six years after the previous conference, and hosted 126 delegates from 29 countries. The conference was hosted at the Université de Lorraine with a mid-conference tour to ultramafic sites in the Vosges Mountains and a post-conference tour to Valle d'Aosta in Italy. All past conferences (except for 2011) have led to proceedings, published either as a book (Baker et al. 1992; Jaffré et al., 1997; Boyd et al., 2004) or as Special Issues of an academic journal (Balkwill, 2001; Chiarucci & Baker, 2007; Echevarria et al., 2018; Rajakaruna & Boyd, 2009; van der Ent et al., 2015). The proceedings of the 10th ICSE are published as two Special Issues in *Ecological Research*. The first appeared in August 2024 (see van der Ent et al., 2024) and this is the second Special Issue. Here, we present some highlights from the mid- and post-conference tours and introduce the final set of papers making up this Special Issue.

2 | THE RETROSPECTIVE AND KEYNOTE ADDRESSES

One of the highlights of recent ICSEs is the Retrospective presentation given by Prof. Robert "Bob" Boyd (Auburn University, AL, USA) who has attended all ICSEs since its inception and began delivering a Retrospective at the fourth conference, held in 2006 at the University of Siena, Italy. His first-hand experiences at each of the conferences provide the delegates the opportunity to hear about the unique ultramafic ecosystems characterizing each country selected to host the ICSE, learn about the main themes and topics covered by the oral and poster presentations, and see memorable photos from the mid- and post-conference tours, while always reminding and informing the delegates, old and new, how unique the ICSEs are both in terms of the interdisciplinary science that is presented but also for the long-term international collaborations and friendships that they continue to foster. Prof. Boyd's enthusiastic style of presentation, combined with his first-hand knowledge of all the ICSEs and the delegates who have attended, excite the audience about the conference sessions and highlight how they are part of a professional community that has continued to foster productive and collaborative global geoecological research.

Starting with the eighth ICSE held in Albania (van der Ent et al., 2015), the conferences also highlight keynote presentations on key themes central to the interdisciplinary field of serpentine ecology. During the 10th ICSE (this conference), three keynote addresses were presented, in addition to the aforementioned retrospective.

Prof. Roger Reeves (Professor Emeritus, New Zealand, and founding member of the ICSEs) spent a career of over 40 years (and over 200 publications) discovering hyperaccumulator plants. This started with the seminal article in *Science* that actually coined the term "hyperaccumulator" (Jaffré et al., 1976) and led to research in diverse regions around the world, working especially with Professors Robert Brooks, Alan Baker, Tanguy Jaffré, and Art Kruckeberg. His background in analytical chemistry, and inductively coupled plasma spectroscopy in particular, enabled him to analyze trace elements in plants from all across the world. In his keynote, Professor Reeves presented a travelogue covering his explorations and discoveries of hyperaccumulators in Brazil, New Caledonia, and many other countries (see Reeves, 2024).

Prof. Nishanta Rajakaruna (California Polytechnic State University, San Luis Obispo, CA, USA), who has attended 8 of the 10 ICSEs, made a call for geobotanists interested in different harsh soil model systems (e.g., ultramafic, calcareous, solfatara fields, saline flats, etc.) to come together to explore the harsh soil syndrome, functional traits associated with plants found on harsh soil, and particularly commonalities and differences across distinct harsh soil-type biotic associations, both within and across biomes. In his presentation, titled "Lessons on Ecology and Evolution from the Study of Edaphic Specialization," he discussed how such efforts will provide opportunities for productive collaboration across research groups with expertise on edaphically distinct communities (e.g., serpentine vs. gypsum) or tools of investigation (e.g., ecophysiological vs. phylogenomic) relating to key questions on drivers of diversity and community assembly on harsh soil ecosystems, ecological and evolutionary theory, and conservation and restoration practices. His keynote address was given during an inaugural conference session on "Plants of Other Edaphically Challenging Substrates" and summarized his recently published paper in *The Botanical Review* (Rajakaruna, 2018).

Dr. Rufus Chaney (former Senior Research Agronomist in the Environmental Management and By-Product Utilization Laboratory of the USDA-Agricultural Research Service at Beltsville, MD, USA) has had a remarkably productive, varied, and wide-ranging career (429 published papers to date), mainly focused on studies of the fate, food-chain transfer, potential effects, and remediation of hazards from soil microelements. Dr. Chaney originated the ideas of phytoextraction and phytomining (Chaney, 1983), was instrumental in the first Ni phytomining trials undertaken in the USA (Li et al., 2003), and has been very active in this field ever since. The history of how phytomining came to be is described in detail in Chaney et al. (2018).

3 | MID-CONFERENCE AND POST-CONFERENCE TOURS

The customary mid-conference tour took place in the Vosges Mountains in France (Figure 1). The delegates

FIGURE 1 Delegates of the 10th International Conference on Serpentine Ecology (ICSE) exploring an ultramafic outcrop in the Vosges Mountains in France.

FIGURE 2 The Blue Lake ("Lago Blu") in the Val D'aosta in Italy during the post-conference tour.

visited an ultramafic hill with a serpentine quarry at the summit. The nickel hyperaccumulating *Noccaea caerulescens* (alpine penny-cress; Brassicaceae), native to the region, was abundant at this site. About 15 delegates took part in the post-conference tour to Italy. The delegates visited the Val D'aosta valley and the Balangero chrysotile asbestos mine (Figure 2). In the Val D'aosta area, extensive ultramafic outcrops are found across a wide altitudinal range up to 2500 m a.s.l. We first explored the area near Saint Vincent (560–700 m a.s.l.), home to species-rich xerothermic vegetation, including the nickel hyperaccumulator *Alyssum argenteum* (Brassicaceae). The next day, we visited the Verra Grande Glacier forefield (2200 m a.s.l.). The area consists of a moraine chronosequence, with pure serpentinite illustrating primary vegetation succession, and associated soils from pioneer communities on fresh moraine tills to subalpine forests with ultramafic endemics, including the Brassicaceae species *Cardamine plumieri* and *Noccaea sylvia*. We then visited the Riserva Naturale Madonna della Neve sul Monte Lera (1350 m a.s.l.), a part of the Lanzo Peridotite Massif. This area has mixed mesophilous forest on an lherzolite substrate with the ultramafic endemic *Euphorbia gibelliana* (Euphorbiaceae). Finally, on the last day, we visited the abandoned chrysotile mine of Balangero and Corio (550–890 m a.s.l.; Figure 3). This was the largest asbestos mine in Europe when mining activities ceased in 1990. The horizontal terraces of the open mine pit host pioneer vegetation, including hyperaccumulators *Odontarrhena bertolonii* and *Noccaea caerulescens,* with substantial plant cover on the large deposits of mine tailings, which have undergone hydrogeological stabilization and revegetation intervention.

4 | THIS SECOND SPECIAL ISSUE OF *ECOLOGICAL RESEARCH*

The 13 articles published in this Special Issue represent a sampling of ongoing research activities worldwide on ultramafic ecosystems and provide broad coverage of the sessions that were held during the conference. New plant species continue to be discovered, even in Europe, and Bettarini et al. (2024) describe *Odontarrhena vourinensis* (Brassicaceae) originating from Mount Vourinos in western Macedonia, Greece. This tetraploid species, related to the Balkan endemic *Odontarrhena decipiens*, is distinguished by its subshrub form and white-silvery leaves due to dense stellate trichomes. Bani, Álvarez-López, et al. (2024) tested agronomic practices for nickel agromining using *Odontarrhena chalcidica* on ultramafic Vertisols in Albania. They show that, after 2 years, fertilization with animal manure or rotation with a legume improved soil properties and increased Ni yield by up to fivefold relative to non-fertilized plots. Fertilization did not affect the bacterial diversity, but changed the bacterial community structure.

Some areas of the world remain very unexplored for hyperaccumulators (Reeves et al., 2017). Brearley (2024) reviewed the literature to identify hyperaccumulators from Indonesia, finding 72 metal hyperaccumulator plant species, including 19 that accumulate nickel, 42 aluminum, 7 copper, 2 zinc, and 2 cobalt (in addition to nickel). Six of these species are hypernickelophores, with potential for agromining, but fewer than 10% are single-island endemics, and one species is endangered. The review highlights the need for urgent conservation efforts, particularly in areas affected by mining, and suggests that many more hyperaccumulators likely remain undiscovered in Indonesia.

FIGURE 3 Delegates of the post-conference tour in protective clothing while visiting the closed Balangero chrysotile asbestos mine in Italy.

Knowledge of hyperaccumulators in Central America is also at an early stage. Disinger et al. (2024) used x-ray fluorescence (XRF) spectroscopy to discover new nickel hyperaccumulators in Guatemala. Four new nickel hyperaccumulators were discovered, and field studies revealed that these species often coexist, with no clear correlation between leaf nickel concentrations and soil nickel levels, indicating that other factors may influence hyperaccumulation. Navarrete Gutiérrez et al. (2024) also used XRF analysis to estimate metal concentrations in specimens of the genera *Orthion* and *Mayanaea* (Violaceae) ranging from Mexico to Nicaragua while discovering several new nickel hyperaccumulators, including *Orthion subsessile* with up to 18,700 mg kg^{-1} nickel. They validated the XRF screening of herbarium specimens by analyzing field collected samples, confirming their findings of nickel hyperaccumulation in these taxa. As these studies illustrate, the use of XRF instrumentation has emerged as a powerful and effective tool for discovering new hyperaccumulators from the study of herbarium collections. Purwadi et al. (2024) assessed the performance and comparability of the results generated by three different XRF instruments and three different quantification methods and make a number of recommendations to improve the accuracy and precision of the XRF method. They concluded that a promising approach is using GeoPIXE to extract XRF peak intensity for empirical calibration, as that provided better performance than manufacturer algorithms without the complex setup.

Mizuno et al. (2024) used XRF analysis to assess how soil type affects the concentrations of seven elements in plants from various soil types in Japan. Plants from ultramafic soils had lower levels of elements, especially phosphorus, while those from calcareous soils showed higher iron and zinc levels, with some correlations between element concentrations reflecting specific soil characteristics. Notably, positive correlations between sulfur and phosphorus were observed across all soil types, while other correlations varied depending on the soil type.

Tang et al. (2024) focused on testing the metal tolerance of three Australian *Crotalaria* (*Crotalaria novae-hollandiae*, *Crotalaria medicaginea*, and *Crotalaria mitchellii*) species (Fabaceae) to see if this trait is shared among species not found on metalliferous soils. The research revealed that *C. novae-hollandiae* (a known hyperaccumulator of zinc, copper, and cadmium) had the highest zinc tolerance but low copper tolerance, while none of the species accumulated lead. Zinc tolerance appears to be a common trait among the tested *Crotalaria* species, though none showed significant copper tolerance or lead accumulation.

One reason for scientific interest in elemental hyperaccumulation by plants is their potential use to remove elements from soils in developing phytomining technologies (van der Ent et al., 2021). Ly et al. (2024) evaluated genotypes of the Ni hyperaccumulator *Bornmuellera emarginata* for "domestication" use in phytomining under controlled conditions for the full life cycle. Geographically proximate accessions had greater phenotypic similarity, but many morphological variations were found, while Ni ranged from 290 to 6250 mg kg^{-1}. This phenotypic variation will be useful for targeted breeding to optimize the potential of *B. emarginata* in phytomining. Bani, Gjeta, et al. (2024) summarized plant discovery of the Shebenik Mountain area of Albania and list the following Ni hyperaccumulators: *Odontarrhena chalcidica*, *O. smolikana* subsp. *glabra*, *O. rigida*, *Bornmuellera baldaccii*, and *Noccaea ochroleuca*. This was combined with a trial to evaluate phytomining potential of three of these species.

The flora of New Caledonia is renowned as one of the world's most significant biodiversity hotpots, primarily resulting from its geodiversity. Jaffré et al. (2024) investigated how soil properties affect plant community and leaf elemental concentration using plots in two adjacent forests on ultramafic and volcano-sedimentary rocks. Their results revealed that the two forests share a relatively high proportion of species (35%–42%), with major differences in leaf elemental concentration for micronutrients (metals), while macronutrients varied in much lower proportion between the two soil types, suggesting a tight regulation of macronutrients compared to micronutrients. Botha et al. (2024) conducted a study on the bacterial and fungal diversity of biological soil crusts, using 16S rDNA and ITS metabarcoding, from ultramafic and nonultramafic soils in South Africa and showed that soil type influenced fungal alpha diversity, specifically in ultramafic soil, resulting in a decrease in fungal species richness. Their research also highlighted the importance of soil × climate effects on patterns of biocrust diversity, showing that precipitation levels influence fungal beta diversity by shaping distinct fungal communities on and off ultramafic soils. For bacteria, no significant differences were observed in species richness or community structure; however, ultramafic soils and low precipitation areas favored certain bacterial taxa like *Archangium* and *Candidatus Solibacter*.

One understudied area in serpentine ecology is transfer of potentially toxic elements (especially accumulated or hyperaccumulated ones) through terrestrial food webs (Gall et al., 2015). Joubert et al. (2024) reviewed the literature associated with trophic transfer of potentially toxic metals and metalloids from ultramafic and other metal-enriched soils, showing that most studies to date focus only on transfer to primary consumers, with a limited number of studies investigating transfer across multiple trophic levels. They also found most research came from Europe. The gaps they identified will hopefully guide future researchers in this area.

5 | CONCLUSIONS AND OUTLOOK

The 10th ICSE was highly productive, enabling interactions among serpentinophiles from across the world. The next conference, the 11th ICSE, will be held in Kyoto, Japan, in June 2025. It is evident from the 10th ICSE and the two Special Issues that serpentine ecology is a thriving area of research with increasing levels of international and interdisciplinary collaborations. Furthermore, serpentine outcrops from around the world are fast evolving into a model study system, providing settings to discover new species and previously unknown metal hyperaccumulators as well as to test ecological and evolutionary theory and conservation and restoration practices.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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