

Development of a metallophyte spatial database covering Australia

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Abstract

Australia is characterised by a high endemic plant diversity and the presence of large areas of serpentine soils naturally rich in heavy metals, which are characteristically occupied by metal-tolerant plants, i.e. metallophytes. Metallophytes are ideal for decontamination and restoration of metal-contaminated sites. Unfortunately, many metallophyte species are under threat of extinction from mining activities in the underlying metal-rich substrates, and urgent action is required to conserve them before they are eliminated.

A centralised metallophyte database covering Australia has been initiated to manage information on metal-tolerant native plant species, habitat and substrate characteristics. The database has also been linked to Phoenix, a 3D-GIS program which allows the user to view the results of spatial database queries superimposed onto an aerial photograph of Australia, and to extract information such as metal concentrations in substrata and plant parts. Since access to the database follows the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) guidelines in not allowing the exact location of rare or endangered species to be revealed, users who require this information will first need to acquire the relevant Australian regulatory authorisations.

Interrogation of the metallophyte database constructed so far established that work in this field in Australia has largely prioritised the identification of native metal accumulators and hyperaccumulators (14 in Australia), and that far less attention has been paid to the identification of other metal-tolerant, but non-accumulating plants, i.e. excluders. However, it is these latter species that will be critical to the success and safety of rehabilitating metal tailings facilities. Australia is highly biodiverse, with 25,000 native species. It is therefore very likely that many more metallophytes from the Australian flora remain to be discovered. Improving and expanding this centralised database is crucial and constitutes one of the research priorities for the conservation of the unique Australian metallophyte biodiversity and mine rehabilitation. The database will assist mining companies in planning operations so as to avoid disturbance of vulnerable and valuable metallophyte biodiversity, as well as support decision-making for remediation and restoration exercises.

1 Introduction

Australia is characterised by an extremely high endemic plant diversity (Williams et al., 1994; Myers et al., 2000) and relatively large areas of serpentine soils with elevated levels of heavy metals, which are characteristically occupied by metal-tolerant plants known as metallophytes (Augee and Fox, 2000). Plant tolerance to metals and associated factors is a prerequisite for growth on contaminated lands and mine tailings (Bradshaw and Chadwick, 1980), and plant strategies may involve either metal accumulation into above-ground parts, or metal exclusion (Baker, 1981). Metallophytes are thus a unique biological resource for remediation of contaminated lands and restoration of mine sites and tailings (Whiting et al., 2004). Unfortunately, metallophytes are threatened by the activities of the minerals industry and immediate action to conserve them is imperative before land-clearing activities eliminate them (Baker and Whiting, 2008). Whiting et al. (2004) identified the development of a well managed and widely accessible metallophyte database as one of the three immediate research priorities for the conservation of the metallophyte

biodiversity. To date, there have been a few attempts to create such a public database, including METALS (metal-accumulating plants) and Environment Canada's PHYTOREM databases – but their global coverage is patchy and focusses on plant use for remediation purposes, as opposed to in situ conservation of metallophyte habitat and populations (Baker and Whiting, 2008). In contrast, there are voluminous research data and compilations of species and habitat held by tertiary institutions and herbaria world-wide, but these are specialised and rarely accessible to the public in a readily usable form.

The objectives of this project are to: i) design a metallophyte relational database prototype; ii) populate the database with existing scientific and herbaria information on metal tolerance of Australian native plant species; and iii) link it to a 3D-GIS program to be able to perform spatial and textual queries of the database.

2 Methodology

2.1 Development of a spatial metallophyte database covering Australia

The construction of the metallophyte database containing existing information on metal tolerance (as tested experimentally) and habitat and distribution of Australian native plant species was divided into five steps: data sourcing; database design and normalisation; database interface development; database population; and database linking with Phoenix GIS (Pudmenzky et al., 2006).

2.1.1 Data sourcing

Existing information on experimentally tested metal tolerance of native Australian species, their occurrences, substrate/soil characteristics, habitat descriptions, metal extraction methods, and concentrations of metals in substrata and plant parts was extracted from the literature, herbarium records and materials. Additional data was accessed from the METALS FoxPro (outdated) database produced by Environmental Consultancy (ECUS Ltd) at the University of Sheffield, United Kingdom, originally for Noranda/Falconbridge, and the Environment Canada's PHYTOREM database (Baker and Whiting, 2008).

2.1.2 Database design and normalisation

A relational database (Garmany et al., 2005) was developed using Microsoft Access 2007. The main difference between a relational database and other database types, such as hierarchical or network databases (data collections in spreadsheet tables, text files or similar are not considered to be databases), is the use of a unique identifier or 'key' enabling the developer to separate the data into several different tables and then relate desired fields during a query using join operations. Based on the information extracted from the data sources mentioned above, the database entities, their types and their relationship with each other were determined and 49 database fields distributed over 17 tables were created. A normalisation process (Codd, 1970) ensured no redundant information was contained in the tables, and also minimised the number of insert, delete and update transactions (Elmasri and Navathe, 2006).

2.1.3 Database interface development

A forms-based data entry user interface was developed using the Microsoft Access forms facility. A visual basic program module had to be developed to allow the display of plant images in this interface.

2.1.4 Database population

The database was populated using the forms interface by manually entering information from the data sources.

2.1.5 Database linking with Phoenix GIS

In order to link the database to the Phoenix GIS system a database view was created containing a unique Phoenix 'record key' field consisting of the location field's longitude, latitude and the species botanical name for each recorded plant specimen extracted from the data sources. Each species was also represented in its spatial location on the Australian GIS model surface map as a coloured marker and linked to its corresponding database record(s) in the database view. Using the ability of the Phoenix GIS to attach images and electronic documents to markers, images of the plant species investigated were included and the

scientific publications related to the metallophyte study were attached to each species sampler as a .pdf file whenever they were available.

3 Results and future directions

A spatial metallophyte database covering Australia was initiated to centralise, manage and facilitate access to existing and new information on native plant species tolerant to metals and metalloids that could be used for both habitat and species conservation purposes, as well as remediation of metal-contaminated sites and mine tailings. Heavy metals and metalloids captured in the database include: silver (Ag), arsenic (As), gold (Au), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), and zinc (Zn). Information on soil/substrate characteristics (pH, electrical conductivity, total and bioavailable metal content), habitat descriptions and images of metallophytes, and electronic versions of published papers are also included in the database. The metallophyte database has also been linked to Phoenix (Figure 1), which allows the user to visualise the results of database queries on an aerial photograph draped over the true topography of Australia and to extract information such as metal concentration values or metal extraction methods used (Figure 2).

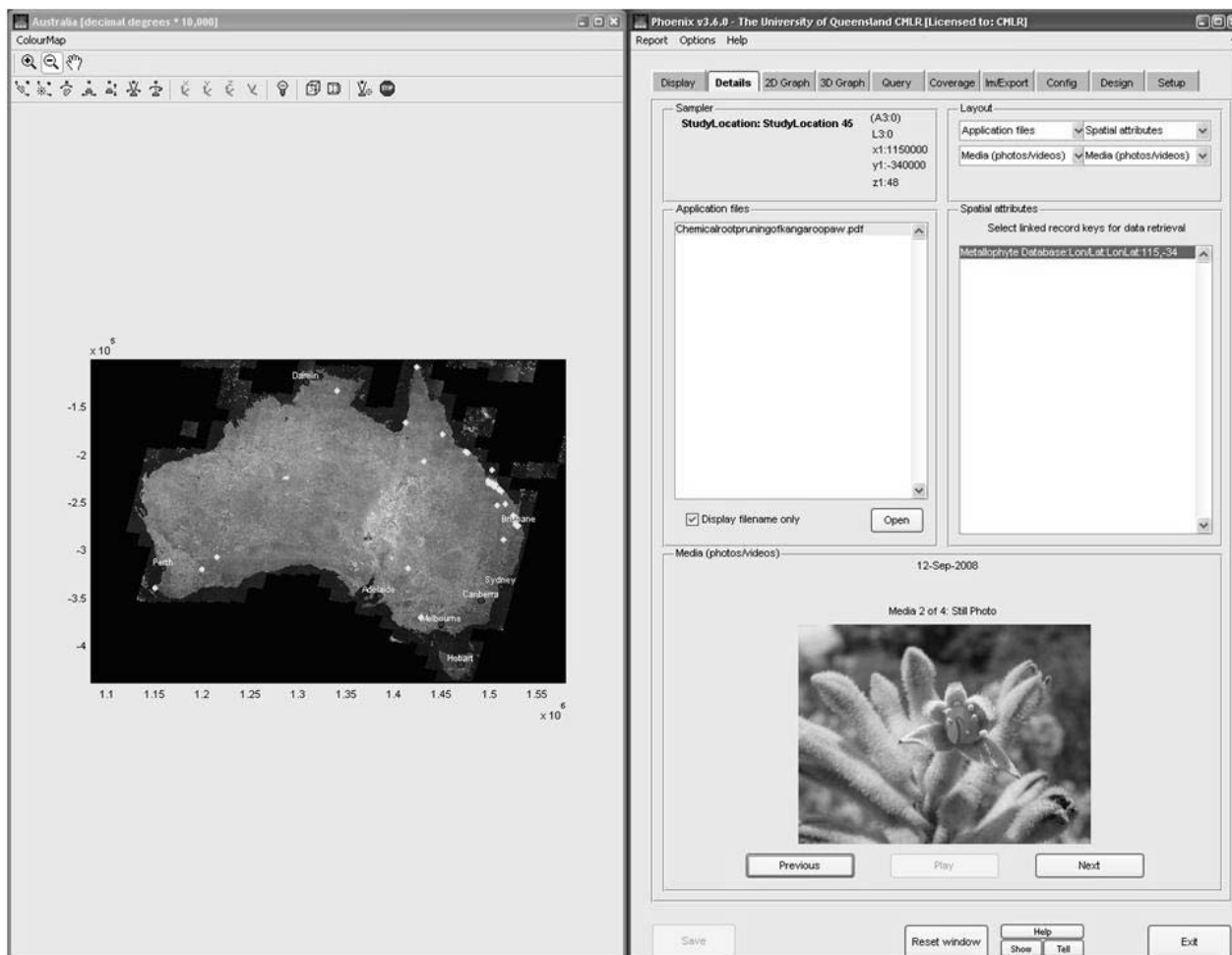


Figure 1 Phoenix screen shot showing an aerial photo of Australia in the map window on the left and information attached to a metallophyte sampler on the control panel window on the right. The selected metallophyte sampler has a .pdf document, a relational database attribute and four photos attached to it

Interrogating the Australian metallophyte database confirmed the statement of Baker and Whiting (2008) that the available scientific literature has mainly focussed on the identification of native metal accumulators and hyperaccumulators, and that there has been limited surveys focussing on the identification of other metal-

tolerant but non-accumulating plants, i.e. excluders. Querying the database for native metal-accumulating species returned only 14 plant species characterised as hyperaccumulators, including:

- Ni hyperaccumulators *Rostellularia adscendens* var *hispida* (Domin.) R.M. Barker (Snake Creek, QLD); *Commelina ensifolia* R.Br. (Gunnawarra, QLD); *Stackhousia tryonii* F.M. Bailey (Rockhampton & South Percy Island, QLD); *Pimelea leptospermoides* F. Muell. (Rockhampton, QLD) and *Hybanthus floribundus* (Lindl.) F. Muell. (Eastern Goldfields, WA).
- Se hyperaccumulators such as *Neptunia amplexicaulis* Domin and *Morinda reticulata* Benth.
- Mn hyperaccumulators such as *Gossia bidwillii* (Benth.) N. Snow and Guymer (EA), *Gossia bamagensis* N. Snow and Guymer (EA); *G. fragrantissima* (F.Muell. ex Benth.) N. Snow and Guymer (EA); *G. sankowsiorum* (F. Muell. ex Benth.) N. Snow & Guymer (EA); *G. gonoclada* (F. Muell. ex Benth.) N. Snow and Guymer (EA); and *Maytenus cunninghamii* (Hook.) Loes. (EA).
- The Pb hyperaccumulator *Polycarphaeae synandra* F. Muell. (NT).

Australia is the second most plant biodiverse country in the world after Brazil, with 25,000 native species out of a total of 250,000 plant species globally. It is therefore very likely that many more metallophytes from the Australian flora remain to be discovered. The number of metallophytes identified is expected to increase in the next few decades as a result of the drive for remediation and restoration of contaminated sites and mining waste using tolerant native and local species (Baker and Whiting, 2008).

The screenshot displays the Phoenix interface, which includes a map of Australia on the left and a detailed database record on the right. The map shows the outline of Australia with several cities marked: Darwin, Brisbane, Sydney, Canberra, Melbourne, Adelaide, Perth, and Hobart. The map is overlaid with a grid and has a scale of $\times 10^6$. The database record on the right is titled 'Metallophyte Database Lon/Lat' and contains the following information:

PhoenixRecordKey	141.512,-31.925,Acacia decurrens
SpeciesScientificName	Acacia decurrens
SpeciesCommonName	black wattle
Family	Fabaceae
MetalSymbol	Cd
PlantTissueDescription	upper plant
ExtractionMethodPlant	HNO3 + HClO4
MetalConcentrationInPlantTissue	5
Unit	mg/kg
TypeOfSubstrate	Field - Altered Soil for past mining activity
pH	4
EC	NaN
ExtractionMethodTotalSoil	HNO3
TotalMetalConcentrationInSubstrate	4
Unit	mg/kg
ExtractionMethodAvailableSoil	Distilled water + EDTA
AvailableMetalConcentrationInSubstrat	1
Unit	mg/kg
AnalysisMethodDescription	AAS(Atomic absorption spectrophotometry)
PlantResponse	Tolerant
ToleranceDescription	Non mentioned
Lon/Lat	141.512,-31.925
HabitatDescription	Native plants surrounding a silver mine at Yerranderie in Blue Mountains, NSW, which
TypeOfMine	Ag
NaturalPresence	1
PaperTitle	Response of Six Australian Plant Species to Heavy Metal Contamination at an aband
Authors	M.J.G. Archer and R.A. Caldwell
Journal	Water, Air, and Soil Pollution
Number	157
Pages	257-267
Years	2004
Comments	null
Longitude	141.512
Latitude	-31.925
ApproximatedLocation	1

Figure 2 Phoenix interface showing the database information for a metallophyte sampler retrieved via a query. In the 'natural presence' and 'approximate location' fields, '1' is equal to yes, 'NaN' and 'null' (in 'EC' and 'comments') indicate 'no value' found for those fields

Future work on the metallophyte database includes performing quality control checking of its content, and maintaining and expanding its coverage and content using new information from the literature and analysis of plant specimens from ongoing geobotanical surveys of serpentine landscapes, herbariums and metalliferous mine sites in Australia. The prototype Microsoft Access 2007 database can also be upsized to a corporate distributed SQL server database but it will be important to ensure that the database follows the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) guidelines, i.e. encodes the location of rare and endangered species, to prohibit uncontrolled bio-prospecting of what may be highly localised, endemic and vulnerable plant populations.

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