How soil geographic databases and resources have been used to better understand ecosystem functioning: An example from Australia

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Abstract
Soil resources and land systems inventories are generally presented as maps with an accompanying explanatory report. The maps are often digitized and can be used in a GIS. Here we show that beyond these products, the database of point observations made during the field survey, linked to other environmental data, can be useful for ecological research, thus value-adding to the land resources inventories. An example from Queensland is used to show that co-evolution of plant and insect diversity is associated with the development of salinity during aridification of northern Australian landscapes. The same dataset also suggests that invasion of grassland by the introduced pasture species buffel grass seems restricted to alkaline soils.

Key Words
Digital soil mapping, legacy data, sodium, soil organic C, soil pH, soil survey, soil salinity

Introduction
During the first phase of the National Land and Water Resources Audit (NLWRA) the Australian Soil Resources Information Systems (ASRIS) project in 2001, a relatively large point database of soil properties was created by collating various legacy databases into a single Oracle database (Johnston *et al*., 2003). Using this point database linked to national environmental data for climate (19 continuous variables), geology (23 discrete classes), land use (14 discrete classes), 4 Landsat MSS bands, and topography (14 continuous terrain variables), rule induction using decision trees was used to predict and map soil properties across the intensively used agricultural areas of Australia (Henderson *et al*., 2001). Here an example of using these data linked with vegetation data will be shown to add to our understanding of ecosystem function in two instances. The data are from a soil survey database in Queensland. They show potential for predicting habitats vulnerable to invasion by buffel grass and also suggest co-evolution of plant and insect diversity and landscapes in the Brigalow Belt bioregion.

Data
About 2000 geo-referenced sites from the soil survey of the Dalrymple Shire (Rogers *et al*., 1999) recorded plant species in three vegetation strata at each site, weed species present, and measurements such as electrical conductivity (EC) and pH. The plant strata species in lower, middle, and upper roughly correspond to grasses, shrubs and trees. The three dominant species, identified from a visual estimate in a circle with a ~50 m radius, were recorded in each stratum. Although percentages of each species were estimated, the study by Bui and Henderson (2003) used binary measurements (presence/absence). Thus a maximum of nine species was available for each site; weeds were recorded in a separate field in the database. Total soluble salt (TSS) was estimated as a depth-weighted average percentage from EC measurements on soil horizons (Bui *et al*., 1996) at 1499 sites, which dilutes the salinity of the most saline horizon.

The area intersects three of Australia's bioregions with threatened endemic species (http://www.deh.gov.au/minister/env/2003/mr03oct03a.html), the Einasleigh Uplands, Desert Uplands, and Northern Brigalow Belt (Figure 1). Thus the results are relevant to a very large area of Australia.

Statistical modelling
A correspondence analysis (CA) was performed to investigate vegetation species composition data (Bui and Henderson, 2003). CA extracts the most important environmental gradients from the site by species data matrix and represents that high-dimensional data matrix in a smaller number of dimensions by deriving a set of species (column) scores and a set of site (row) scores that maximally separate the species and sites. The site scores summarize the species profile for each site. Locations with similar site scores thus have similar species present. The species scores provide a summary of the site occurrence profile for each species. Species with similar species scores tend to be present at similar locations. Both sets of scores give an ordering along the environmental gradients identified.

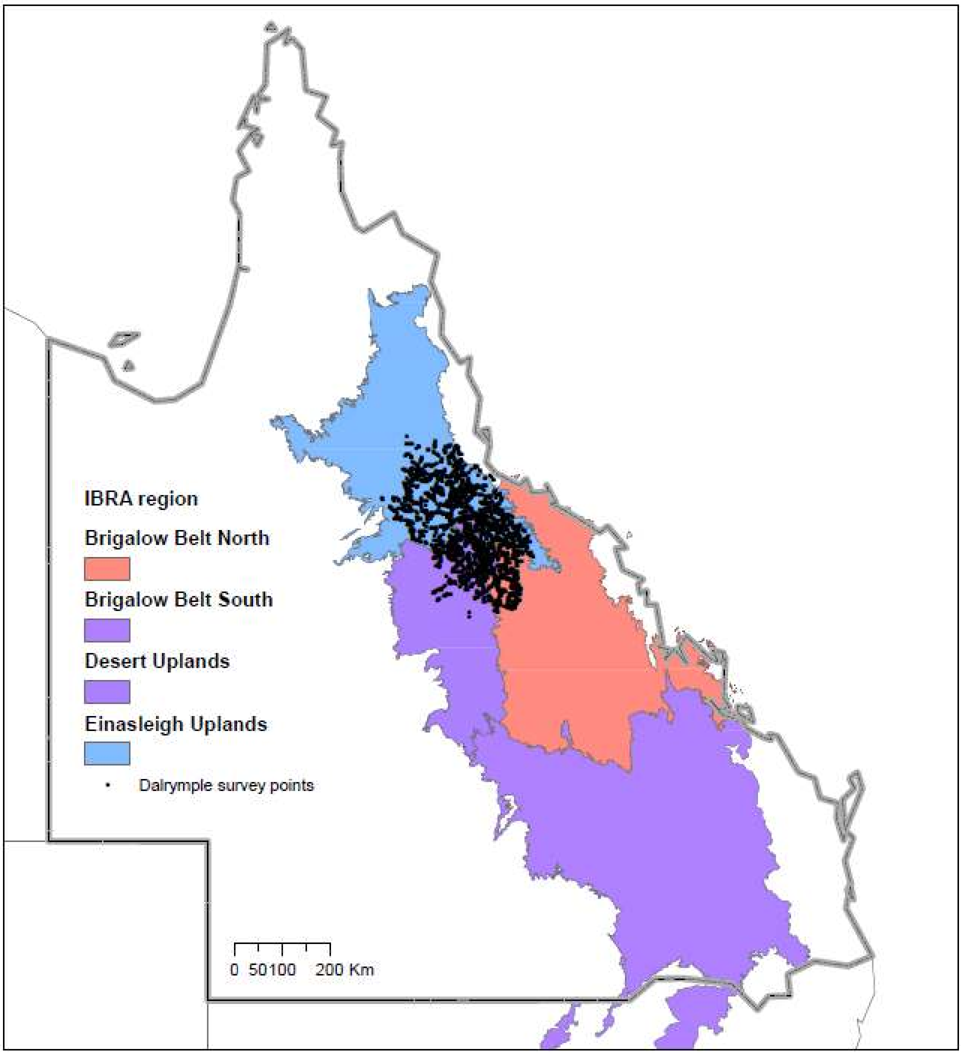

Figure 1. Location of soil survey points with respect to bioregions.

The site by species matrix is shown in Figure 2. Some species are found everywhere but some are restricted in extent (lower right hand corner in Figure 2). These are: *Cenchrus ciliaris* L. (buffel grass) (CECIL), *Lysiphillum carronii* (F. Muell.) Pedley (LYCA1), *Eucalyptus cambageana* Maid. (EUCA1), *Terminalia oblongata* F. Muell. (TEOB1), *Acacia argyrodendron* Domin. (ACAR), *A. harpophylla* F. Muell. (ACHAR), and *A. cambagei* R. T. Bak. (ACCAM).

Species attributes and environmental variables can be investigated to see whether they account for the variation in the species composition as summarized by these species and site scores. An environmental variable that influences species would be expected to show a monotonic relationship with the site scores. A regression model for the site scores with log (TSS) as the sole explanatory variable had an *R*2 of 37% and a mean square error (MSE) of 0.95.

The sites scores were related to other environmental variables in a generalized additive model (GAM): 19 climatic, 10 terrain, two bands of Landsat MSS, soil %clay and thickness, and lithology were investigated. These attributes were sampled from the ASRIS database (Johnston *et al*., 2003) at the sites. Site scores tended to increase with higher elevation, relief, precipitation and moisture index and lower % clay, temperature and radiation. The GAM fitted with the environmental variables had an *R*2 of 41% and a mean squared error (MSE) of 0.89. Adding a smoothing spline for log (TSS) with five degrees of freedom increased the explanatory power of the site scores (*R*2 57%, MSE 0.65). Soil salinity therefore plays an important role in describing the environmental gradient, even after accounting for the variation explained by other environmental predictors.

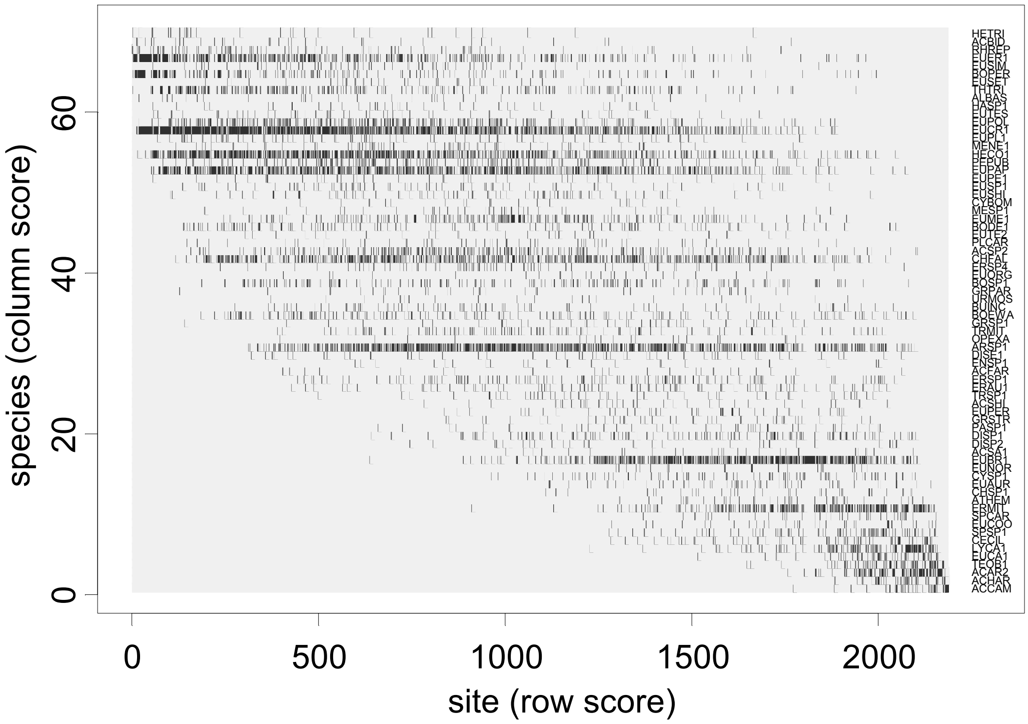

Figure 2. Site by species matrix after correspondence analysis.

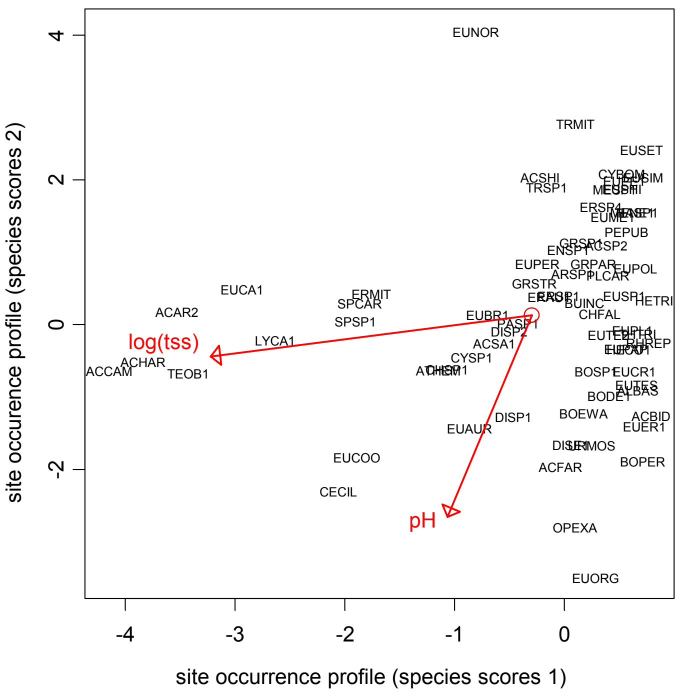

Figure 3. The environmental gradient represented by the first axis of the correspondence analysis is strongly related to log (TSS); the environmental gradient represented by the second axis is strongly related to pH (0-30 cm).

Soil salinity and topsoil pH, respectively, are strongly associated with the first two score axes after correspondence analysis of site by species data (Figure 3). The distribution of individual species, *Eremophila mitchelii* Benth., *Lysiphillum carronii* (F. Muell.) Pedley, *Eucalyptus cambageana* Maid., *Terminalia oblongata* F. Muell., *Acacia argyrodendron* Domin., *A. harpophylla* F. Muell., and *A. cambagei* R. T. Bak., responds strongly to a salinity gradient, starting at low levels of salinity—levels much lower than would typify a saline soil.

Weed invasion

Cenchrus ciliaris L. (buffel grass) (Poaceae) is considered one of Australia's worst environmental weeds and invasion by *C. ciliaris* is seen as a major threat to key habitats in the arid zone (Jackson, 2005). In addition to out-competing native species directly and decreasing herbaceous species richness, *C. ciliaris* invasion may result in major habitat change via its effects on fire regimes because it produces more biomass than native species and this greater biomass, which cures later in the year, leads to hotter late-season fires and an increased incidence of fire (Jackson, 2005). Its occurrence appears to be restricted to soils with alkaline topsoil pH (Figures 2 and 3), thus topsoil pH may be useful to predict its potential to invade new grassland habitats.

Biogeography, biodiversity, and soils are linked over time

Investigations of *Acacia* thrips systematics and their host-plant relationships show that:

- *A. harpophylla* and *A. cambagei* harbor two sister-species pairs of elongate and round gall thrips (*Kladothrips* spp.);
- phyllode-glueing thrips also show host specificity; and
- thrips on *A. harpophylla* and *A. cambagei* display high species richness (Crespi *et al*., 2004).

More recently McLeisch *et al*. (2007) have linked host-driven diversification of gall-inducing *Acacia* thrips and the aridification of Australia in the late Miocene (~6 My).

Taxonomic and recent chloroplast-DNA evidence shows that *Acacia harpophylla, A. cambagei and A. argyrodendron* are closely related species of microneurous *Plurinerves* (Crespi *et al*., 2004). These are the three *Acacia* species that exhibit tolerance of the highest levels of salt (Figure 3). However not all *Plurinerves* are salt-tolerant thus salinity may have played a role in the speciation within this clade. Certainly the brigalow plant communities have adapted to high soil salinity. Thus it seems that co-evolution of acacias related to brigalow and their thrips is linked to development of soil salinity in semi-arid landscapes.

Conclusion

The results have important implications for the conservation of biodiversity under global warming/climate change: they show that climatic variables are not the only important drivers of biogeographic patterns; soil chemistry plays an equally important role. Design of natural reserves for conservation of biodiversity should take both change in climatic pattern and soil geography into account, in particular climate-soil-plant interactions. In many instances soil resources have been neglected in conservation plans, partly because information on soil properties, especially chemical ones, is not extensively available—this example should serve as impetus for soil survey organizations around the world to make more attempts to improve their soil property mapping and to link their data with biological collections.

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