A comparison of deflation basin (wetland) soils from wet and dry climatic zones in Tasmania

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Abstract Deflation basins, or shallow depressions formed by wind erosion, are found in many semi-arid regions around the world. Because these features are topographic lows they become sites of water accumulation and are often associated with wetlands that represent important refugia for biota in dry environments. Despite being important habitats little is known about the relationship between water and sediment in these features. This study assesses soil geochemical properties from 50 wet-climate and 39 dry-climate deflation basins in Tasmania. The results reveal clear differences between wet-climate and dry-climate deflation basin soils. Macronutrients typically have higher concentrations in wet-climate soils (with the exception of potassium and calcium) while metals and other trace elements typically have higher concentrations in dry-climate soils. These findings have important implications for wetland biological-soil associations, with high plant productivity likely in wet-climate deflation basins as a result of both favourable nutrient status and better water availability.

Key words water balance; geochemistry; nutrients; trace elements; Tasmania, Australia

INTRODUCTION

Deflation basins (also known variously as pans, salt lakes and playas depending upon location, size and hydrological regime) are found in many semi-arid regions around the world (Goudie & Wells, 1995; Goudie, 2008). The deflation basin unit is frequently (but not always) comprised of two components: the basin itself, which is a low-relief closed depression, and an associated crescent-shaped dune or lunette (Bowler, 1986; Goudie, 1991, 2008; Sabin & Holliday, 1995). The presence of lunettes on the leeward side of many basins indicates the importance of aeolian (i.e. wind) processes in their formation. However, several other mechanisms, such as solution processes or karstic collapse, can play a role in deflation basin development depending upon the environment (Goudie, 1991; Goudie & Wells, 1995; Holliday *et al.*, 1996).

Despite its humid climate, the southern Australian state of Tasmania contains a surprisingly large number of deflation basins, particularly within the midlands and northeastern regions. These features are mostly inactive at present, indicating that the environmental conditions responsible for their formation are not currently operating. Indeed, the few dates that have been obtained from their lunettes suggest that the Tasmanian deflation basins formed during and shortly after the last glacial maxima, when conditions were colder, drier and windier than they are today (Colhoun, 2002). Thus, most Tasmanian deflation basins are probably Late Pleistocene in age (consistent with many similar features on mainland Australia) and represent important relict features in the landscape (Bowler, 1986; Dixon, 1997).

Importantly, Tasmanian deflation basins that have not otherwise been cleared or drained are often associated with lowland wetlands that show a rich biodiversity and represent important refugia for native plants and animals (Kirkpatrick & Tyler, 1988; Atkinson, 1992). These wetlands form where basins are close to, or at the water table, and where their bases are composed of fine sediments. These conditions combine to limit drainage and promote the ponding of precipitation on the ground surface, at least seasonally (Dixon, 1997). Thus, in addition to their intrinsic geomorphic values (especially with respect to their unique physical and hydrological properties), deflation basins in Tasmania are also important for their habitat and ecosystem values (Dunn, 2002). Despite their importance as refugia for both plant and animal species, however, it is unknown at present what aspects of deflation basin character favour an abundant and diverse flora.

Scholz *et al.* (2002) identified the importance of wetting and drying cycles on the availability of nutrients in ephemeral deflation basins in western New South Wales. Their work indicated that both drying and re-wetting events promoted increases in nitrogen and phosphorous concentrations in the Menindee Lakes system, a network of lakes fed primarily by river overflows. Although their work suggests that the ecological quality of the deflation basins in this system is closely linked with a diverse hydrological regime, it is unknown whether similar soil nutrient patterns can be observed in basins fed by precipitation (as opposed to riverine inputs) or whether other soil chemical concentrations also differ with hydrology. The aim of this project, therefore, is to improve our understanding of the physical function of deflation basins in eastern Tasmania, particularly with respect to differences between climatically "wet" and "dry" (precipitation-fed) deflation basins. This is achieved by comparing soil geochemical (including nutrient) properties from wet-climate and dry-climate basins and considering the relative strengths of biological and physical controls on soil character. The ultimate goal of this study is to use this knowledge to develop a mechanism for identifying the conservation potential (in an ecological sense) of precipitation-fed deflation basins.

METHODS

Study location

Soil characteristics were assessed for 89 deflation basins in eastern and central Tasmania, Australia (Fig. 1), all of which receive hydrological inflows only from precipitation. Prior to soil collection the basins were sub-divided into two climatic classes based on their water balance and according to a natural break in the data. Thus, basins in climates with an annual rainfall to evaporation ratio of ≥0.7 were classified as "wet" whereas basins with an annual rainfall to evaporation ratio of <0.7 were classified as "dry". This classification defined 50 wet-climate and 39 dry-climate basins throughout eastern and central Tasmania. Whereas the wet-climate basins were distributed throughout the study region, the majority of the dry-climate basins (36) were clustered in the midlands (Fig. 1).

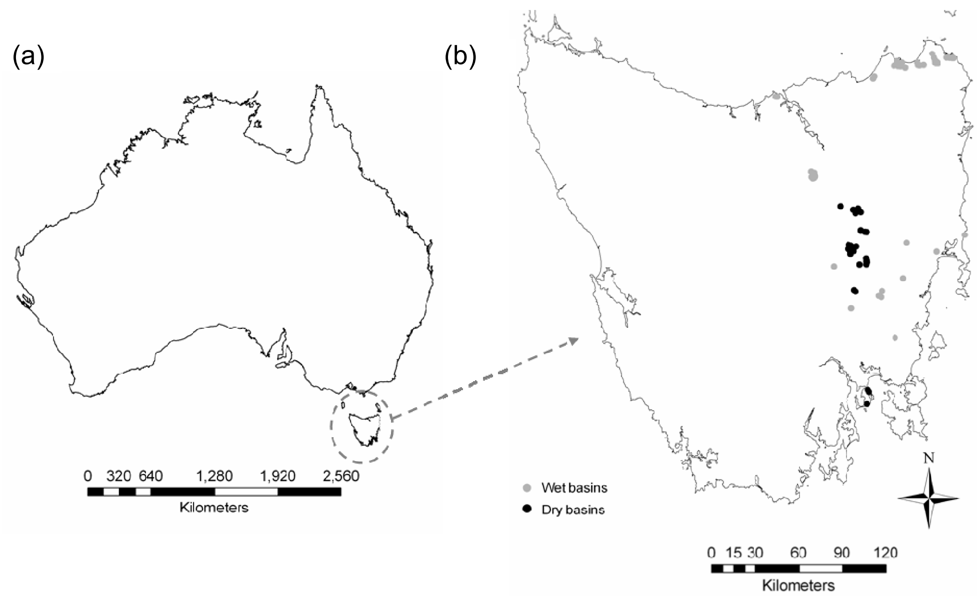

Fig. 1 Location of the deflation basins within (a) Australia and (b) Tasmania.

Soil analyses

Four randomly distributed replicate soil samples were collected in each of the 89 deflation basins investigated in this study, giving a total of 356 soil samples for analysis. For each sample, surface sediment, or the top 5 cm of the soil, was collected. The physical and chemical characteristics of the samples were determined using industry standard procedures. Electrical conductivity (EC) and pH were measured using digital field meters, carbon and nitrogen were assessed using a Leco TRuSpec CN nutrient analyzer, and 19 other geochemical elements were measured using inductively coupled plasma atomic emission spectroscopy (ICP-AES). The elements assessed using ICP-AES included: aluminium, barium, calcium, cobalt, chromium, copper, iron, lead, potassium, magnesium, manganese, sodium, nickel, phosphorus, sulphur, strontium, titanium, vanadium and zinc.

Statistical analysis

The wet-climate and dry-climate soil samples were compared using both uni- and multi-variate statistical techniques. Descriptive statistics (mean and coefficient of variation) were computed for each of the 23 soil variables investigated in this study. Statistical similarities and differences between variables for the wet-climate and dry-climate samples were assessed using Mann-Whitney U tests, a standard univariate technique suitable for data that are not normally distributed. Finally, multi-dimensional scaling (MDS) and an Anosim were used to assess for differences between the wet and dry samples when all soil parameters are considered collectively.

RESULTS

The means and coefficients of variation for the 50 wet-climate and 39 dry-climate deflation basins are listed in Table 1. Fourteen variables were statistically different between the two climate types, and most of these (10 out of 14) were higher for the dry-climate basins, suggesting that wetter basins are geochemically depleted relative to drier basins (especially for metals and trace elements). However, the four variables that had higher concentrations in the wet-climate soils are all critical plant nutrients (carbon, nitrogen, phosphorous and sulphur).

When the 23 soil variables were combined in a multivariate analysis, the results confirmed those of the univariate statistics with significant differences ($R = 0.22$; $p < 0.001$) evident between soils from the wet-climate and dry-climate deflation basins (Fig. 2). Once again, these differences were driven by the higher concentrations of most geochemical elements in the dry deflation basin soils and the relatively high nutrient levels found in the wet deflation basin soils.

DISCUSSION

Deflation basins in general have received relatively little research attention and have often been viewed as problem sites in the landscape (Harmse & Le Grange, 1994), although their ecological significance has been acknowledged in certain environments (e.g. Scholz *et al.*, 2002). Because of their complex hydrology, however, deflation basins often provide a diverse array of productive habitats (Gawne & Scholz, 2006) that vary temporally within individual basins and spatially between basins. In particular, many basins serve as oases in semi-arid environments, often containing highly productive wetlands. The maintenance of these ecosystems is dependant upon both wet and dry cycles and, thus, any alteration to the local hydrological regime can affect their condition (Gawne & Scholz, 2006). Water, therefore, is clearly an important driver of biological productivity and diversity in deflation basin ecosystems. It remains unclear from previous work, however, if basins with differing hydrological characteristics have unique physical properties and the importance of these properties in determining ecosystem structure and function.

The results of this study clearly show that the surface soils of wet-climate and dry-climate deflation basins are significantly different to one another; hence the hydrological regime is closely linked to the physical character of precipitation-fed deflation basins. This is true whether the soil parameters are considered collectively (using multivariate approaches) or individually (using univariate approaches). The most obvious difference between wet-climate and dry-climate deflation basin soils is the lower concentrations of many geochemical elements in the wet soils.

Table 1 Soil properties and statistical differences between wet-climate and dry-climate deflation basins.

Variable	Wet Mean	Coefficient of variation	Dry Mean	Coefficient of variation
pH	5	0.17	5	0.15
EC (μS/cm)	74	1.28	145	2.01
Al (ppm)	28783	0.80	35938	0.49
Ba (ppm)	95	0.67	80	0.65
C (ppm)	181130	0.74	48200	0.89
Ca (ppm)	5493	1.08	9301	1.52
Co (ppm)	8	0.96	11	0.54
Cr (ppm)	29	1.07	30	0.59
Cu (ppm)	16	0.83	178	0.44
Fe (ppm)	17721	0.75	23447	0.40
K (ppm)	1503	0.95	3923	0.58
Mg (ppm)	2043	0.67	6375	1.17
Mn (ppm)	189	1.14	293	0.94
N (ppm)	11300	0.57	4100	0.79
Na (ppm)	846	1.14	2425	0.93
Ni (ppm)	23	1.31	22	0.49
P (ppm)	380	0.54	189	0.50
Pb (ppm)	9	0.54	11	0.80
S (ppm)	3048	1.02	1031	1.50
Sr (ppm)	52	0.81	70	1.90
Ti (ppm)	99	2.00	104	0.85
V (ppm)	51	1.08	69	0.42
Zn (ppm)	22	0.80	29	0.51

Note: values shaded grey indicate statistically significant differences using a Mann-Whitney U test ($p < 0.05$) with grey indicating the higher concentration or level.

This relative depletion does not appear to be geological in nature as most basins co-occur in similar geological regions (especially in the midlands where wet and dry basins are in close proximity to one another), and is confirmed using Ti/Al ratios that indicate no statistically significant difference between the wet and dry deflation basin soils. The differences between the wet and dry soils must, therefore, be the result of other non-geological factor(s). The two most obvious mechanisms to explain these differences are eluviation, or the downward movement of elements through the soil profile with water, and biologic inputs. The wet deflation basins are subject to more frequent and sustained periods of wetting when compared to the drier deflation basins. This enhanced wetting regime is likely to drive a significant downward movement of many soil elements (especially those that are soluble in water) resulting in depleted levels at the surface. Assessments of the ratios of mobile elements (Ca, K, Mg and Na) with a known stable element (Ti) lend support to this hypothesis, with all ratios being statistically higher for dry-climate basin soils. At the same time, the wet-climate deflation basins exhibited much higher concentrations of several critical plant nutrients, including carbon (or organic matter), nitrogen, phosphorous and sulphur. In this case, the relatively wet conditions favour a considerably higher and more persistent vegetation cover than what is observed in the drier basins. This vegetation acts to enrich the soil by adding nutrients and organic matter at the surface, thereby sustaining these elements at relatively high levels. This finding is consistent with work undertaken beneath shrubs in semi-arid environments that highlighted the importance of plant cycling in the horizontal distribution of nutrients in these ecosystems (e.g. Noy-Meir, 1973; Schlesinger *et al*., 1996). Thus, wet-climate deflation basin soils experience both geochemical depletion (through eluviation) and enrichment (through biological inputs) leading to a differentiation in the geochemical content of wet-basin and dry-basin soils.

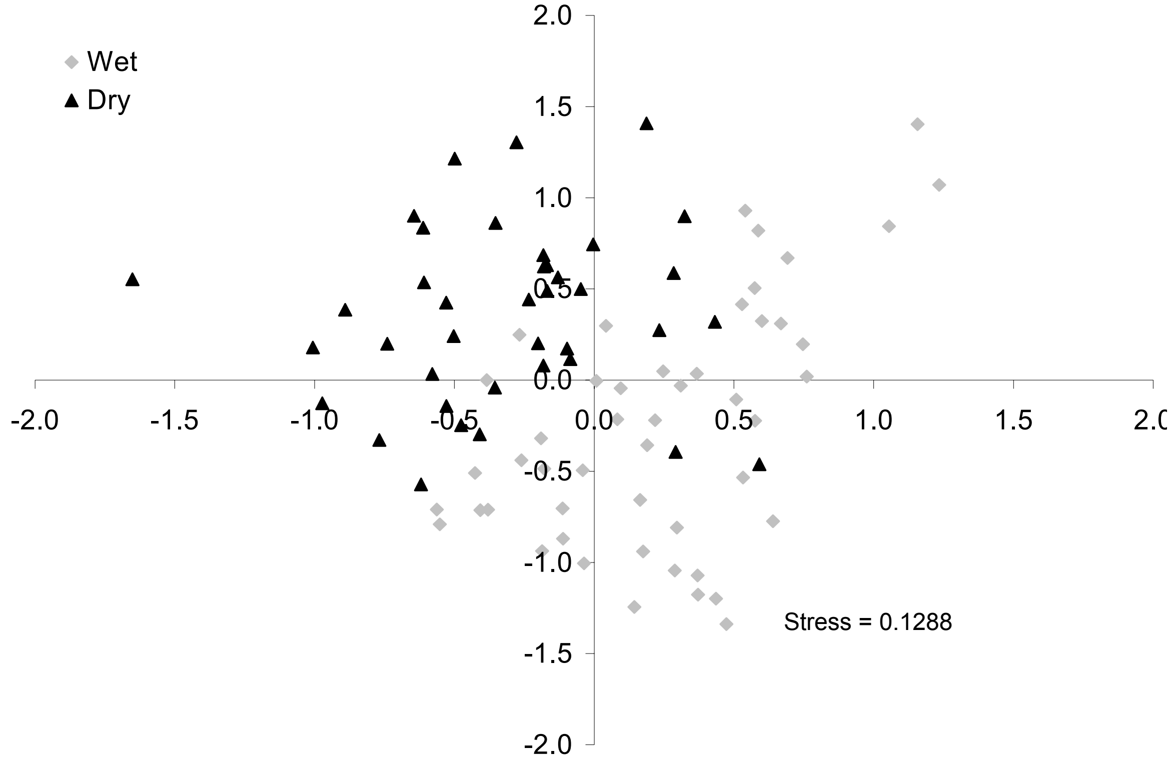

Fig. 2 Multidimensional scaling (MDS) plot of soil character for wet and dry deflation basins. Anosim results show that these data are significantly different ($R = 0.221$; $p < 0.001$).

The moisture and soil differences between wet-climate and dry-climate deflation basins have important implications for the biological productivity and diversity of the basins, with wetter basins being more likely to exhibit high ecological values. The wet deflation basins are more favourable to both plant and animal life than the drier deflation basins for two reasons. First, they are wetter for longer than their drier counterparts, meaning there is ample moisture to support vegetation growth throughout the year. Second, the higher nutrient status of the wet basins ensures that plants and animals have sufficient resources available to them to facilitate their growth (evidenced in this study by the higher carbon contents of the wet-basin soils). If deflation basins are to be preserved for their physical and/or ecological values, a potential mechanism to stratify basins without recourse to extensive ecological surveys is a simple water balance calculation that segregates basins into wet and dry units, such as was performed here. Such an approach provides a simple method of differentiating basins with high biological potential from those with lower potential.

CONCLUSION

Deflation basins are common physical features in the Tasmanian landscape that have recently received attention for conservation due to their unique geomorphic and ecological values. Many of these basins are heavily modified by anthropogenic activities, however, and there is a need to identify which basins are the most suitable for on-going conservation. This study has shown that a simple segregation of precipitation-fed deflation basins according to a water balance calculation that classifies basins as either climatically wet or dry highlights important hydrological and physical (soil properties) characteristics that serve as significant ecological indicators. This approach suggests that wet-climate deflation basins have greater ecological value (all else being equal) than dry-climate basins owing to their higher moisture and soil nutrient states.

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REFERENCES

Atkinson, J. (1992) An inventory system for Tasmanian wetlands. A working copy in abbreviated form of Phase I. Department of Parks, Wildlife and Heritage, Tasmania, Australia.

Bowler, J. M. (1973) Clay dunes: Their occurrence, formation and environmental significance. *Earth-Science Reviews* **9**, 315–338.

Bowler, J. M. (1986) Spatial variability and hydrological evolution of Australian lake basins: an analogue for Pleistocene hydrologic change and evaporite formation. *Palaeogeogr. Palaeoclim.* **54**, 21–24.

Colhoun, E. A. (2002) Periglacial landforms and deposits of Tasmania. *S. Afr. J. Sci.* **98**, 55–63.

Dixon, G. (1997) A preliminary survey of the distribution and conservation significance of inland aeolian features in the midlands, northeast and southeast Tasmania. Department of Parks and Wildlife Service, Tasmania.

Dunn, H. (2002) Assessing the condition and status of Tasmania's wetlands and riparian vegetation. Nature Conservation Branch Technical Report 02/09, Department of Primary Industries, Water and Environment, Tasmania.

Gawne, B. & Scholz, O. (2006) Synthesis of a new conceptual model to facilitate management of ephemeral deflation basin lakes. *Lakes & Reservoirs: Research and Management* **11**, 177–188.

Goudie, A. S. (1991) Pans. *Prog. Phys. Geogr.* **15**, 221–237.

Goudie, A. S. (2008) The history and nature of wind erosion in deserts. *Ann. Rev. Earth Planet. Sci.* **36**, 97–119.

Goudie, A. S. & Wells, G. L. (1995) The nature, distribution and formation of pans in arid zones. *Earth-Science Reviews* **38**, 1–69.

Harmse, J. T. & Le Grange, C. N. (1994) The influence of urbanization on pans on the East Rand (Johannesburg, South Africa). *Landscape and Urban Planning* **28**, 17–24.

Holliday, V. T., Hovorka, S. D. & Gustavson, T. C. (1996) Lithostratigraphy and geochronology of fills in small playa basins on the Southern High Plains, United States. *Geog. Soc. Am. Bull.* **108**, 953–965.

Kirkpatrick, J. B. & Tyler, P. A. (1988) Tasmanian wetlands and their conservation. In: *The Conservation of Australian Wetlands* (ed. by A. J. McComb & P. S. Lake), 1–16. Surrey Beatty & Sons Pty Ltd, Australia.

Noy Meir, I. (1973) Desert ecosystems: environment and producers. *Ann. Rev. Ecol. Syst.* **4**, 25–41.

Sabin, T. J. & Holliday, V. T. (1995) Playas and lunettes on the Southern High Plains: Morphometric and spatial relationships. *Ann. Assoc. Am. Geogr.* **85**, 286–305.

Schlesinger, W. H., Raikes, J. A., Hartley, A. E. & Cross, A. F. (1996) On the spatial pattern of soil nutrients in desert ecosystems. *Ecology* **77**, 364–374.

Scholz, O., Gawne, B., Ebner, B. & Ellis, I. (2002) The effects of drying and re-flooding on nutrient availability in ephemeral deflation basin lakes in western New South Wales, Australia. *River Research and Applications* **18**, 185–196.