Catena 121 (2014) 186–194

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Patterns of variation in Australian alpine soils and their relationships to parent material, vegetation formation, climate and topography

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ARTICLE INFO

Article history:
Received 10 July 2013
Received in revised form 29 April 2014
Accepted 8 May 2014
Available online 7 June 2014

Keywords:
Alpine
Australia
Climate
Soil-forming factors
Topography
Vegetation

ABSTRACT

We tested the degree to which parent material, climate, vegetation and topography influenced the characteristics of alpine soils at two scales: across the full range of alpine vegetation in Australia and in the Snowy Mountains of New South Wales, where geological relationships with soils may be obscured by the aeolian deposition of sediment and there are strong local gradients in climate. We derived eleven soil groups from numerical analysis of the national data, three of which were confined to the island State of Tasmania and ten of which clearly fitted in one of the organosol, dermosol or rudosol soil orders. Linear mixed models indicated that climate, parent material, topographic position, and vegetation type are all important in influencing alpine soil at a national scale in Australia. Parent material was prominent in models for most attributes of the soil. Whilst vegetation formation had only a weak influence on soil characteristics at the national level, in the Snowy Mountains it interacted strongly with geology. The fact that Snowy Mountains short alpine herbfield soils were affected by geology, but tall alpine herbfield and heath soils were not, could reflect differences in accumulation of aeolian material.

1. Introduction

Jenny (1941) suggested that soils are a function of parent material, climate, topography, vegetation and time. Fire regimes can also have a strong influence on soil characteristics (di Folco and Kirkpatrick, 2011; McIntosh et al., 2005). Most of the alpine soils of the world have had only ten millennia in climatic conditions comparable to the present, with most loose material previously eroded by glacial and periglacial processes. This youth means that, in general, alpine soils are shallow, coarsely textured and have poorly developed horizons (Retzer, 1974). The characteristics of alpine soils in many different places have been shown to be strongly influenced by varying combinations of parent material, topography, biota and climate (e.g. Archer and Cutler, 1983; Baruch, 1984; Bäumler and Zech, 1994; Belsky and del Moral, 1982; Diaz et al., 1997; Ives and Cutler, 1972; Messer, 1988; Molloy and Blakemore, 1974; Nolan and Robertson, 1987; Retzer, 1974).

In Scottish moorlands as a whole, Nolan and Robertson (1987) found that soil type was related to topographic position, through its influence on slope and soil drainage, within the over-riding influences of climate and geology. Ives and Cutler (1972) found that whilst soil characteristics were mainly determined by topographic position within a particular geological substrate, they were also influenced by vegetation type and altitude. Archer and Cutler (1983) highlighted the importance of aspect and elevation, surrogates for climatic conditions, in affecting the processes of soil formation. In the Mt Everest region of Nepal, Bäumler and Zech (1994) demonstrated a relationship between soil types and elevation. Some regional studies reinforce climate as the major influence in the formation of alpine soils, due to its effect on biological activity and chemical weathering (Dahlgren et al., 1997; Knapik et al., 1973; Retzer, 1974). Snow cover duration can dramatically affect soil properties in mountain landscapes (Dahlgren et al., 1997), through its effects on erosion rates and vegetation productivity.

In Australia, the alpine soils of the Snowy Mountains (Costin, 1954), Mount Sprent in southwestern Tasmania (Bridle and Kirkpatrick, 1997) and the organic alpine soils of Tasmania (di Folco, 2007) have been described in detail. The alpine soils of Australia are known to be highly diverse, including at least eight great soil groups (Bridle and Kirkpatrick, 1997; Costin, 1954; McKenzie et al., 2004).

There is known to be variation in Australian alpine soils related to variation in climate and substrate (Williams and Costin, 1994). Topography and vegetation type are also known to relate to edaphic variation, as in the case of the soils of fjaeldmark, short alpine herbfield and organic soils in Tasmania (Bridle and Kirkpatrick, 1997; Gibson and Kirkpatrick, 1985, 1992; Kirkpatrick and Dickinson, 1984; Kirkpatrick and Gibson, 1984; Lynch and Kirkpatrick, 1995).

The soil-forming factors are also known to interact. For example, the alpine soils of the Snowy Mountains illustrate an interaction between

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http://dx.doi.org/10.1016/j.catena.2014.05.005

parent material and climate. The parent material is partly constituted of aeolian dust from the western plains (Walker and Costin, 1971), with Johnston (2001) estimating an influx of 1.8–113 kg ha^{-1} per annum. The frequency of major dust storms, one in 10–20 years in the 20th century (Walker and Costin, 1971), has increased with four such storms occurring in the past decade (Green, 2012).

Whilst much is known of the alpine soils of Australia, there has been no systematic study of variation over their full range and no national scale quantitative testing of the relationships between the soil-forming factors and this variation. We use repeatable numeric methods to fill these gaps. Our specific aims were, first, to determine whether a numerical classification of soils based largely on chemical characters conforms to existing understanding of variation in Australian alpine soils. Second, we wished to determine which soil characteristics were related to surface geology, climate, vegetation and topographic position throughout the range of alpine environments in Australia. Within the iconic alpine area in the Snowy Mountains of New South Wales we tested whether a high level of aeolian dust deposition has overwhelmed the influence of the underlying rocks on soil characteristics.

2. Methods

2.1. Field data collection

Soil data were collected from 166 locations distributed throughout the full geographic range of Australian alpine and treeless subalpine vegetation, including the Snowy Mountains (Fig. 1), as part of a study focused on describing and explaining variation in the flora and vegetation (Kirkpatrick and Bridle, 1999). At each location data were collected from a 5 × 5 m area. Soil depth was measured using a metal probe. Depths were obtained from the centre of the quadrat and halfway from the centre to each of the four corners, giving five measurements. Mean soil depth and maximum soil depth were extracted from these data. Surface soil texture was determined using the field technique of McDonald et al. (1984). The fifteen classes of soil texture from this source were ordered by mean particle size. A score of 1 was given for sand and a score of 15 for clay. The hue, value and chroma of the surface soil after wetting were determined using a soil colour chart (Oyama and Takehara, 1967). The surface 5 cm of the soil below the litter layer was collected from three subsamples in each quadrat for later analysis.

The vegetation formation was described for each quadrat following Kirkpatrick and Bridle (1999). Topographic position was noted in one of four classes: crest or ridgetop, upper slope, lower slope, valley or flat. The geological type was denoted as one of: basalt, dolerite, quartzite, granite, Permian sediments, rhyolite, gneiss or conglomerate.

In the Snowy Mountains (Fig. 1) we used data from 53 locations additional to those sampled in the national data set. Some of these data were collected to characterise the environments of snow patches (Green and Pickering, 2009), whilst others were collected as background information in a study of the effects of variation in altitude and snow lie on alpine vegetation (Pickering and Green, 2009). Soil sampling and environmental data collection were the same as for the nationwide sampling, with the addition of direct measurements of soil temperature using Tinytag plus-Gemini Data Loggers buried 7.5–10.0 cm below the surface on each site between 2004 and 2011.

2.2. Laboratory analysis

The soil sample for each location was bulked from subsamples. The following attributes of the nationwide samples were determined, following the methods described in Rayment and Higginson (1992), except where indicated otherwise below by the absence of a reference number to this volume: pH, 1:5 soil:water suspension (4A1); conductivity, EC of 1:5 soil water suspension (3A1); extractable P, bicarbonate extractable (9B2); total P, nitric/perchloric digest and I.C.P. analysis; %N, semimicro Kjeldahl with steam distillation (7A1); NO_3N, KCl extract (7C2); NH_4N, KCl extract (7C2); extractable K, bicarbonate extractable (18A1); total Ca, nitric/perchloric digest and I.C.P. analysis; Cu, DTPA (12A1); Zn, DTPA (12A1); Mn, DTPA (12A1); Fe, DTPA (12A1); organic carbon, Walkley and Black (6A1).

For the Snowy Mountains data set, total carbon and nitrogen were determined by high temperature combustion in an atmosphere of oxygen using a Leco CNS-2000. Carbon was converted to CO_2 and determined by infrared detection. Nitrogen was determined as N_2 by thermal conductivity detection (Matejovic, 1997). Inorganic nitrogen was determined by segmented flow colorimetry following extraction using 2 M KCl. NH_4^+ was separated from interferences by gas diffusion and determined after reaction with sodium salicylate and dichloroisocyanurate (DCIC). Nitrate (NO_3-N) was dialysed then reduced to nitrite (NO_2-N) by Cd reduction and the resultant nitrite reacted with N-1-naphthylethylenediamine dihydrochloride (NEDD) with sulphanilamide (Rayment and Higginson, 1992). Total metals were determined by US EPA method 3051A (1998). The finely ground sample was digested in a microwave oven with a mixture of nitric acid and hydrochloric acid. The solution was then analysed for a wide range of elements by inductively coupled plasma optical emission spectrometry (ICP-OES). Other attributes of the samples were determined, as above, following the methods described in Rayment and Higginson (1992).

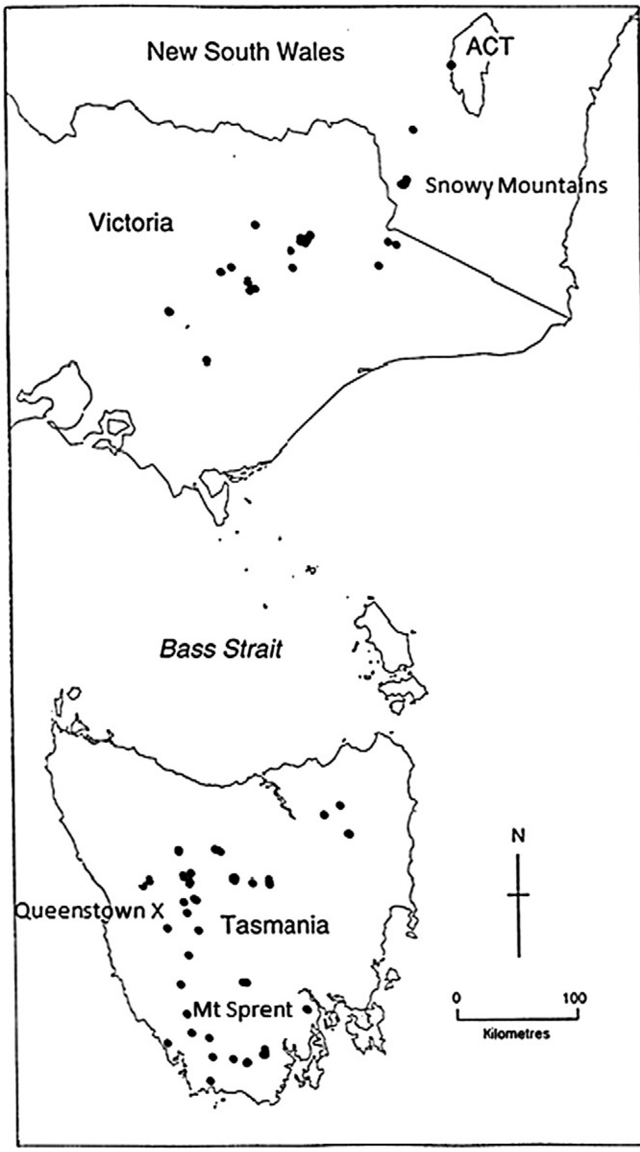

Fig. 1. The locations of soil samples (black dots) and places mentioned in the text.