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Impacts of deforestation and burning, and the role of bracken fern, on the properties of surficial or buried soil A-horizons

David J. Lowe
Department of Earth and Ocean Sciences, University of Waikato, Hamilton
Paul McDaniel
University of Idaho, Moscow, Idaho, USA

Bracken fern (*Pteridium* spp.) is an aggressive plant that commonly invades disturbed sites. Its success as an invader is attributable, in part, to its ability to produce abundant growth, both below ground in the form of rhizomes and fine roots and above ground as fronds and stems. This biomass production has been shown to affect numerous soil properties. In describing soils of the 'Pumice Lands' (Pumice Soils or Vitrands mainly) in New Zealand, Molloy and Christie (1998) attributed black A horizons 'to bracken fern, which replaced much of the forest'. Analyses of humus and phytoliths in the A horizons of soils developed especially on Kaharoa and Taupo tephras in central North Island (buried beneath 1886 Tarawera eruptives in the Rerewhakaaitu area) showed that type-A humic acids predominated and that fernland and grassland had replaced the pre-existing forests (Birrell et al., 1971; Sase et al., 1988; Hosono et al., 1991; Sase and Hosono, 1996). Pollen, phytolith and associated studies, together with tephrochronology, have shown that human-induced deforestation by burning began in New Zealand soon after Polynesian settlers arrived (e.g. McGlone, 1989; Clarkson et al., 1992; Kondo et al., 1994; McGlone et al., 1994; Newnham et al., 1998; McGlone and Wilmshurst, 1999; Watanabe and Sakagami, 1999; see also article on Polynesian settlement by Lowe, this volume). The repeated burning resulted in the formation of extensive fernlands (McGlone et al., 2005).

In northern Idaho, USA, establishment of bracken is associated with the conversion of allophanic to non-allophanic Andisol mineralogy (Johnson-Maynard et al., 1997); these changes include increased soil carbon, darker soil colours, lower pH, and increased organic forms of active Al.

Bracken biomass comparisons – New Zealand and northern Idaho, USA

Location	Rhizome biomass (kg m^{-2}) Mean	Range	Frond biomass (kg m^{-2}) Mean	Range
Nelson, New Zealand[1]	--	7.08 (max.)	--	1.41 (max.)
New Zealand (23 stands)[2]	2.92	0.91-5.19	--	--
Idaho, USA (9 stands)[3]	1.96	1.14-2.54	0.52	0.27-0.89

[1]Bray (1991)
[2]Unpublished data of D. Whitehead, Landcare Research, Lincoln, NZ, cited by McGlone et al. (2005)
[3]Jimenez, J. 2005. Accumulation of belowground C in Andisols under bracken fern (*Pteridium aquilinum*). MS thesis. Univ. of Idaho, Moscow.

In Japan, a major part of soil organic carbon in Andisols and associated soils comprises humic acids, which are characterized by their stability and aromatic (humified) structure (Shoji et al., 1993; Hiradate et al., 2004). These features arise from the presence of labile and active metals, chiefly Al and Fe, supplied by the weathering of glass and other tephric materials, which are able to bind humic substances through strong coordination bonding to form macromolecules of Al- and Fe-humic acid complexes very resistant to degradation or leaching (Hiradate et al., 2004). The resultant very dark or commonly black A horizons, typically melanic epipedons in *Soil Taxonomy* (see table), can contain up to 15% organic carbon (Hiradate et al., 2004). The Japanese pampas grass or 'susuki', *Miscanthis sinensis*, a C4 plant with large amounts of root residues, has been maintained artificially for millennia in ancient Japan to provide roofing material, straw bags, and fodder. Burning the grass in early spring before germination was common practice (buds of the pampas grass are several centimetres underground and so are not damaged) (Lowe, 2006). During burning, large amounts of very dark-coloured and charred microparticles were produced and these provided a second source of humic acids. The pampas grass has been regarded as a classic 'andisolizer' or 'melaniser' (Wada, 1986; Shoji et al., 1990, 1993; Hiradate et al., 2004).

Main properties of melanic epipedon*

- Munsell colour values and chromas of ≤ 2 (dark) throughout
- Melanic index ≤ 1.70 throughout
- ≥ 6% organic C as weighted average
- Andic soil properties
- ≥ 30 cm thick

* After Soil Survey Staff (1999, p.23)

The relative importance of these two mechanisms – (1) stabilization of humic acids by complexing reactions with Al and Fe, or (2) cultivation of *M. sinensis* and its charred derivatives as a major source of carbon in humic acids – was evaluated by Hiradate et al. (2004) using $\delta^{13}C$ analyses of humic substances in a range of soils in Japan. Hiradate et al. (2004) were able to compare the contributions from C3- or C4-plant- derived carbon because *M. sinensis* was effectively the only C4 plant species in (traditional) Japan. They found that the contribution to humic and fulvic acids of carbon derived from *M. sinensis* ranged from 18 % to 52 %. Their conclusions were that although highly-humified, i.e. dark-coloured, humic acids tended to be derived from C4-plant-derived carbon (ultimately *M. sinensis*), the dominant source of carbon for humic and fulvic acids in many cases was from C3 plants (mainly forest vegetation). Consequently, the overriding importance of active Al and Fe especially on the formation and accumulation of the dark-coloured humic acids in *Kuroboku* soils (Andisols) was reinforced (Hiradate et al., 2004).

In New Zealand the 'black' A horizons generally have melanic properties, but do not meet the thickness criterion for melanic epipedons, and hence are regarded as 'melanic-like'. As noted above, they formed under fernland and tusssock grassland and most contain A-type humic acids (± charcoal). Non-melanic topsoils are formed under forest (most have non A-type humic acids, including Pg in P-type humic acids from deciduous trees) (see figures below). Differences between New Zealand and Japan thus relate largely to differences in human settlement history and impacts, with New Zealand having an exceptionally short prehistory of only c. 700 years (since c. 1250-1300 AD) in comparison with 10,000 years or more in Japan.

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Summary from Birrell et al. (1971)

Buried horizons of an intense black colour have been found in beds of Kaharoa Ash, Taupo Pumice, and Mamaku Ash in the Rotorua and Bay of Plenty districts. They underlie material erupted in 1886, from Mt Tarawera and Lake Rotomahana. They are characterised by high organic-carbon contents, very high C/N ratios, a preponderance of humic acids in the organic constituents, and remarkably low methoxyl-carbon contents. In these respects, as well as in colour and consistence, they closely resemble the organic horizons which occur in some volcanic ash soils in Japan, but they differ in that they sometimes show both a moderately high pH, and a high content of exchangeable bases. Pollen analysis and examination of occasional plant fragments found in these horizons have shown that the previous plant cover was dominated by bracken-fern (*Pteridium aquilinum* var. *esculentum*). Analyses of this plant and its rhizomes have shown that the chemical properties of these horizons could be largely inherited from this plant, and need not result from severe acid leaching conditions acting over a long period of time, as has been suggested for similar soil horizons in Japan.

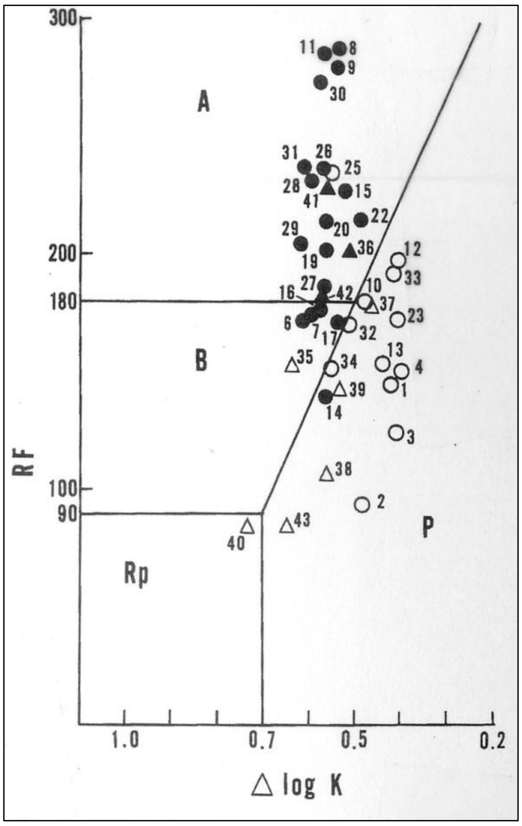
Chemical and Mineralogical Conversion of Andisols following Invasion by Bracken Fern

J. L. Johnson-Maynard,* P. A. McDaniel, D. E. Ferguson, and A. L. Falen

ABSTRACT

Andisols support ≈200 000 ha of mid-elevation grand fir (*Abies grandis* [Dougl. ex D.Don] Lindl.) forests in the Pacific Northwest region that are characterized by little or no natural conifer regeneration following removal of the forest canopy. Previous work suggests that the properties of these Andisols have been altered as a result of the establishment of successional communities dominated by bracken fern (*Pteridium aquilinum* [L.] Kuhn) in deforested areas. In this study, we compared soil properties in a 30-yr-old bracken fern site (clear-cut in 1965), a natural bracken fern site that is estimated to be centuries old, and an adjacent undisturbed forest in the Clearwater National Forest of northern Idaho. Results indicate that changes in chemical properties have accompanied establishment of successional communities. Mean weighted pH within the ash cap of the 30-yr-old bracken fern site (4.6) is significantly lower than that of the undisturbed forest (5.2). Mean values for Al saturation range from 27% in the undisturbed forest to 52% in the 30-yr-old bracken fern site; organic C is also lower in the undisturbed forest (37 g/kg) than in the 30-yr-old bracken fern site (54 g/kg). The dominant secondary mineralogical component of soils of the undisturbed forest is inorganic, short-range-order Al–Fe minerals, while metal–humus complexes are dominant in the bracken-fern-influenced soils. Data indicate that bracken fern successional communities are responsible for a shift from allophanic to nonallophanic properties in these soils, probably due to increased levels of soil organic C associated with bracken fern and a subsequent increase in formation of Al–humus complexes. Furthermore, such a mineralogical shift may contribute to the observed problems with conifer regeneration.

From *Soil Science Society of America Journal* (1997) 61, 549-555.



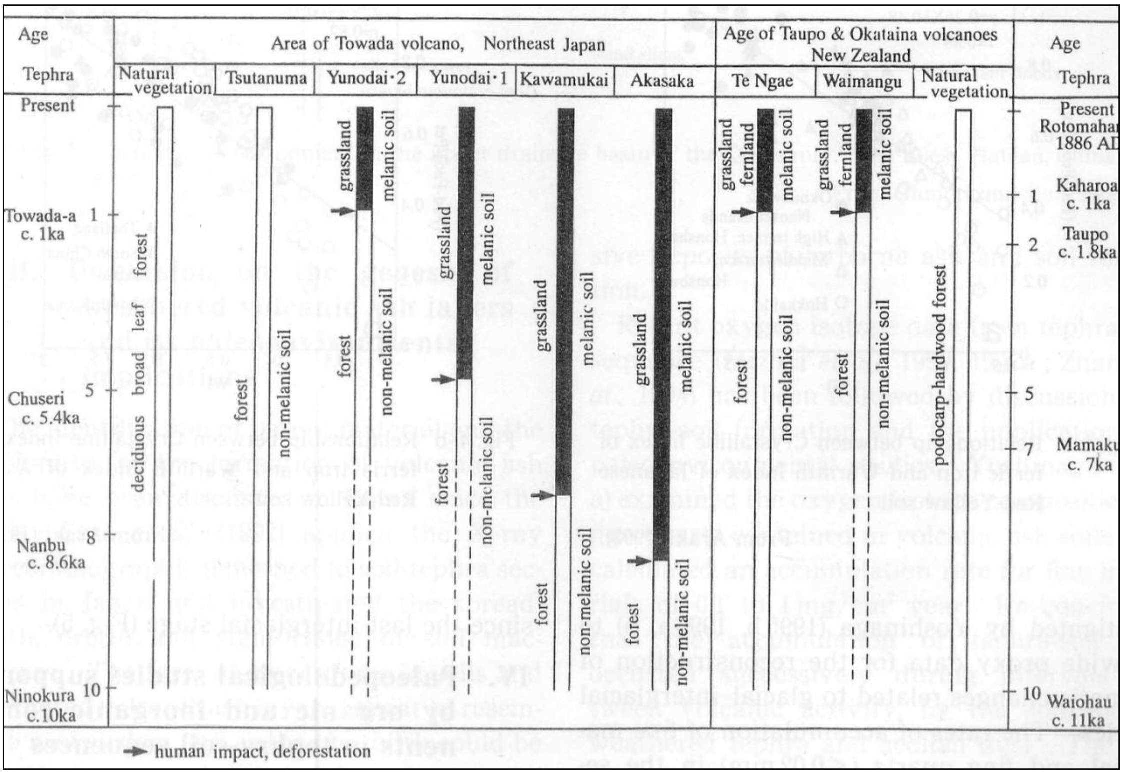
Comparison of humic acids from volcanic ash-derived soils in Japan and New Zealand (from Watanabe and Sakagami,1999)

RF, relative colour intensity
Δlog K, colour coefficient

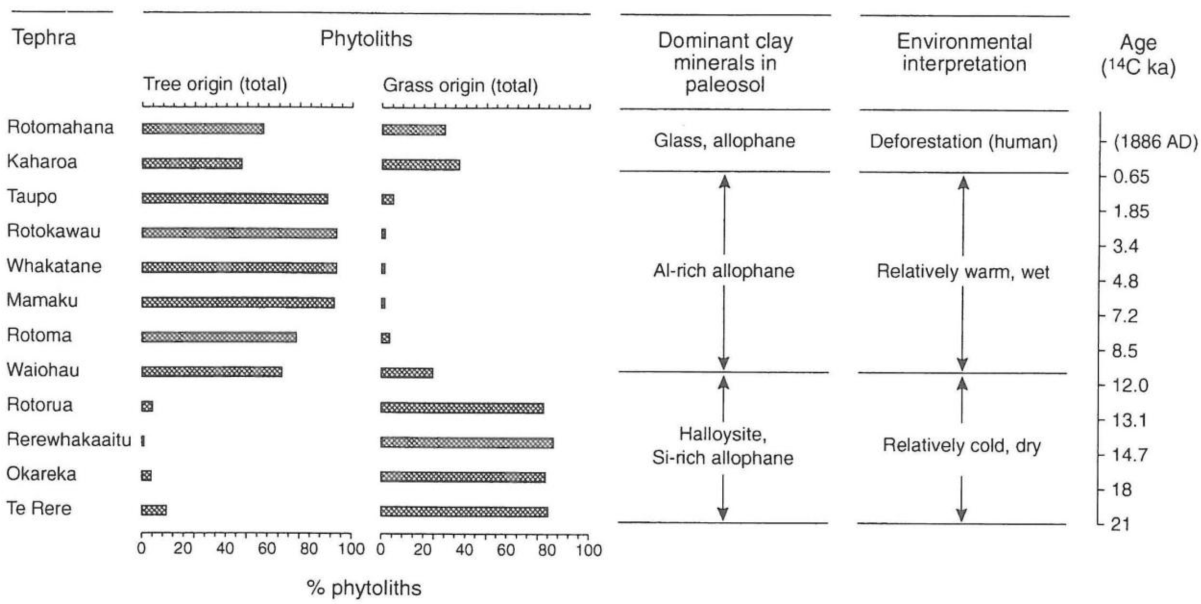
Type A = grassland, fernland (melanic)
Types B, Rp, P = forest

● Melanic soil, Japan
○ Non-melanic soil, Japan

▲ *Melanic-like soil, New Zealand*
Δ *Non-melanic soil, New Zealand*



Relationship between vegetation, tephra age (in ^{14}C ka) and human impact (from Watanabe and Sakagami, 1999 – after Sase and Hosono, 1996). Note dates for initial human impact vary in Japan. Initial settlement of New Zealand occurred between c. 1250-1300 AD, a few decades prior to the Kaharoa eruption.



Evidence of environmental change since c. 25,000 cal. years BP based on phytolith and clay mineral data from analysis of buried soil horizons on rhyolitic tephras at Te Ngae, near Rotorua (from Newnham et al., 1999 – after Green, 1987; Hodder et al., 1990; Sase et al., 1988; Kondo et al., 1994)