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Topsoil inversion as a restoration measure in sand dunes, early results from a UK field-trial

M. Laurence M. Jones · Kim Norman · Peter M. Rhind

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Abstract Over-stabilisation and eutrophication affect many dune systems in north-west Europe. This leads to lower diversity of typical dune species and an accumulation of soil nutrients. Existing management techniques to remove excess nutrients include mowing, with removal of cuttings, and turf stripping. A new restoration technique called topsoil inversion or deep ploughing may also be able to counter some of the negative effects of eutrophication. It simulates the burial of established soils with fresh mineral sand, by inverting the soil profile. A trial was carried out on two small blocks of eutrophic dune grassland in North Wales, UK. Nutrient-rich surface soils were buried beneath mineral sub-sand using a double-bladed plough, designed to plough to depths of up to 100 cm. Results show that the organic soil horizons were buried to a depth of 80 cm, and covered with 40–50 cm of mineral sand. The pH and organic matter of the surface layers became comparable to those of mobile dunes. Fifteen months after ploughing, bare sand cover was still 70–90%, but significant sand loss through wind erosion resulted in a thinning of the mineral sand over-burden, leaving the buried organic layer closer to the surface. Natural vegetation colonisation was slow, with the first surviving plants observed after 8 months. The majority of species present at 15 months were present before ploughing and had regenerated from rhizomes or root fragments. The effect of excluding disturbance caused by rabbits, people and dogs was assessed within fenced areas. After 11 months, vegetation cover was greater in the fenced areas than in plots exposed to disturbance, therefore disturbance replaced physical conditions as the dominant influence on plant growth and establishment. These early results suggest the trial has been partially successful, but that topsoil inversion could be combined with other methods such as turf stripping or by stabilisation of the ploughed surface by planting with pioneer species, depending on the ultimate restoration goal.

Keywords Eutrophication · Deep ploughing · Succession · Colonisation · Grassland · Rabbits

M. L. M. Jones (✉)
Centre for Ecology and Hydrology, Environment Centre Wales, Deiniol Road,
Bangor LL57 2UW North Wales, UK
e-mail: LJ@ceh.ac.uk

K. Norman
BHP Billiton, Field Study Centre,
Unit 1, Station Road, Talacre,
Flintshire CH8 9RD North Wales, UK

P. M. Rhind
Countryside Council for Wales, Maes-y-Ffynnon,
Penrhosgarnedd,
Bangor LL57 2DW North Wales, UK

Introduction

Many dune areas in the UK and in North-West Europe are currently over-stabilised and show low levels of natural mobility (Rhind et al. 2007, Provoost et al. 2009). In an over-stabilised dune system, most of the dunes are covered by well-established grassland or scrub vegetation and areas of bare sand or pioneer vegetation are rare or absent. As a result the land-forms are static, no new features are being formed and existing dunes are not migrating. The situation at Newborough Warren, a large dune system in North Wales, where the amount of mobile and open dunes has declined from 75% in 1951 to less than 6% in 1991 (Rhind et al. 2001) is typical of dunes in much of England and Wales. The over-stabilisation may be a result of many, often co-occurring, factors. These include natural successional development of both vegetation and soils (Jones et al. 2008; Packham and Willis 1997); reductions in managed grazing (Doody 1989); rabbit population crashes due to disease; application of conservation measures such as erection of fences, planting *Ammophila*, and laying of brash to prevent disturbance (Ranwell and Boar 1986); artificial stabilisation of the leading dunes for sea defence measures (Westhoff 1989); changing climatic conditions reducing natural mobility (Arens et al. 2004; Arens and Geelen 2006; Hugenholtz and Wolfe 2005; Jones et al. 2009); and nutrient enrichment from a range of sources including atmospheric deposition (Jones et al. 2004; Kooijman et al. 1998), groundwater (Jones et al. 2006; Stuyfzand 1993; van Dijk 1989) and localised enrichment from nitrogen-fixers (Stewart and Pearson 1967; Stuyfzand 1993). Land management practices such as agricultural improvement have also historically been practiced on some hind-dune areas, and these are sometimes incorporated within designated sand dune nature reserves or protected sites, leading to inherited eutrophication problems. Irrespective of the source of nutrients, eutrophication raises issues for the maintenance of typical sand dune habitats which are naturally nutrient-poor (Willis and Yemm 1961). Eutrophication can adversely impact many parts of the system. Evidence suggests that nutrients from atmospheric deposition increase the growth of graminoids and nitrophilous species, reducing plant diversity (Jones et al. 2004; Kooijman et al. 1998; Plassmann et al., 2009; Remke et al. 2009, van den Berg et al., 2005). Soil characteristics such as C:N ratio and available nitrogen can be altered (Jones et al. 2004), and N deposition may be one factor accelerating soil development in dunes (Jones et al. 2008). In the long-term, soil N enrichment leads to increased vegetation growth with typical dune species outcompeted by faster growing nitrophiles resulting in loss of diversity and conservation value.

Removing soil nutrients is a pre-requisite for restoration of infertile habitats on eutrophic soils (Bradshaw 1996; Marrs and Gough 1989). However, there are relatively few techniques available for managing eutrophication. Adverse effects on vegetation composition can be countered by managed grazing which keeps fast-growing species in check and allows light-dependent species to persist. However, grazing itself does not remove nutrients from low fertility systems (Perkins 1978). Supplementary winter feeding of stock may even exacerbate the problems by introducing extra nutrients in the fodder material. Mowing does remove nutrients, but only if cuttings are removed from site or burnt (Bakker et al. 2002). Removal of dung is possible, but is labour-intensive. Chemical remediation is possible in some soils (Marrs 2002). In dune systems, remobilisation or re-creating earlier successional stages is another way to remove nutrients. Large scale remobilisation schemes have, for example, been conducted in the Netherlands (Arens et al. 2004; Arens and Geelen 2006). However, in the UK there has been little demand among site managers for similar action. Furthermore public perception, encouraged by decades of conservation effort aimed at preventing disturbance, sees mobility as undesirable. Such schemes are also limited by the small size of many UK sand dune sites or their proximity to urbanised areas. Therefore, the potential for large-scale destabilisation in the UK is limited and disturbance techniques such as turf stripping, also called sod cutting, have so far been applied on a smaller scale—typically less than 0.5 ha. Turf stripping has been practiced extensively in the Netherlands, primarily as a dune slack restoration tool (Grootjans et al. 2001; Grootjans et al. 2002), and in restoration of other habitats in Europe including saltmarsh, heathlands and wet meadows (Allison and Ausden 2004; Tallowin and Smith 2001). Turf-stripping is efficient but time-consuming and requires somewhere, usually off-site, to dump the stripped material, making stripping of large areas expensive. An alternative is to bury the nutrients *in-situ*, which is the approach taken with topsoil inversion.

Topsoil inversion, also called deep ploughing, is a technique developed in Denmark in the 1990s where it was originally used in forestry planting to bury the weed seedbank and suppress competition for newly planted trees (Matthesen and Damgaard 1997). Since then its use has widened into the area of conservation management principally in the restoration of sites impacted by eutrophication. The basic principle is to invert the soil profile to a target depth of up to 100 cm so that nutrient-rich surface soil together with the unwanted seedbank is buried under infertile mineral sub-soil. Similar techniques have been used recently, described variously as deep-cultivation, to 40 cm (Pywell et al. 2002), or deep-ploughing, to 30 cm (Allison and Ausden 2004). However, topsoil inversion as described above operates to a greater depth, typically 50–70 cm or deeper, and is considered a different technique (Glen 2008). In dunes it can be seen as simulating rapid burial of a soil surface by blown sand. It differs from the natural process in that the existing soil profile is inverted rather than buried. Therefore, in common with other mechanical techniques such as turf-stripping and re-profiling of dune slacks it alters the soil horizon structure and may damage features of archaeological or geomorphological interest. It is potentially a useful technique in over-stabilised systems where natural burial by sand is unlikely to occur and is an alternative to large-scale destabilisation of natural dune features which may not be appropriate on small sites, or those close to built-up areas.

The vegetation re-colonisation of disturbed bare sand is governed by physical and chemical soil characteristics, availability of propagules, and is also influenced by disturbance (Packham and Willis 1997). Despite regular outbreaks of