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Eco-hydrological requirements of dune slack vegetation and the implications of climate change

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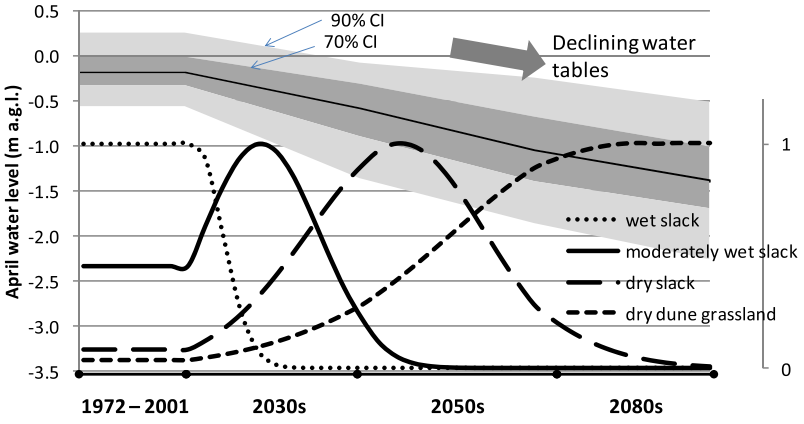
HIGHLIGHTS

- Eco-hydrological requirements of UK dune slack communities have been quantified.
- Only 40 cm separated minimum water levels of the wettest and driest communities.
- Declining water tables under climate change pose a serious threat to dune slacks.

GRAPHICAL ABSTRACT



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ABSTRACT

Dune slacks are a seasonal coastal wetland habitat, whose plant assemblages and soil properties are strongly linked to a fluctuating water table. Climate change is predicted to cause major shifts in sand dune hydrological regimes, yet we know remarkably little about the tolerance of these communities to change, and their precise hydrological requirements are poorly quantified. Dune slack vegetation and soils were sampled within five vegetation types across four west coast UK sites. Relationships between vegetation assemblages, and parameters of soil development (moisture, loss on ignition, pH, KCl extractable ions) and groundwater hydrological regime (annual maximum and minimum water levels and range, duration of flooding) were established to define the environmental tolerances of different communities. In multivariate analysis of the vegetation, the dominant gradient was hydrological: dry to wet, followed by a secondary soil development gradient: young calcareous organic-poor soils to acidic/neutral soils with greater organic matter contents. Most measured hydrological and soil variables explained a significant proportion of observed variation in species composition when tested individually, with the exception of soil nitrate and soil calcium concentrations. Maximum water level was the key hydrological variable, and soil moisture and soil pH were the key soil

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variables. All hydrological and soil parameters together explained 22.5% of the total species variation. There were significant differences in hydrological and soil parameters between community types, with only 40 cm difference in mean annual minimum water levels (averaged over 4 years) separating the wettest and the driest dune slack communities. Therefore, predicted declines in water level exceeding 100 cm by 2080 are likely to have a major impact on the vegetation of these priority conservation habitats.

1. Introduction

Sand dunes are rich in biodiversity due to the heterogeneity of habitat niches, and have both considerable amenity value and a strategic function as coastal defence (e.g. Everard et al., 2010; Jones et al., 2011; Louisse and van der Meulen, 1991). Dune slacks are seasonally flooded humid depressions between dune ridges, and are a priority habitat for rare species of conservation importance, including orchids such as *Liparis loeselii*, *Dactylorhiza praetermissa* and *Dactylorhiza purpurella*, lower plants like *Petalophyllum ralfsii*, a liverwort listed in Annex II of the European Union Habitats Directive, and amphibians like *Epidalea calamita* which breed in temporary pools (Smith, 2006). Many of these species are restricted to pioneer or successionally young vegetation communities (Davy et al., 2006; Rhind and Jones, 1999; Sival et al., 1998) where competition is low.

Dune slacks form when bare sand is disconnected from seawater influence by the establishment of a new dune front, or inland, where wind erosion scours bare sand down to the water table or to the capillary wetted layer (Ranwell, 1960). Thus their formation and subsequent plant and soil development are intimately connected to the dune groundwater hydrological regimes. Large water table fluctuations are a feature of most slacks, and control slack vegetation development. Variation of water levels occurs both within the year, typically around 70 cm with a rapid rise in autumn and a gradual decrease from spring to summer (Ranwell, 1959) and between years, depending on precipitation and evapotranspiration balances (Ranwell, 1959).

Winter flooding, intensity of drought and persistence of waterlogging in the rooting zone during the growing season are key environmental factors affecting vegetation, through impacts on germination and productivity (Ernst, 1990; Grootjans et al., 1998). The timing and duration of these events can alter inter/intraspecific competition, thus changing community composition (Bossuyt et al., 2003, 2005). Groundwater fluctuations also control nutrient status: high water levels in slacks reduce the mineralisation of organic matter, maintaining low nitrogen and phosphorus levels (Lammerts and Grootjans, 1997). The chemistry of groundwater is important, and can vary considerably across a site (Jones et al., 2006). In older de-calcified dune slacks, buffering action of carbonate-rich groundwater allows the survival of basiphilous wetland plants (Grootjans et al., 1988, 1991; Sival et al., 1998; Van Dijk and Grootjans, 1993).

Most authors agree that species distribution and community structure across slacks are highly correlated with groundwater levels (Grootjans et al., 1991, 1998; Jones and Etherington, 1971; Lammerts & Grootjans, 1998; Lammerts et al., 2001; Noest, 1994; Olff et al., 1993; Ranwell, 1960; Sival et al., 1998; Van der Laan, 1979; Willis et al., 1959). The differentiation as wet or dry slacks and the hydrological characteristics of different communities are well understood by ecologists (e.g. Rodwell, 2000). Yet, despite this, the precise eco-hydrological requirements of these communities are poorly, if at all, quantified in the UK. In The Netherlands there is a wealth of ecohydrological knowledge on dune slacks (e.g. Witte et al., 2007; von Asmuth et al., 2012), but slacks in the UK differ somewhat from those on the continent. In general they experience higher rainfall, they are often present on narrower dune sites with greater potential for groundwater influence from inland. In the majority of west coast sites, the sand parent material is usually more calcareous, resulting in highly buffered systems with slower decalcification rates, despite the higher rainfall. However, in north UK, slacks can be less well buffered and higher rainfall leads to decalcification of surface soils and rapid organic matter accumulation.

Previous attempts to define eco-hydrological requirements for UK dune slack communities have been based on relatively small numbers of combined vegetation and hydrology records (Ranwell, 1959), and conducted at single sites (Jones, 1993; Ranwell, 1959). A further failing is the short duration of hydrological records considered: 2 years or less, with little understanding of longer term hydrological variability and whether the vegetation is in equilibrium with hydrological conditions (Davy et al., 2010).

Dune slack habitats worldwide are under increasing anthropic pressure from water abstraction, afforestation, urbanisation (Grootjans et al., 1998; Martinez et al., 2004; Provoost et al., 2011), nitrogen deposition (Jones et al., 2004; Plassmann et al., 2008; Sival and Strijkstra-Kalk, 1999) and from grass and scrub encroachment or exotic species invasion (Martinez et al., 2004). In addition, changes in evapotranspiration due to vegetation change or management will affect the water balance (Davy et al., 2010; Ford et al., 2012). An emerging threat is climate change, which may shift the biogeographical range of dune slack species, but which also alters the dune environment. Changes in precipitation and temperature affect groundwater levels directly by altering the delicate balance between rainfall and evapotranspiration which controls recharge. Sea-level rise or shoreline erosion act indirectly on groundwater levels by altering water table gradients (Clarke and Sanitwong Na Ayutthaya, 2010; Saye and Pye, 2007). Modelling of groundwater trends for dune slacks in a sand dune system in northwest England based on long term records, predicted a substantial lowering of water levels of 1 to 3 m over the next 90 years (Clarke and Sanitwong Na Ayutthaya, 2010). Physiological adaptations typical of plants growing on humid calcareous substrates can make them less resilient to rapid habitat changes (Bakker et al., 2007; Grootjans et al., 2004; Schat, 1984) and the rapidity of community shifts in response to variations of groundwater regime is difficult to estimate (Noest, 1994; Van der Laan, 1979). The predicted changes in water levels are so large that major changes in slack vegetation are probable, but the outcomes will remain uncertain until we better understand the hydrological requirements of these vegetation communities.

The aim of this investigation was therefore to improve our understanding of the relationships between dune slack vegetation communities and the underlying hydrological and biogeochemical controls, across a range of west coast UK sites, through the following steps:

1. Creating a network of co-located vegetation and hydrological monitoring locations, maximising the use of previously unconnected long-term vegetation or hydrological data records.
2. Using multivariate analysis to determine the principal environmental parameters governing species assemblages in sampled dune slack communities.
3. Using hydrological data from a reasonably climatically stable four year period, to characterise the hydrological and environmental requirements of each community type.
4. Interpreting those requirements in the light of predicted climate change impacts on dune groundwater regimes.

Using this information, the following specific questions were postulated. Can vegetation communities be distinguished according to hydrological regime? Are projected changes in groundwater regime likely to have serious consequences for current dune slack assemblages?