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Quantifying the hydrological requirements of plants as a tool for the water management of wet grassland

Abstract

The distribution of plants within lowland wet grasslands is largely determined by small variations in the water-table regime. It is therefore necessary to understand the water requirements of individual species in order to manage wet grasslands most effectively. Little quantitative data is available on the water requirements of wild plant species. Silsoe College has developed a system of using existing ditch-drained wetlands as an infinite set of natural lysimeters and combining these with a hydrological model to quantify the water-table regime experienced by each plant species present.

A threshold analysis technique is used to interpret the levels of aeration and drought stress experienced at each position within the field. This is compared with the plant distribution to enable the conditions required by each plant to be quantified.

Results from trial sites in England show that plant distribution patterns strongly correlate with water regimes, thus indicating this technique to be valid. The work is currently being extended to cover a wider range of sites on different soil types and in different climatic areas to create a more comprehensive data set.

Knowledge of the water regime tolerance levels for each plant can be used in several ways to improve wet grassland management. It can help predict the likely outcome of a change in the water management of an area or it can aid the active management of a site with the aim of conserving a specified plant community.

Key words: wet grassland, water regime, hydrological model.

Introduction

Water table regime is probably the single most important environmental factor influencing the distribution of plants within groundwater-fed, lowland wet grasslands. Other significant factors, including nutrient availability and surface management, also tend to be heavily influenced by water table regime. Management of grasslands to maintain and enhance their species diversity therefore necessitates a quantitative knowledge of plant water regime requirements. Ellenberg (1988) ranks central European plant species for their tolerance of soil moisture on an arbitrary scale but no quantitative dataset exists.

Silsoe College has attempted to quantify the hydrological requirements of plants by modelling the hydrology of ditch-drained, species-rich meadows and matching this with the results from a detailed survey of the vegetation in these fields. The trial sites used are located in the west of England on the Somerset Moors. Initially two trial sites have been investigated, Tadham Moor and West Sedgemoor. These sites both contain approximately flat, ditch-bound fields where the plant communities have reached near equilibrium position with respect to water regime. Each field contains a variety of water regimes due to microtopographic and seepage potential variations. This allows the different regimes to be correlated with the distribution of the plant species. The soils investigated so far are deep peat overlying clay. Current work will extend the database to cover a much broader range of climatic areas and soil types.

Hydrological modelling

Controlled environment methods for measuring plant water requirements were investigated by Silsoe College (Gowing *et al.* 1994) but it was considered that the effects of competition between species could not be taken fully into account using artificial lysimeters. This problem was surmounted by studying the plants in their natural environment. Quadrats of $1 m^2$ were positioned randomly throughout the field sites and every species that occurred in each quadrat was recorded. A total of 1500 quadrats have be studied. The hydrological models suggested by Youngs (1989 & 1991) in conjunction with historical data, were used to ascertain the water table depth and shape beneath each field. This model has so far only been validated for relatively flat ditch-drained land on peat. The exact elevation of each quadrat was measured so that the water table under each quadrat could be calculated, hence each quadrat could be used as a natural lysimeter.

Threshold analysis approach

A threshold analysis technique was used to convert the water table regime of each quadrat into two values, one representing the degree of flooding and one representing the degree of drought. Plants undergo aeration and drought stress when the water table moves above and below critical levels. The threshold for drought stress is taken as the water table depth below which soil surface evaporation is limited by soil unsaturated hydraulic conductivity. Henson *et al.* (1989) showed that plants respond to soil moisture tensions of greater than 0.5 m. The Gardner equation (Gardner 1958) can be used to calculate the threshold depth for drought stress given a surface tension of 0.5 m. In this instance the drought thresholds of the field sites are 0.44 m and 0.47 m for Tadham Moor and West Sedgemoor respectively.

The threshold for aeration stress is taken as the water table depth above which the surface soil layers would be near to saturation due to capillary rise, thus excluding oxygen from plant roots. Wesseling and van Wijk (1957) showed that at least 10% air-filled porosity is needed for free oxygen diffusion to occur during periods of rapid plant growth. This translates to tensions of around 0.4 m in peat and hence the threshold for flood stress can be calculated in the same way as drought threshold. The values for the field sites are 0.39 m and 0.42 m for

Tadham Moor and West Sedgemoor respectively.

For each quadrat site the number of weeks that each threshold was exceeded was calculated and multiplied by the mean value of the exceedance. This then gives a measure, in units of metre.weeks, of the susceptibility of each quadrat site to flooding and drought. This is termed the quadrat's Sum Exceedance Value (SEV). The technique was originally devised by Seiben (1965).

The quadrat sites were then ranked for each threshold in ascending order of SEV. The 50 lowest aeration SEVs form a subgroup. The number of quadrat sites within this subgroup in which a certain species occurs divided by 50 gives the observed frequency. The expected frequency is the total number of quadrat sites in which this species occurs divided by the total number of quadrat sites. The relative frequency is given as follows:

$$\text{Relative frequency} = \frac{\text{observed frequency}}{\text{expected frequency}}$$

If the SEV were having no effect on the distribution of species then relative frequency should be unity for all SEVs, however, if the species under investigation showed a preference for a low aeration SEV then its relative frequency should have a value greater than unity. Similarly if the species avoided quadrats of low aeration SEV then its relative frequency should have a value less than unity. Relative frequency is calculated for each sequential subgroup of 50 and then plotted against the mean SEV for that subgroup. Figure 1 shows how aeration SEV affects the distribution of *Agrostis capillaris* L. 95% confidence limits are also shown calculated using the κ^2 test. The sharp transition from "preferred" SEVs to "avoided" SEVs suggests that SEV is ac-

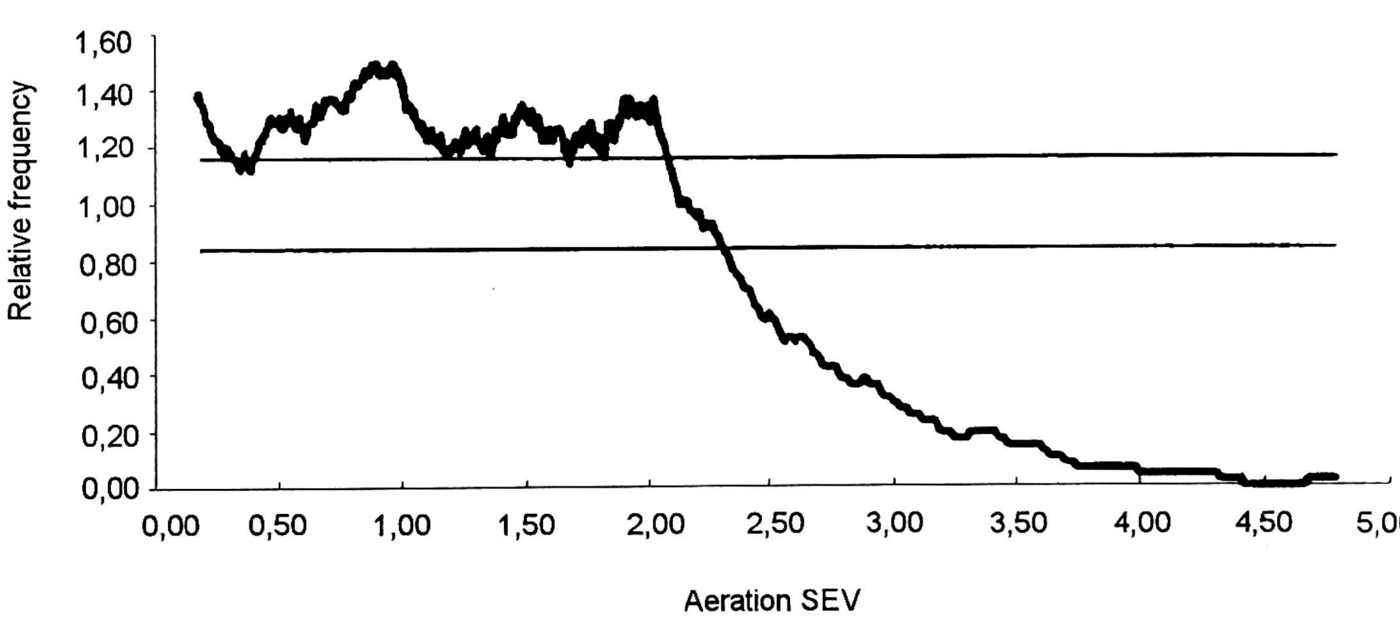

FIGURE 1. A plot relative frequency of *Agrostis capillaris* against a measure of aeration stress
The horizontal lines define the 95% confidence interval for the „expected" value of unity

tually quantifying a real variable in terms of plant requirements.

This procedure was repeated for both drought and aeration SEV for each species that was observed in more than 60 quadrats.

Discussion

Figures 1 and 2 show how the distribution of *Agrostis capillaris* is affected by both drought SEV and aeration SEV. It is important to consider both drought stress and flood stress when studying the tolerances of plants since plants show different physiological adaptations to each of these. Ellenberg only assigns one value to each species and figure 3 shows how this value relates to drought SEV for a group of wet grassland plants. The species are listed in descending order of Ellenberg F value. The preferred range shown for each species is the range of drought SEVs for which it has a relative frequency greater than the 95% confidence limits for unity. The tolerated range is that for which the relative frequency for each species is greater than the 95% confidence limits for less than unity. It can be seen that the preferred range of drought SEVs for each species approximately follows the same trend as the Ellenberg F values.

Application

The plant SEV database could be utilised as an aid to managing land to benefit nature conservation. It is possible for a land manager to identify the type of vegetation community that he or she would like to conserve at a site. The SEVs of the constituent species can then be found and a hydrological regime designed for the site that matches the requirements of the community as a whole. Another use for this database is as a predictive tool. If the hydrology of a site is going to be altered, the expected hydrological regime could be modelled to find out what the anticipated SEVs of each part of the site would be. By studying the SEV database it could

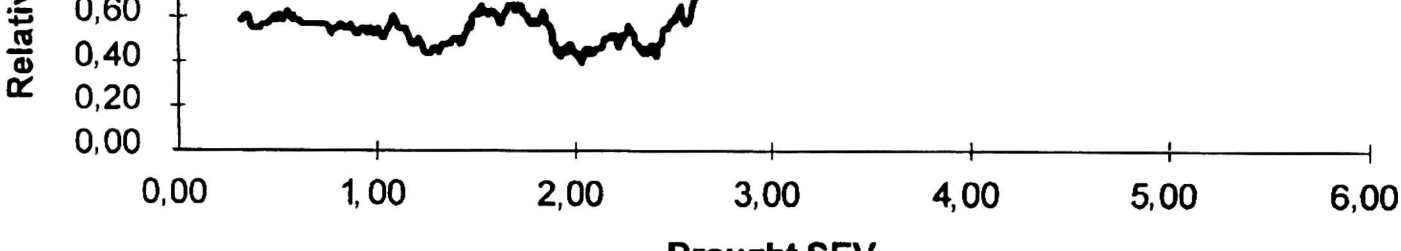

FIGURE 2. A plot of relative frequency of *Agrostis capillaris* against a measure of drought stress The horizontal lines define the 95% confidence interval for the „expected" value of unity

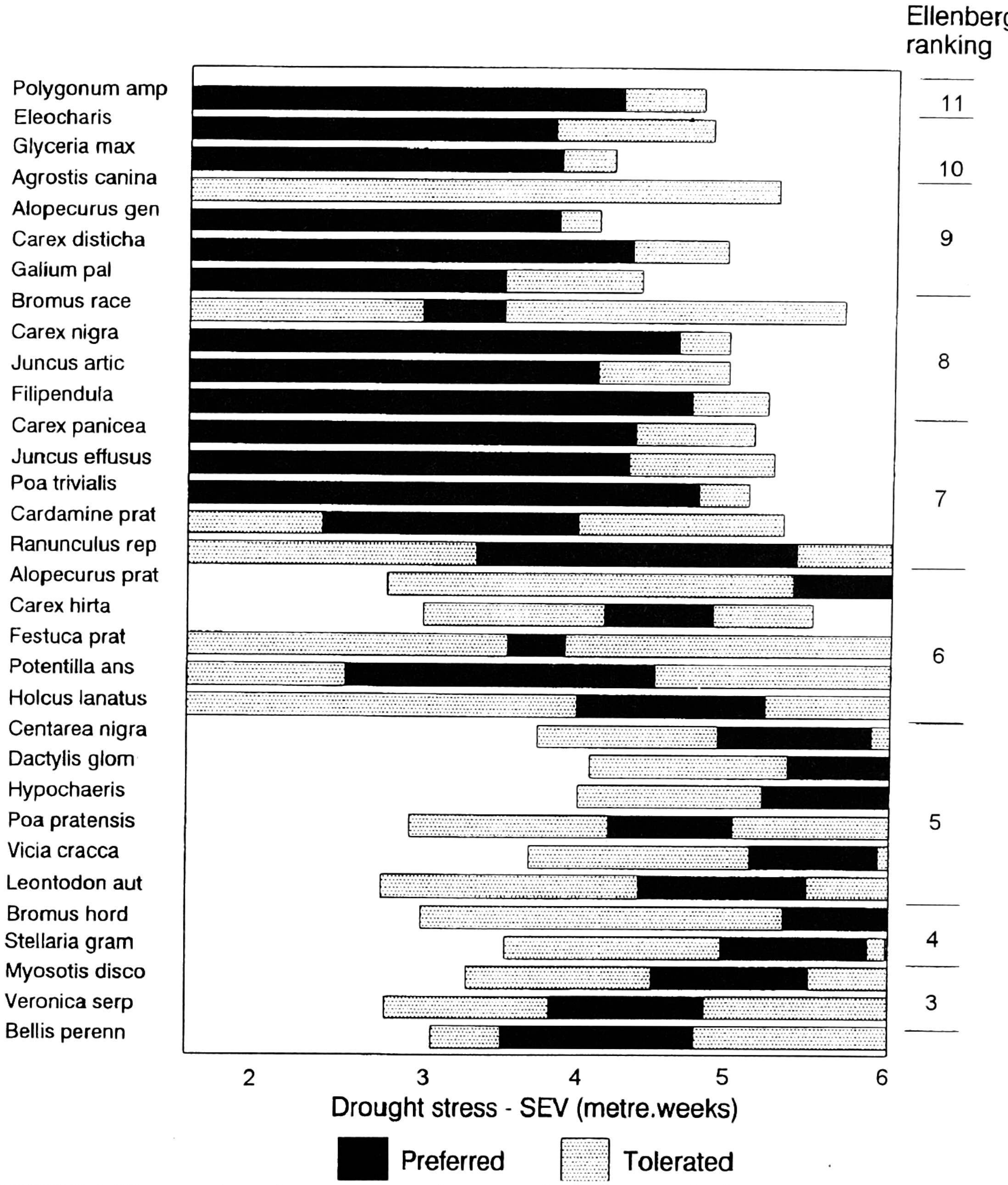

FIGURE 3. Water remige tolerance ranges of wet grassland plant species in Somerset

be seen which species one might expect to loose from a site and which species might be expected to colonise, assuming that there were a local source of propagules. The SEVs of wild plant species could also be compared with the requirements of pastoral agriculture to find a hydrological regime that can satisfy the needs of both and thus enable farms to remain productive whilst retaining some value to nature conservation.

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