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Recording relative water table depth using PVC tape discolouration: Advantages and constraints in fens

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Abstract

Question: Recognizing water table dynamics in wetlands is crucial for understanding species-environment relationships, ecosystem function and changes during restoration. The PVC tape discolouration method enables spatially and temporally extensive studies of reductive conditions associated with long-term water table dynamics in peat soils. The reliability of the method has been verified only for ombrotrophic bogs, even though wide usage can be expected in minerotrophic fens.

Location: Třeboň basin, Czech Republic.

Methods: Using data from 49 plots in six poor and moderately rich fens, we correlated the directly measured lowest, highest and mean water table depths and the same variables indicated by discolouration of PVC tape attached to green bamboo stakes installed vertically in the soil profile.

Results: The depth to the first sign of PVC discolouration was highly correlated with the directly measured position of the highest water table, the correlation between the depth of complete discolouration and the directly measured position of the lowest water table was poorer. The accuracy of the minimum water table measurement depended on the depth of the peat layer. Surprisingly, the depth at which the green bamboo stakes turned brown correlated highly with the minimum water table.

Conclusions: The PVC tape discolouration method reliably indicates water table maxima in fens, but minima are not accurately indicated. The depth of the green bamboo discolouration is suggested as a new alternative indicator of the minimum water table, even in fens and mineral soils. Combining both methods enables efficient monitoring of water table dynamics at a large number of mire sites.

Keywords: Monitoring; Peat hydrology; Redox; Water level; Wetland.

Nomenclature: Kubát et al. (2002) for vascular plants; Kučera & Váňa (2003) for bryophytes.

Abbreviations: HV = Height of vegetation; MWT = Mean water table; WTD = Water table depth.

Introduction

Water table depth is one of the major factors influencing the composition of mire vegetation. Knowledge of wetland hydrology is essential to understanding, quantifying and evaluating wetland functions and processes (Koerselman 1989; Bragg 2002). Water table level and water quality play important roles in determining the composition of mire vegetation (Bragazza 1997; Asada 2002; Tahvanainen et al. 2002; Hájková & Hájek 2004a). The scarcity of ecological studies dealing with water level dynamics of a large area across multiple vegetation types and climatic regions is caused, in part, by the logistical complexity and large demands on time and finances of such studies. Therefore, inexpensive, flexible, indirect methods of measuring water table levels would be valuable. The PVC tape discolouration method, developed by Belyea (1999) and further used by Hájková & Hájek (2004a), meets these requirements. It allows reducing conditions connected to long-term water table dynamics to be recorded in peat soils.

The method is based on the premise that reducing conditions cause discolouration of PVC, which incorporates metal ions (Clymo 1965; Bragazza 1996). As reducing conditions are often highly correlated with water table depth in mires (Belyea 1996; de Mars & Wassen 1999; Seybold et al. 2002), the discolouration of PVC can indirectly indicate basic characteristics of the water regime. Because it makes efficient use of time and money, the PVC tape discolouration method could potentially become widespread in basic and applied mire ecology, especially for spatially and temporally extensive studies of many sites. However, the reliability of the method has only been verified for bogs in south-western Scotland (Belyea 1999). There is no evidence to verify the application of this method in minerotrophic fens, which contrast ecologically with ombrotrophic bogs (Wheeler & Proctor 2000; Hájková & Hájek 2004b). The aim of this study is to verify the applicability of the PVC tape discolouration method in minerotrophic fens.

Material and methods

Study site

Six locations were chosen to observe the spatial variation of water level and water chemistry in fens; the fishponds Kukla (48°57'20" N, 14°53'23" E), Příbrazský (49°02'15" N, 14°56'14' 'E), Staré jezero (48°58'43" N, 14°53'52" E), Starý Vdovec (49°02'22"N, 14°50'12" E), Velká Lásenice (49°03'11" N, 14°57'44" E) and Vizír (48°57'43"N, 14°53'19"E). The study fens are located in the Třeboň basin area, South Bohemia, Czech Republic. The climate is temperate with a mean annual temperature of 7.8 °C, a mean temperature of the coldest month (January) of –2.2 °C, a mean temperature of the warmest month (July) of 17.7 °C and a mean annual rainfall of 627 mm (Vesecký 1961). Fens around the fishponds are characterized by a well-developed peat layer spread over sandy deposits. The depth of the peat ranges from 10 cm to a few meters. Three main vegetation types were studied: (1) poor fens dominated by *Carex rostrata*, *Eriophorum angustifolium*, *Sphagnum papillosum* and *S. fallax* with *Drosera rotundifolia* and *Oxycoccus palustris*, (2) moderately rich fens with high frequencies of *Carex lasiocarpa*, *C. nigra*, *Oxycoccus palustris* and *Potentilla palustris* in the herb layer and *Warnstorfia exannulata*, *Hamatocaulis vernicosus, Sphagnum subsecundum*, *S. contortum* and *S. palustre* in the moss layer. There is also vegetation dominated by tall sedges (commonly *Carex acuta*, *C. elata* and *C. lasiocarpa*, often accompanied by *Lysimachia thyrsiflora* and *Calliergonella cuspidata*) and (3) flooded fen habitats, which could be further divided into flooded sandy deposits with *Utricularia* species and successionally advanced quaking fens with initial production of peat dominated by *Rhynchospora alba*, *Sphagnum denticulatum* and *Juncus bulbosus*.

Vegetation data sampling

To verify the applicability of the PVC tape discolouration method in minerotrophic fens, we established 49 permanent plots in the six localities described above. Species composition was recorded during the summer of 2003 at each site in 1-m^2 plots. The cover of both vascular plants and bryophytes was recorded using the nine-grade van der Maarel (1979) scale. The height of the vegetation cover was measured to approximate the productivity of the vegetation.

Water level recording

The water table depth was measured in perforated PVC tubes at 20-day intervals from March to October 2003. A strip of red PVC electric insulating tape (RS Components Ltd, Corby, UK) attached lengthwise to a fresh bamboo stake, was installed vertically near each tube following the method described by Belyea (1999). The PVC strips were installed in March and recovered in October 2003. This interval corresponds to the growing season in central Europe when the water regime has the greatest influence on peat vegetation. After recovery, the colour of the strips was compared subjectively with a common standard (fresh tape and fully discoloured tape). The discolouration of green bamboo stakes (interface between the green lower part and the browned upper part) was also recorded. Seven plots were not included in the analysis of water table minima, because the water table fell below the bottom of the PVC tubes.

The depth of unmineralized organic peat was recorded in each sampling plot with a soil probe. Water pH was measured *in situ* using portable instruments (PH 114, Snail Instruments, Czech Republic).

Data processing

Means, minima and maxima of water level, pH and mean values of vegetation height and peat depth were measured. Vegetation data were subjected to Detrended Correspondence Analysis (DCA) with downweighting of rare species (ter Braak & Šmilauer 1998). Ordination site scores were correlated with environmental factors using Pearson's correlation coefficient. Six environmental variables displaying the most significant correlation with the ordination axes were plotted onto DCA ordination diagram as supplementary environmental data for better ecological interpretation of the axes.

The discoloured PVC tapes and bamboo stakes were described in terms of (1) depth to first sign of discolouration, presumably indicating the depth to the highest water table and (2) depth to complete discolouration, presumably indicating the lowest water table. These values and the directly measured depths of lowest and highest water table levels were plotted on a scatter graph. A linear regression was fitted and Pearson's correlation coefficient was calculated. The 'ideal' line corresponding to absolute agreement between directly and indirectly measured variables was also entered on the graphs (Fig. 1).

Results

Analysis of PVC tape showed that the depth to the first sign of discolouration was highly correlated ($r = 0.97$; $p < 0.001$) with the directly measured position of the highest water table (Fig. 1a). The deviation of measurement was within 3 cm. However, systematic bias was pronounced for flooded habitats, where the first sign of discolouration was always several centimetres below the directly measured water table (Table 1).

Correlation between the depth of complete discolouration of PVC tape and the directly measured position of the lowest water table (Fig. 1b) was poorer ($r = 0.77$; $p < 0.001$). In all cases, the tape was

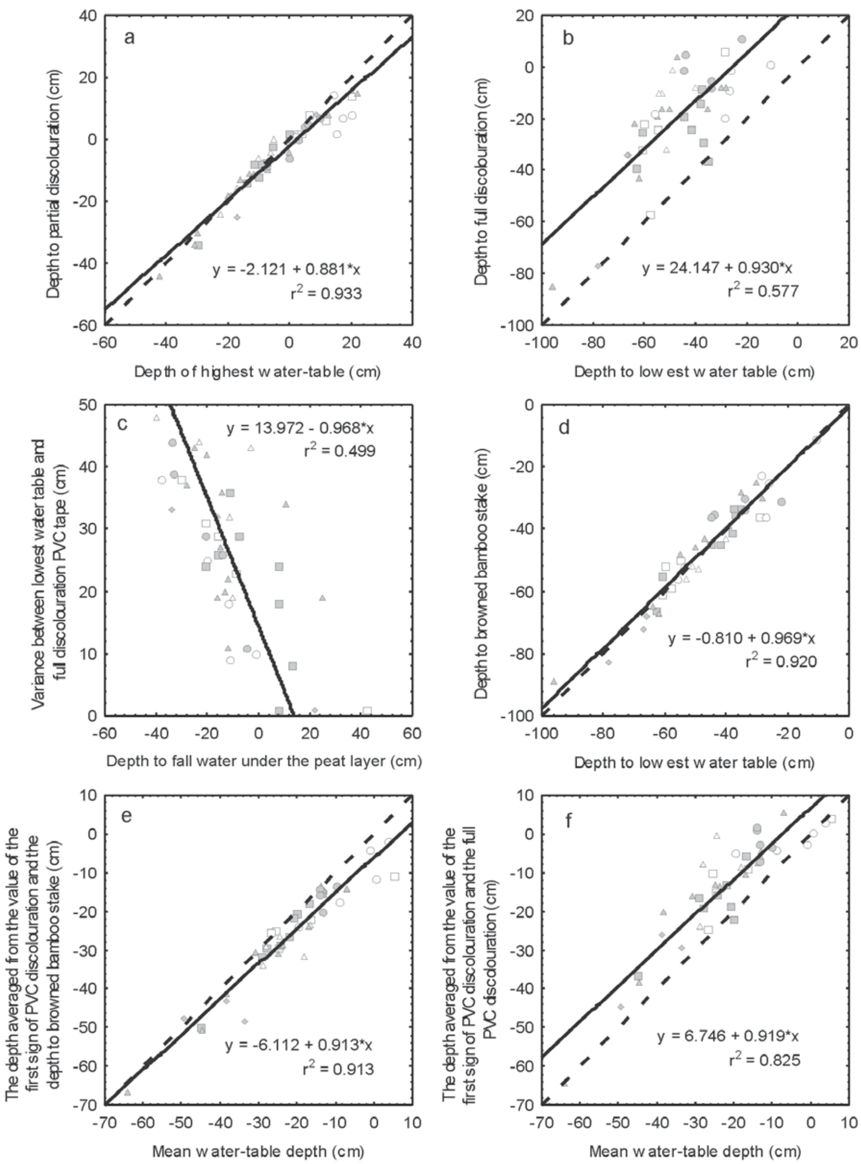

Fig. 1. Indirectly recorded variables (discolouration of PVC or green bamboo) plotted against the directly measured water level. A linear regression (significant at $P < 0.001$) is shown as a solid line; the dashed line indicates potential absolute agreement between directly and indirectly measured variables. Depths are relative to the moss or bare surface level: (**a**) depth to first sign of PVC discolouration compared with directly measured depth to highest water table; (**b**) depth to complete PVC discolouration compared with directly measured depth to lowest water table; (**c**) disagreement between the lowest water table and the full discolouration of PVC tape compared with the depth of the water level below the peat layer; (**d**) depth to green bamboo stake compared with directly measured depth of lowest water table; (**e**) mean value of the first sign of PVC discolouration and the full PVC discolouration compared with the mean water table; (**f**) mean value of the first sign of PVC discolouration and the depth to browned bamboo stake compared with the mean water table. Vegetation types: (1) △ = *Sphagnum palustre* poor fen, ▲ = *Sphagnum fallax* poor fen, ◆ = *Polytrichum commune* poor fen; (2) □ = tall sedges; ■ = medium-rich fen; (3) ○= *Utricularia* fen, ● = *Rhynchospora alba* community.

Table 1. Comparison of regressions and Pearson's correlation coefficients (in brackets) with respect to the response of PVC tape/bamboo discolouration to water level among three vegetation types. MWT = Mean water table.

Vegetation type:	Poor fens	Moderately rich fens	Flooded fens
First sign of PVC discolouration – highest water table	0.938 (0.98)	0.927 (0.97)	0.561 (0.71)
Full PVC discolouration – lowest water table	1.193 (0.84)	0.735 (0.58)	0.259 (0.35) n.s.
Browned bamboo stake – lowest water table	1.027 (0.97)	0.858 (0.93)	0.779 (0.87)
Mean of first sign of PVC and full PVC discolouration – MWT	1.113 (0.94)	0.773 (0.87)	0.201 (0.47) n.s.
Mean of first sign of PVC discolouration and depth to browned bamboo stake – MWT	0.949 (0.96)	0.756 (0.92)	0.766 (0.88)

completely discoloured at a higher level than the directly measured water table depth. This disagreement was more pronounced when the water table had fallen below the peat layer (Fig. 1c). The depth to which the water level fell below the peat layer correlated significantly with the disagreement between the directly and indirectly measured lowest water table. We conclude that the recording of lowest water levels using PVC tape is unreliable in fens, especially in shallow peat which is low in organic matter. The green bamboo stakes consistently changed colour to dark brown above the lowest water level. The lower part remained green. The correlation between the directly measured lowest water table and the same variable indicated by green bamboo discolouration was highly significant ($r = 0.96$; $p < 0.001$). The mean deviation of this indirect measurement was 4 cm, and the linear regression was very close to the 'ideal' line (Fig. 1d).

Measured mean water table correlated significantly ($r = 0.96$; $p < 0.001$) with the depth calculated from the level of the first PVC tape discolouration and the depth to the browned bamboo stake (Fig. 1e). Poorer correlation ($r = 0.91$; $p < 0.001$) was found between measured mean water table and the depth calculated from the level of the initial PVC tape discolouration and total PVC discolouration (Fig. 1f).

Accuracy rate of PVC tape/bamboo discolouration method is dependent on vegetation type. Method accuracy is lowest in flooded habitats. In the case of lowest water table, it is higher in poor than in moderately rich fens (Table 1).

As compared to the acidity-alkalinity gradient, the water table level is of secondary importance for vegetation variation in our study area. The variables related to the water regime correlate markedly with the second DCA axis. Among them, the directly measured maximum water table level shows a stronger correlation to vegetation composition than the minimum and mean water table levels (Fig. 2). Height of the vegetation rises with both increasing alkalinity and increasing water table level.

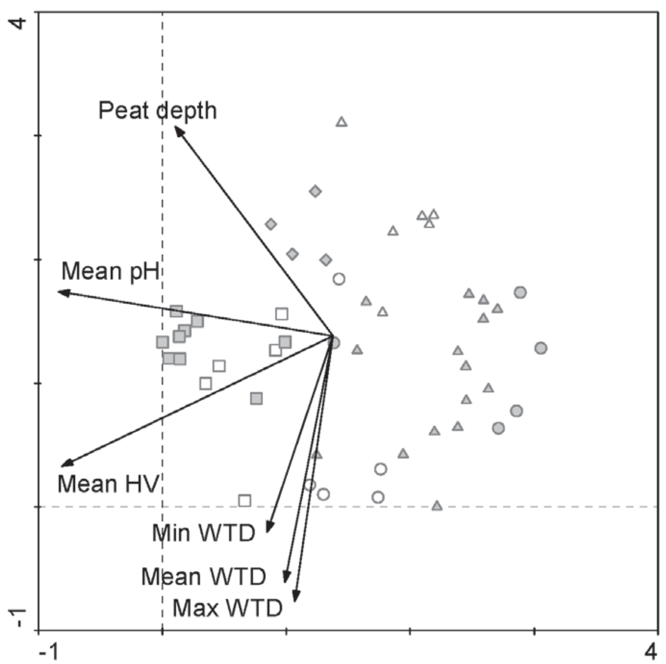

Fig. 2. DCA ordination of vegetation samples with the environmental variables passively projected onto the ordination. (Mean HV = mean height of vegetation; Min, Mean and Max WTD = minimum, mean and maximum water table depth; Eigenvalue 1st axis = 0.503, Eig. 2nd axis = 0.283). See Fig. 1 for symbols.

Discussion

The species composition pattern and environmental correlates found in our study area are similar to those in other European mires (e.g. Gerdol 1995; Bragazza & Gerdol 1999; Wheeler & Proctor 2000; Hájek et al. 2002). We can therefore consider our fen habitats representative and the PVC tape discolouration method applicable to other temperate regions. In our study area, the maximum water table level is of higher importance for species composition than the minimum. The pattern in vegetation height observed in the studied habitats is controlled, not only by water level but also probably by nutrient availability. The studied vegetation types are often rich in tall sedges and do not suffer from lack of water. They are mostly limited by inundation.

The high correlation between the first sign of PVC tape discolouration and the position of the highest water table level confirms results of Belyea (1999). It implies that the method can be used for detecting maximum water table levels in both fens and bogs. The large difference between directly measured water maximum and first sign of discolouration PVC tape in *Utricularia* fens can be explained by the higher oxygen saturation in open water compared to the water in soil pores (Belyea 1999).

In contrast to Belyea's results, this study does not verify a high correlation between the depth of complete discolouration of PVC tape and the measured position of the lowest water table. The accuracy of the minimum water table measurement depends on the depth of the peat layer. Minima cannot be detected indirectly if the water level falls bellow the peat layer. Nevertheless, full discolouration does not correspond to the lowest water table even in plots which have a sufficiently deep peat layer. It is important to note that discolouration of PVC tape primarily reflects reducing conditions, which may not correspond with water table depth in all types of habitats (Wheeler 1999). The full discolouration of PVC tape just below the peat layer suggests that reducing conditions could be related to the organic matter. The oxidation-reduction potential is considered as a function of water level, organic matter, temperature and microbial activity in mires (Baas Becking et al. 1960; Urquhart & Gore 1973; Haraguchi 1995; de Mars & Wassen 1999). Moisture content in the root zone is dependent on the water level. This relationship may differ between peat soils as it depends on soil capillary action, which in peat varies with the degree of decomposition of the organic matter (Heathwaite & Göttlich 1993). High acidity and degree of decomposition of the organic matter decrease the microbial activity in peat (Heathwaite & Göttlich 1993), which can influence the redox potential.

We propose an alternative method for recording the lowest water table in fens. The discolouration of fresh bamboo stakes turned out to be a better indicator of the lowest water table. The stakes remain green in the part which is continuously under the water table. The green bamboo stakes reliably became brown above the water table, probably due to chlorophyll degradation or enzymatic oxidation of organic compounds in the tissues. Additionally, mean water table can be estimated from the patterns of PVC tape discolouration and discolouration of green bamboo stakes.

The difference between colour reactions of the PVC tape and green bamboo stake can be explained by different causes of discolouration. A fresh bamboo stake remains green as long as the water level maintains reductive conditions. It turns brown when oxygen becomes available, even for a short time. However, the PVC tape turns black irreversibly during long-term reductive conditions; a short seasonal lowering of the water level cannot be recorded by its discolouration. The unreliability of recording minimum water table depth by PVC tape discolouration is larger in mineral soils probably due to more dynamic water regime.

Conclusion

This study confirms the advantages of the PVC tape discolouration method for relative water table depth measurements. On the other hand, it uncovers some faults and limitations which must be taken into consideration for practical use. Minimum and mean water table level cannot be reliably determined in fens with this method, but we found the alternative green bamboo stake discolouration method to be very precise. Combination of these indirect methods enable the monitoring of a large number of sites, even when they are far apart. Therefore, we can recommend this method to ecologists as an efficient, flexible and inexpensive tool for obtaining a good understanding of water fluctuation in mire habitats. The potential utilisation of the PVC tape discolouration method in mire ecology is comparable to the widespread measurement of water conductivity, which indirectly indicates calcium concentration (Sjörs & Gunnarsson 2002).

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