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Research Paper

The relationship between vegetation and groundwater levels as an indicator of spontaneous wetland restoration

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ABSTRACT

The main aim of the research was to identify areas of spontaneous restoration by investigating the relationship between the depth to groundwater table (DTW) and vegetation. A secondary aim was to confirm whether restoration is possible without any hydrotechnical engineering. The study was performed in one of the largest wetlands in central Poland, protected as a National Park and Natura 2000 site. The study area was modelled using an orthogonal discretization grid with grid cells of $\Delta x = \Delta y = 100$ m. The hydrodynamic model calculations were performed with VisualMODFLOW software, which uses the finite difference method. Vegetation analysis was based on the map of vegetation compiled for the area of 17697 ha. These results were next analyzed using ArcGIS to find areas where the correlation between depth to groundwater table and vegetation units was disturbed. Areas where DTW was significantly lower than would be expected based on their vegetation were identified as areas with potential for spontaneous renaturalization: around 10% of the entire study area was indicated as such, representing 1193 such grid cells. Restoration is possible through extensification or discontinuation of agricultural use, without the need for hydrotechnical engineering works which would result in DTW changes in the study area. As the last step of the analysis, the results were validated using soil maps of study wetlands.

1. Introduction

The evaluation and prioritization of sites in terms of protection and restoration is one of the most important problems discussed in renaturalization research. Defining priorities is absolutely necessary when time and funds for renaturalization are limited (Hyman and Leibowitz, 2000), to maximize benefits gained with limited resources. This paper deals specifically with the renaturalization of the wetland environment, which is considered to be one of the most endangered ecosystems in the world (Amezaga et al., 2002; Bronmark and Hansson, 2002; Bobbink et al., 2006; Kelly et al., 2011; Rashford et al., 2011; Wang et al., 2011; Laurance et al., 2012).

Numerous models have been created to ensure optimum selection of sites for wetland renaturalization (Schweiger et al., 2002; Lin et al., 2006; Wardrop et al., 2007; Copeland et al., 2010). The models comprise both the aspect of water flow and the quality of water obtained after renaturalization (Newbold, 2005), the potential for maintaining biodiversity (Schweiger et al., 2002) and social aspects (Kim et al., 2011). Of course it must be borne in mind that a major difficulty in creating a restoration model that could be generally applicable is that no one universal type of wetland exists to which a single restoration template can be applied (Lin et al., 2006).

Dynamic processes in wetland vegetation depend primarily on humidity conditions (Dwire et al., 2006; Lowry et al., 2011; Mata-González et al., 2012) related to the depth to groundwater (DTW) and the intensity of infiltrating water flow to the hydrogeological system. A shallow groundwater table facilitates interactions with vegetation roots, supplies water to plants and, through fluctuations in groundwater table levels, influences oxygen and nutrient availability in soil (Muneepeerakul et al., 2008). In turn, vegetation affects soil water balance through growth dynamics, transpiration and interception. This strong coupling between wetlands vegetation and groundwater level leads to important and interesting feedback between hydrological and ecosystem processes (Ridolfi et al., 2006; Rodriguez-Iturbe et al., 2007; Laio et al., 2009).

DTW, apart from geogenic factors that result from geological, weather and geomorphological conditions, is considerably affected by human activities through changes in spatial development (Fan et al., 2011). Therefore vegetation is not only directly influenced

Abbreviations: *MV*, moisture value; *MI*, moisture index; EMI, expected moisture index; DTW, depth to groundwater.

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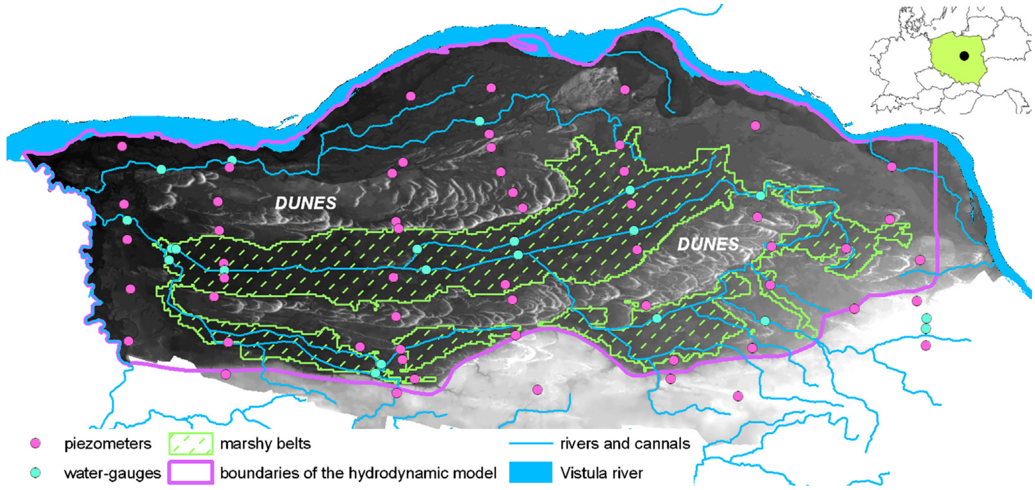

Fig. 1. Study area on the background of DTM.

by humans by activities such as mowing, grazing and farming, but also indirectly through the modification of hydrological conditions. Agriculture can have an impact on the hydrological regime of a wetland by means of land direct drainage, changes in wetland sedimentation or hydroperiods (Rashford et al., 2011) or by water removal from aquifers, rivers and streams (Beltran et al., 2011; Lemly et al., 2000)

An understanding of the relationship between DTW and vegetation seems especially important in areas when restoration projects are implemented in wetlands used agriculturally or in densely populated areas. In this case, the range of the restoration project is limited because the socio-economic aspect must be taken into account. Hence, there is a strong motivation to better understand these main wetland components, i.e. the hydrologic and vegetation systems, to help guide efforts in their protection and restoration (Chui et al., 2011).

Creating models that describe the relationship between habitat conditions and vegetation is one of the methods most commonly applied in modern wetland conservation (Choromański et al., 2009; Piniewski et al., 2012). Hence, the increasing number of studies aimed at defining the correlation between individual environmental factors (e.g. Aerts and Van der Peijl, 1993; Olff et al., 1995). Vegetation is most often used for the creation of such models due to the ease of observation and relatively low costs (Venterink and Wassen, 1997; Diekmann, 2003; Holtland et al., 2010).

In nature, the condition of hydrogenic plant communities depends on the DTW. Under human influence, vegetation conditions are determined by factors other than water. With DTW varying over decades due to variations in precipitation and the variable intensity of drainage on wetland areas, vegetation characteristic of habitats can develop on land which is drier than would be expected based on the DTW. In this paper areas with this kind of vegetation are described as either disturbed areas or areas with the potential for spontaneous regeneration – these two phrases should be understood as synonymous. The aim of this study was then to check whether disturbed areas with potential for spontaneous vegetation restoration could be identified based on the analysis of the relationship between vegetation and the DTW.

2. Material and methods

2.1. Study area

Model studies were conducted in part of the Vistula valley, a large river of the North European Plain: the Vistula is 1047 km long, and the catchment area is 194 424 km^2. The section of the Vistula valley addressed in this study is located in the Kampinos Forest, part of which is a national park subject to many forms of conservation. The investigated wetlands (marshy belts) cover 176.9 km^2, but the area studied by the hydrodynamic model is 518.8 km^2 (Fig. 1).

The whole area of the park consists of two belts of dunes interspersed with two belts of marshes, oriented west-east and parallel to the Vistula. Our studies were conducted in the marshy belts, which are drained by a system of artificial channels and ditches. The soils of the marshy belts are mostly hydrogenic, with only 7% of the area being covered by mineral soils. Among the hydrogenic soils, the most frequent are mucky (41%) and mineral-moorsh (25%), the rarest are peat and peat-mud (only 1%). In the past, the latter two overed about 19% of the wetlands (Piórkowski et al., 2011) but were converted into mucky and mineral-moorsh as a result of the mineralization process.

Hydrogeological data comprising manual (regular) observations of underground water levels since 1999 using 56 piezometers was obtained from the Kampinos Forest water monitoring network (Krogulec, 2004, 2011). Manual measurements, being the basis of the analysis of the range and tendency of changes in DTW, have been performed for the period 1999–2011; thanks to which the base presently contains 16,000 measurements. The number and range enable statistical analysis to be performed and, consequently, the range of groundwater level changes and their average values to be calculated. These measurements were next used for model calculations.

The marshy belts are characterized by a shallow groundwater table. The annual average depth of the groundwater table is 1.08 m, with the observed maximum depth to groundwater in 2011 being

Table 1
Groundwater conditions (DTW) in the marsh belts - result of hydrodynamic modelling and monitoring observations.

DTW [m]	Monitoring observations		Hydrodynamic modelling	
Period/year	1999–2011	2009	1999–2010	2009
Average	1.08	1.12	1.22	1.32
Max depth	3.16	1.98	1.99	1.92
Min depth	−0.83	−0.58	−0.81	−0.52
Standard deviation	0.69	1.89	0.72	1.58
Amplitude	3.99	2.34	2.80	2.44
Average annual amplitude	1.68	2.34	1.62	2.44