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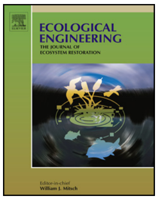

Wetland restoration management under the aspect of climate change at a mesotrophic fen in Northern Germany

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ABSTRACT

Wetland restoration management is an important tool for stakeholders and practitioners to mitigate climate change and preserve ecological functioning. Various approaches to modifying the water management of a catchment for restoration purposes exist and were performed in a preservation area in northwest Germany. To validate the effect of the re-wetting practice, a monitoring network of 46 wells was established and monthly readings were taken from 1997 onwards. A declining trend in water table depth was present at 39 wells and equaled on average a lowering of 20 cm during the study period from 1997 to 2012. So far, half of the trend lines are above 40 cm below ground, which is an indicator of an effective re-wetting practice, but they will decline below this threshold until 2032 according to linear regression analysis. The progress of water table depths might be accelerated by climate change. According to the meteorological forecast, air temperatures will rise and the annual precipitation pattern will change. Thus, the climatic water balance tends toward more negative values in the summer and positive values in the winter, favoring an earlier and more intense water table draw-down. Because root water extraction from shallow groundwater is limited to a certain depth, the forecast of water table depth development according to the recent trend depicts a worst-case scenario. Nevertheless, the results emphasize that restoration management should be validated and has to be adapted in certain ways when mitigating the impact of climate change.

1. Introduction

Wetlands are important and complex ecosystems and globally account for 800 million ha, which is equal to 6% of the Earth's land surface (Reddy and DeLaune, 2008). They can serve as sinks, sources, or transformers of contaminants, filter nutrients from atmospheric deposition, contain mechanisms to regulate floods, and sustain and promote endangered species because of their biological productivity. The physical, chemical, and biological processes in wetlands control their functioning. Wetlands are usually located in landscapes with low elevation and shallow water tables (WTs). Hence, important characteristics are seasonal or permanent water saturation, which favors anaerobic soil conditions. In the absence of oxygen, many microbially mediated processes are slowed down. As a result, organic carbon (C_{org}) accumulates, which makes wetlands important terrestrial carbon pools. Different types of wetlands can be classified according to their position in the landscape and other characteristic features. Fens are one of the dominant wetland types worldwide with an extent of 148 million ha (21.8% of all wetlands) (Kirk, 2004). Together with bogs, the estimated carbon stocks account for 455 Pg, which is one third of the soil carbon pool (Laine et al., 1996).

1.1. Protection and restoration management

To protect and conserve wetlands around the world, the international treaty known as the Ramsar Convention was signed 1971 in Iran and currently has 168 contracting parties. Since then, numerous projects have evolved to stop the loss of wetlands in central Europe due to drainage and intensification of agriculture (Brülisauer and Klötzli, 1998). Price et al. (2003) summarize various approaches to modifying the water management of a catchment for restoration purposes. The general approaches include (i) blocking or refilling of ditches, (ii) minimizing surface-runoff using terraces or bunds, (iii) hydrological buffer-zones, (iv) re-modeling of the

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Abbreviations: WT, water table; CWB, climatic water balance; RCP, representative concentration pathways.

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surface, and (v) minimizing water loss via evapotranspiration by micro-climate modifications. To reduce the effects of drainage, measures to achieve ecological restoration have to be adapted. Besides the restoration measures, a network of wells to monitor the development of WT depths is essential to verify the success of the restoration strategy and re-wetting goals.

1.2. Impacts of wetlands on climate change

Drainage and aeration of formerly undisturbed wetlands contribute carbon fluxes to the atmosphere via oxidation of organic matter and gaseous loss of carbon dioxide (CO_2) (Maljanen et al., 2010). Further, the transformation into arable land leads to the emission of nitrous oxide (N_2O) from organic soils, which accounts for an estimated 25% of the national anthropogenic N_2O emission in Finland (Kasimir-Klemedtsson et al., 1997). However, simultaneously enhanced activity of methane-oxidizing bacteria in the aerated part of the soil profile due to drainage and oxidation will reduce the emission of methane (CH_4) being released to the atmosphere. Carbon dioxide, N_2O, and CH_4 are by far the most important greenhouse gases (GHGs) and have a significant impact on the global warming potential (GWP) (Yu and Patrick, 2004). Because of complex feedback mechanisms on different time-scales, the source–sink function of the soil and atmosphere for the three GHGs is difficult to obtain. Freeman et al. (1992) measured fluxes of CO_2, CH_4, and N_2O from soil columns packed with peat monoliths while subsequently lowering the WT height. They found maximum increases in CO_2 and N_2O fluxes of 146% (646–1590 mg CO_2 m^{-2} d^{-1}) and 936% (0.11–1.14 mg N_2O m^{-2} d^{-1}), respectively, and a decrease in CH_4 of −80% (230–45 mg CH_4 m^{-2} d^{-1}). Moore and Knowles (1989) verified this process, where lowering of the WT height resulted in a linear increase of CO_2 production and a logarithmic decrease in CH_4 evolution.

1.3. Climate change

Recently, Koirala et al. (2014) demonstrated the important role of capillary flux from groundwater in the representation of land surface models. According to their results, global mean evapotranspiration increases by 9% when considering water flux to the atmosphere by capillary rise from shallow groundwater, with the largest impact occurring in the semi-arid regions during the dry season (25%) and minimal impact in humid and high-latitude regions. On the other hand, enhanced evapotranspiration rates due to climate change would alter the WT drawdown in the summer time (Laine et al., 1996; Manabe and Wetherald, 1986) because the atmospheric boundary condition, as well as the soil texture, determines the depth to which plant roots can extract water from the groundwater surface. Overall, long-term developments of WT depths are of interest because the boundary between aerobic and anaerobic zones within wetlands might shift toward oxidizing conditions in formerly water-saturated environments.

The primary aim of the study is to assess (i) the impact of wetland restoration and management on the WT depth development of a formerly drained meadow fen in western Germany. Restoration started in 1997 and WT depth monitoring was performed from 1997 onward on a monthly basis at 46 groundwater wells along the study site. Based on precipitation and reference evapotranspiration, we calculated the climatic water balance (CWB) to address (ii) the influence of the ambient meteorology on WT fluctuations. According to the trend line derived by linear regression of WT data for each monitoring well, increasing, constant, or decreasing WT depths under the recent hydrological situation were evaluated. We used a climate projection until 2100 to give an outlook of the future development of WT depths and to discuss the (iii) impact and vulnerability to climate change when restoring formerly drained wetlands.

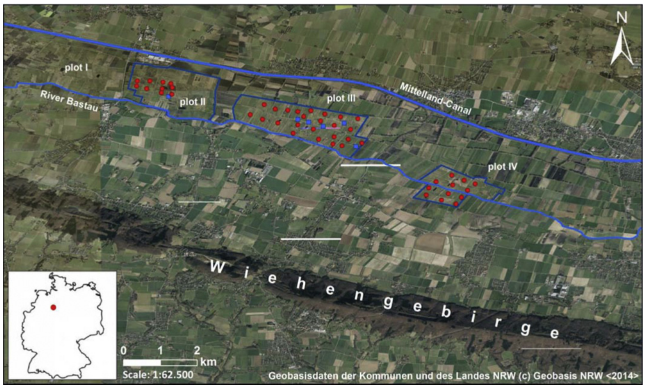

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Fig. 1. Map of the study site showing the boundaries of the plots (blue line), the locations of the groundwater monitoring wells (red dots), and concrete weir (blue dots).

2. Materials and methods

2.1. Study site

The conservation area Bastauwiesen is a mesotrophic meadow fen which extends 10.5 km eastwards and 1.4–2.1 km southwards in the district of Minden-Luebbecke, North Rhine-Westphalia (latitude 52°18′ N, longitude 8°47′ E). The setting is within the glacial valley of the River Weser and the basement is composed of Pleistocene sandy to gravel deposits underlying Holocene glaciofluvial calcareous material showing loamy texture underlying peat of variable heights. A decrease of the peat occurs from 4 m thickness in the west to non-coverage in the east and to the edges of the conservation area, which is coherent with a decline of the relief from 50 m asl in the west to 45.3 m in the east (Fig. 1). Analogous to the relief is the main flow direction of the channelized River Bastau in the south of the conservation area and a smaller trench running parallel through the study site 100 m northwards. The channels collect interflow from the southwards-located Wiehengebirge and from numerous rectangular shaped ditches, constructed from 1958 to 1960 to intensify agriculture as a result of land consolidation acts. Before that, 90% of the area was managed as intensive grassland and the peat was exploited as fossil fuel. Mean annual precipitation and air temperatures of 688 mm and 9.3 °C characterize the climate as moderate sub-Atlantic with mild winters and relatively cool summers.

2.2. Restoration acts and WT depth monitoring

In 1988, the study site became a natural conservation area to protect several endangered flora and fauna species. Former agricultural land was bought by public authorities and changed into extensively managed grassland. Besides this, drain pipes in the fields were destroyed by deep plowing, artificial subsidence was performed by excavation and decommissioned ditches were refilled with the excavated material, numerous concrete weirs (Fig. 1) were established to alter the flow characteristics, and hardwood was cleared to facilitate a land cover of pasture and meadow with sedges. For management purposes, four plots were established (I–IV, Fig. 1) where WT depths were recorded on a monthly basis in 200-cm perforated polyvinyl chloride pipes (Ø 2.7 cm). Monitoring of WT depths started in December 1999 at plot II, in November 2000 at plot III, and in April 1997 at plot IV, in 10, 24, and 12 monitoring wells, respectively, using an acoustic water