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Seasonal dynamics of soil salinity in peatlands: A geophysical approach

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ABSTRACT

Inland salt meadows are particularly valuable ecosystems, because they support a variety of salt-adapted species (halophytes). They can be found throughout Europe; including the peatlands of the glacial lowlands in northeast Germany. These German ecosystems have been seriously damaged through drainage. To assess and ultimately limit the damages, temporal monitoring of soil salinity is essential, which can be conducted by geoelectrical techniques that measure the soil electrical conductivity. However, there is limited knowledge on how to interpret electrical conductivity surveys of peaty salt meadows. In this study, temporal and spatial monitoring of dissolved salts was conducted in saline peatland soils using different geoelectrical techniques at different scales (1D: conductivity probe, 2D: conductivity cross-sections). Cores and soil samples were taken to validate the geoelectrical surveys. Although the influence of peat on bulk conductivity is large, the seasonal dynamics of dissolved salts within the soil profile could be monitored by repeated geoelectrical measurements. A close correlation is observed between conductivity (~salinity) at different depths and temperature, precipitation and corresponding groundwater level. The conductivity distribution between top- and subsoil during the growing season reflected the leaching of dissolved salts by precipitation and the capillary rise of dissolved salts by increasing temperature (~evaporation). Groundwater levels below 0.38 cm resulted in very low conductivities in the topsoil, which is presumably due to limited soil moisture and thus precipitation of salts. Therefore, to prevent the disappearance of dissolved salts from the rooting zone, which are essential for the halophytes, groundwater levels should be adjusted to maintain depths of between 20 and 35 cm. Lower groundwater levels will lead to the loss of dissolved salts from the rooting zone and higher levels to increasing dilution with fresh rainwater. The easy-to-handle conductivity probe is an appropriate tool for salinity monitoring. Using this probe with regressions adjusted for sandy and organic substrates (peat and organic gyttja) additional influences on bulk conductivity (*e.g.* cation exchange capacity, water content) can be compensated for and the correlation between salinity and electrical conductivity is high.

1. Introduction

Saline environments are mainly located in coastal zones, but they can also be found inland. Natural causes for inland salinization are the presence of salt-rich rainwater or saline groundwater, high evaporation and low precipitation. In such regions, upward-directed soil water movement by capillary rise is a dominant process and rates of precipitation are too low to leach out salts. This leads to an accumulation of salts within the topsoil or at the soil surface. Typically, such conditions are found in arid regions.

Inland salt meadows are present in central Europe, for instance in Bulgaria, Austria, Hungary and Germany (Wolfram, 2006). In Germany, such ecosystems can be found in the northern and north-eastern (Schleswig-Holstein, Brandenburg) and central (Saxony-Anhalt, Thuringia) federal states. Far from the coast, saline water that rises from the Zechstein formation at around 1 km depth is responsible for the saline conditions (TLMNU, 2007). Inland salt meadows are geologically and botanically unique and support a high biodiversity with a variety of salt-adapted plant (halophytes). In Brandenburg these ecosystems are of particular conservation value because they are exclusively located in lowland peatlands, which themselves are ecosystems with a high level of biodiversity. However, due to extensive drainage activities

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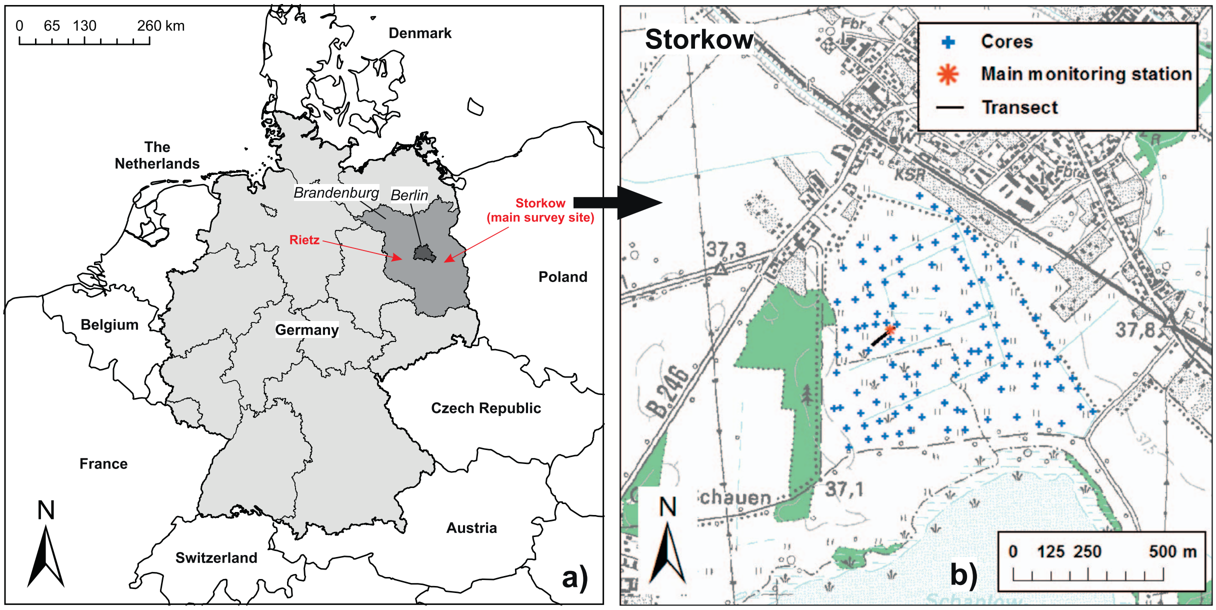

Fig. 1. (a) Location of the two study sites *Storkow* and *Rietz* in north-eastern Germany and (b) plot of the field surveys undertaken at the main study site *Storkow*.

conditions for halophytes have worsened significantly in the peatlands of Brandenburg in recent decades (LUA, 2010). Lower groundwater levels hamper the migration of salts *via* capillary rise into the rooting zone. Conversely, the complete abandonment of pastoral use induces natural succession with other more competitive plants replacing the halophytic plant communities. To design effective protection measures for halophytes, monitoring and an understanding of the salt concentration dynamics are necessary.

Soil salinity can be measured from the electrical conductivity of the pore-fluid (σ_w), which is proportional to the concentration of total dissolved ions, their charges and mobility (Rhoades et al., 1976; Corwin et al., 2012). Soil salinity monitoring is conventionally conducted by manual sampling, but this is impractical over large areas. For several decades, geoelectrical techniques, such as surveys of electrical conductivity, have been used to map and monitor soil salinity (*e.g.* Hanson and Kaita, 1997; Corwin et al., 2003). Electrical conductivity surveys are conventionally carried out with a four-electrode (two current injection and two potential electrodes) system. The depth of investigation is increased by increasing the distance between the two injection electrodes. Such methods therefore provide soil data economically with minimal invasiveness at larger scales. However, there is limited knowledge on how to interpret electrical conductivity readings with respect to salinity variability in peatlands.

Most of the geoelectrical investigations at saline sites have been conducted in coastal regions (*e.g.* Tronicke et al., 1999; Wiederhold et al., 2013) or in arid areas, which are affected by salinization as a result of intensive human irrigation activities (*e.g.* Hanson and Kaita, 1997; Rhoades et al., 1999; Corwin et al., 2003): all were conducted on mineral soils. We know of no studies that focus on salinization of inland peatlands. Rhoades et al. (1999) summarize from various field investigations that σ_w is the largest influence on bulk electrical conductivity at saline sites. There are various approaches and models described in the literature that link the simple-to-measure bulk soil electrical conductivity to σ_w (*e.g.* Rhoades et al., 1989; Hanson and Kaita, 1997; Scudiero et al., 2012). However, these models are calibrated for mineral substrates, whereas peat has completely different soil properties. Bulk density is very low (down to 0.05 g cm^{-3}: Päivänen, 1973; Eggelsmann et al., 1993; Bridgham et al., 2001), organic matter content can reach almost 100% (Päivänen, 1973; Hobbs, 1986) and cation exchange capacity is much higher (up to 200 cmol$_c$ kg^{-1}: Puustjärvi, 1956) compared to mineral soils.

In water-saturated non-saline peatlands, σ_w is typically the major factor that determines the bulk electrical conductivity (Comas and Slater, 2004; Comas et al., 2011; Ponziani et al., 2012b; Walter et al., 2015, Walter et al., 2016). This is particularly the case for fen sites, which are fed by solute-rich groundwater. In addition to electrolytic conduction (which is proportional to σ_w), conduction along the surface of the organic particles determines the bulk conductivity of peat (Comas and Slater, 2004; Walter et al., 2015; Walter et al., 2016). This contribution can be approximated by the cation exchange capacity, which is large in peat and increases with the degree of decomposition (Kuntze, 1976; Seybold et al., 2005; Asadi et al., 2011). The soil water content is an important factor in conductivity surveys because it controls the correlation between bulk electrical conductivity and properties such as σ_w and cation exchange capacity. This becomes more important in drained peatlands, where lower levels of water saturation occur.

The aim of this study is to test geoelectrical methods at saline fen sites for the monitoring of the seasonal dynamics of soil salinity at different scales. The objectives are (i) to investigate the applicability of electrical conductivity surveys to monitor the temporal and spatial vertical dynamics of dissolved salts in peatland soils at different scales (1D, 2D) using different conductivity techniques, (ii) to quantify the relationships between bulk electrical conductivity, salinity (σ_w) and water content and (iii) to study the relationship between salt dynamics and local climate parameters (precipitation and temperature).

2. Methods

2.1. Study sites

In Brandenburg, there are around 100 inland salt meadows, which vary in their salinity (4–30 mS cm^{-1}, 3-year average of σ_w within the top 0.4 m of the soil profile: Bauriegel et al., 2010). Our main study site (*Storkow*) was chosen due to the occurrence of very large seasonal groundwater fluctuations and corresponding vertical migration of dissolved salts. *Storkow* lies 60 km southeast of Berlin (Fig. 1a) in a glacial valley. The fen was formed in the Holocene as a result of terrestrialization and a rise in the local water table. *Storkow* has medium salinities with an average σ_w of ~8 mS cm^{-1} (3-year average of σ_w within the top 0.4 m of soil the profile: Bauriegel et al., 2010). In the 1970s, the fen at *Storkow* was covered with a 30 cm-thick sand layer in order to improve accessibility for agricultural equipment. The distribution of