



## Environmental controls of plant species richness in riparian wetlands: Implications for restoration

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### Abstract

Wetland restoration projects often focus on mitigating losses of nutrients (nitrogen and phosphorus) toward downstream aquatic recipients and, so far, there is no clear guidance on how to restore environmental conditions to improve biodiversity values in the restored areas. However, to provide such guidance, it is necessary to obtain a better understanding of the factors driving biodiversity in natural wetlands. For this purpose, we investigated plant community characteristics in 35 plots located at 10 Danish riparian wetlands to identify critical factors required to sustain species diversity. We hypothesized that species richness is influenced by groundwater characteristics and nutrient availability and that threshold values for these environmental variables can be defined to characterize conditions needed to sustain high diversity plant communities. We found that high groundwater level (less than 37 cm depth) and low soil phosphorus content ( $<347 \mu\text{g cm}^{-3}$ ) were two important drivers of plant species richness. Furthermore, at high groundwater and low soil phosphorus content, low nitrogen concentration in the groundwater also favors greater species richness. Our results imply that establishment of a groundwater table close to the soil surface and low nutrient availability are important factors for improving species richness in restored areas.

### Zusammenfassung

Projekte zur Feuchtgebietsrenaturierung konzentrieren sich oft darauf, die Nährstoffverluste (Stickstoff und Phosphor) hin zu flussabwärts gelegenen aquatischen Empfängern abzuschwächen, und bislang gibt es keine klare Anleitung, wie Umweltbedingungen wiederhergestellt werden sollten, um die Biodiversitätswerte in den renaturierten Gebieten zu verbessern. Um solche Handlungsanleitung zu geben, ist es indessen nötig, eine bessere Kenntnis der Faktoren zu erhalten, die die Biodiversität in natürlichen Feuchtgebieten steuern. Zu diesem Zweck untersuchten wir die Eigenschaften von Pflanzengemeinschaften auf 35 Untersuchungsflächen, die in zehn dänischen Flussauen lagen, um die kritischen Faktoren für den Erhalt der Artendiversität zu identifizieren. Wir nahmen an, dass der Artenreichtum durch die Grundwassergegebenheiten und die Nährstoffverfügbarkeit beeinflusst werden sollte und dass es möglich sein sollte, Schwellenwerte für diese Umweltvariablen zu definieren, um die

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Bedingungen zu beschreiben, die für den Erhalt von hochdiversen Pflanzengemeinschaften erforderlich sind. Wir fanden, dass ein hoher Grundwasserspiegel (weniger als 37 cm Flurabstand) und ein geringer Phosphorgehalt ( $<347 \mu\text{g cm}^{-3}$ ) die bestimmenden Faktoren für den Artenreichtum der Pflanzen waren. Darüber hinaus fördert bei hohem Grundwasserspiegel und geringem Phosphorgehalt auch eine geringe Stickstoffkonzentration größeren Artenreichtum. Unsere Ergebnisse bedeuten, dass die Einrichtung eines Grundwasserspiegels nahe der Bodenoberfläche und geringe Nährstoffverfügbarkeit wichtige Faktoren für die Verbesserung des Artenreichtums in renaturierten Gebieten sind.

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## Introduction

Riparian wetlands are ecotones located between terrestrial upland and aquatic ecosystems. They are generally considered ecological hotspots in the landscape due to their often high biodiversity (Naiman, Decamps, & Pollock, 1993; Naiman & Decamps, 1997; Ward, Tockner, & Schiemer, 1999). Additionally, these zones provide valuable ecosystem services such as floodwater storage and nutrient retention and transformation (de Groot, Wilson, & Boumans, 2002).

Unfortunately, anthropogenic pressures have severely impacted riparian wetlands and about 80% of European wetlands have been lost (Verhoeven, 2014). Many riparian areas have been disrupted or even completely destroyed; for instance by drainage works converting wetlands to agricultural fields (Tockner & Stanford, 2002; Verhoeven, 2014). Furthermore, stream channelization and establishment of weirs and dams to regulate the water level or to produce energy also affect riparian areas by lowering the water table and disturbing the interaction between ground waters and surface waters through the hyporheic zone (Ward et al., 1999; Boulton, 2007). In addition, many wetlands located in agricultural catchments receive high nutrient loadings because of fertilization of fields, and this may provoke eutrophication of the ecosystems (Smith, Tilman, & Nekola, 1999).

Taken together, these multiple anthropogenic pressures affecting wetlands have resulted in a degradation of the water quality and a decline of the biodiversity (Dudgeon et al., 2006; Verhoeven, 2014). During the last decades several initiatives have been implemented to counteract these threats; for instance in the European Union the Habitats Directive (Directive 92/43/EEC) and the Birds Directive (Directive 2009/147/EC) aim at preserving species and habitat types of European importance, including wetlands, and the Water Framework Directive (Directive 2000/60/EC) and the Nitrate Directive (Directive 91/676/EEC) aim to assist in reducing the excessive loadings of nutrients to aquatic ecosystems. Among the tools to mitigate eutrophication of aquatic ecosystems, wetland restoration is considered one of the most efficient to reduce nutrient loadings to lakes and estuaries because of the capacity of wetlands to remove or store nutrients (Mitsch & Jørgensen, 2004;

Hoffmann & Baattrup-Pedersen, 2007; Moss & Monstadt, 2008; Hoffmann, Kronvang, & Audet, 2011). However, when restoring wetlands the focus is mostly directed at nutrient reduction (N and P) and, so far, restoration projects lack a clear guidance on how to restore and improve environmental conditions to sustain high biodiversity within the restored areas (Zedler, 2003; Hansson, Bronmark, Nilsson, & Abjornsson, 2005).

Vegetation diversity in wetlands is mainly driven by the discharge of groundwater and the resulting flow patterns creating heterogeneities in soil moisture and nutrient availability, thus supporting the development of a variety of community types (Baldwin, Egnatovich, & Clarke, 2001; Jansson, Laudon, Johansson, & Augspurger, 2007). However, in Danish agricultural catchments, areas of groundwater discharge may receive large amounts of nutrients, especially nitrate, derived from fertilization of the fields (Baattrup-Pedersen et al., 2014). Because nitrate is a major limiting macro-nutrient for plant growth, its presence in riparian areas can be critical and when found in excess the increase in the productivity of the vegetation is generally associated with a decrease in species richness (Olde Venterink, Wassen, Verkrout, & De Ruiter, 2003). Especially groundwater-dependent vegetation such as rich fen vegetation is particularly impacted by the increase in nutrients (Baattrup-Pedersen et al., 2014).

To advance the development of guidance on how to restore environmental conditions with the objective to create favorable conditions for high biodiversity within riparian areas, understanding of the factors controlling plant species diversity under natural conditions is a prerequisite (Viers et al., 2012). Therefore, in the present study, we investigated plant community characteristics in 35 plots located in 10 Danish riparian wetlands to identify critical factors for sustaining high species diversity and in particular to restore rich fen vegetation. Specifically, we hypothesized that (i) groundwater characteristics (e.g. mean groundwater level or groundwater flow direction) will influence species richness by affecting nutrient availability and that (ii) threshold values for environmental variables (e.g. groundwater level or water nutrient content) can be determined to characterize conditions needed to sustain high diversity plant communities that can be used as guiding factors in restoration projects.

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