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Impact of drainage and hydrological restoration on vegetation structure in boreal spruce swamp forests

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ABSTRACT

Drainage to increase timber production is a major cause of degradation of boreal peatlands in Europe. As a consequence of the forestry drainage, the area of pristine spruce swamp forests has declined drastically in northern Europe over the past century. In restoration by rewetting, drainage ditches are blocked to restore the pre-disturbance hydrological regime and, ultimately, the biodiversity values and ecosystem functions of pristine spruce swamp forests. In this study, we quantify vegetation recovery and examine mechanisms behind the changes in plant community composition. For this, we surveyed the understorey vegetation of 9 undrained, 9 drained and 18 rewetted spruce swamp forest sites in southern Finland. The vegetation survey was accompanied by water table (WT) position and tree stand measurements. *Sphagnum* cover decreased after drainage and increased after rewetting. Drainage increased the cover of the unvegetated ground surface, while the cover of moss species other than *Sphagnum* and feather mosses was highest in the rewetted group. A constrained ordination analysis shows that following rewetting, species composition had developed towards the undrained reference state. Regarding their plant community composition, the rewetted sites were situated in the middle of the undrained–drained axis, differing significantly from both the undrained and the drained sites. Similarity to the undrained reference state depended on current WT and was driven by the *Sphagnum* mosses. Among the rewetted sites, which varied in their rewetting age from 1 to 14 years, similarity to undrained was not dependent on time since rewetting. The most important predictors for the between-site variation in plant community composition were the division between the undrained and the other (drained or rewetted) sites, WT position and birch volume. Species diversity was lower in the undrained than in the drained and rewetted sites, mainly due to lower species evenness. It appears that the competitive superiority of the *Sphagnum* mosses in wet conditions results in a lower species diversity in the undrained reference state. The less optimal conditions for *Sphagna* that result from drainage enable higher diversity by opening space for other species.

1. Introduction

Restoration of degraded ecosystems has been recognized as an indispensable tool for achieving global biodiversity targets and for maintaining ecosystem services that support human communities at the local scale and, in the case of carbon-storing ecosystems, at the global scale as well (Convention on Biological Diversity, 2010; Millennium Ecosystem Assessment, 2005). Quantification of restoration success is important for assessing the effectiveness of restoration measures in fulfilling the policy targets. Target attributes of restored ecosystems have been listed by the Society of Ecological Restoration International in the SER International Primer (SERI, 2004). They extend all the way to the level of connectivity in the landscape and ecosystem resilience over long temporal scales. Yet even targets 1 and 3 (Table 1), which are concerned with the recovery of community structure and functional type composition of the restored sites themselves, are seldom explicitly quantified in restoration studies on real ecosystems (Suding, 2011).

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Table 1
Attributes of restored ecosystems 1 & 3 in the SERI (Society of Ecological Restoration International) Primer on Ecological Restoration (SERI, 2004).

Attribute	
1.	The restored ecosystem contains a characteristic assemblage of the species that occur in the reference ecosystem and that provide appropriate community structure
3.	All functional groups necessary for the continued development and/or stability of the restored ecosystem are represented or, if they are not, the missing groups have the potential to colonize by natural means

Furthermore, more studies that cover a longer time period than the first few years after restoration are needed to understand the ecological effectiveness of restoration (Montoya et al., 2012).

Increased biodiversity and provision of ecosystem services are the main motivations for ecological restoration (Bullock et al., 2011). Biodiversity refers to site-level species occurrence and abundance structure, or to landscape-level biodiversity to which the restored site is expected to contribute. Higher biodiversity is often the outspoken target of restoration – and indeed, restoration usually results in increased site biodiversity (Rey Benayas et al., 2009). Biodiversity and ecosystem services may be concurrently promoted by restoration but not necessarily so (Bullock et al., 2011).

Wetlands are areas where saturation with water is the dominant feature determining the nature of soil development and the types of plant and animal communities present (Cowardin et al., 1979). Peatlands are wetland ecosystems that are further characterized by a naturally accumulated peat layer at the surface (Joosten and Clarke, 2002). Spruce swamp forests, the ecosystems focal to this study, are boreal peatlands in northern Europe with a dense cover of trees, mainly Norway spruce (*Picea abies*), but also some birch (*Betula pubescences*). The water table is normally positioned well below the ground surface, which allows the spruce to persist. *Sphagnum* mosses dominate the forest floor, while forest mosses occur on drier surfaces, such as tree bases, roots and logs (Laine et al., 2012b).

Drainage to increase timber production is a major cause of degradation of boreal peatlands (Kaakinen et al., 2008). Despite having high nature conservation (Hörnberg et al., 1998) and ecosystem service values when undrained, spruce swamp forests are commonly drained due to their large timber production potential (Päivänen and Hånell, 2012). In Finland, the greatest degradation of spruce swamp forests has occurred in the southern part of the country, where spruce swamp forests are among the most threatened habitat types (Kaakinen et al., 2008). Spruce swamp forests have been restored by rewetting in protected areas in Finland since the 1990s for nature conservation purposes. Ditches are filled or blocked to raise the water table position. Because Norway spruce (*Picea abies*) is physiologically intolerant of flooding, rewetting typically causes mortality in the tree stand, which decreases evapotranspiration and may raise the water table position further (Aapala et al., 2013). Previous studies indicate that after the hydrology of forestry-drained peatlands is restored by ditch blocking, *Sphagnum* mosses re-establish (Mälson et al., 2008; Haapalehto et al., 2011; Hedberg et al., 2012). However, several wetland studies suggest that many community components may still be lacking even a decade after rewetting (Haapalehto et al., 2011; Hedberg et al., 2012; Matthews et al., 2009; Soro et al., 1999).

In some spruce swamp forest sites rewetting has resulted, after flooding and substantial tree mortality, in a dense stand of young birch, which bears little resemblance to the late-successional stands (Hörnberg et al., 1998) that are the common view of spruce swamp forests (Fig. 1). This has raised concerns among forestry professionals and recreational forest users about if the restoration measures function as planned.

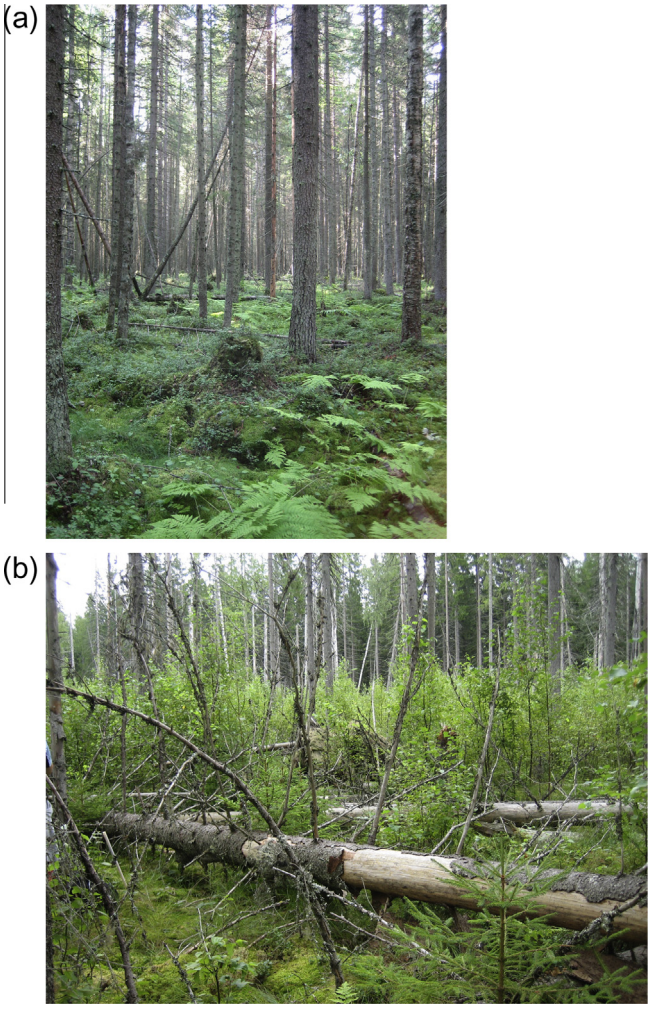

Fig. 1. (a) An undrained spruce swamp forest and (b) a formerly drained site, where tree mortality caused by rewetting was particularly high, 15 years after rewetting. Photos by Maija Aarva.

In this study we determine if rewetting measures, as currently practiced, are effective in initiating a recovery of the plant community composition of spruce swamp forests towards a pristine-like state. We consider restoration to be successful if, ultimately, the plant communities of the rewetted sites are situated within the range of variation of the undrained reference ecosystems in the region. We hypothesize that the mean water table position obtained upon rewetting will be the main driver of community composition.

2. Material and methods

2.1. Study sites and sampling

The study sites comprised 9 undrained, 9 drained and 18 rewetted spruce swamp forests. The sites were selected to represent the same original (before drainage) habitat type (i.e. *Vaccinium myrtillus* spruce mires, Laine et al., 2012b). Norway spruce (*Picea abies*) was the dominant tree at all sites. All sites have peat depths >80 cm and are located in the southern boreal vegetation zone