Ecological Engineering 110 (2018) 99–106

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Research Paper

Application of oil-shale ash and straw mulch promotes the revegetation of extracted peatlands

Triin Triisberg-Uljas[a], Kai Vellak[b,c], Edgar Karofeld[b,*]

[a] Estonian Museum of Natural History, 29 a Lai St., Tallinn 10133, Estonia
[b] Institute of Ecology and Earth Sciences, University of Tartu, 40 Lai St., Tartu 51005, Estonia
[c] Natural History Museum, University of Tartu, 46 Vanemuise St., Tartu 51014, Estonia

ARTICLE INFO

Keywords:
Extracted peatlands
Environmental parameters
Nurse species
Oil-shale ash
Revegetation

ABSTRACT

The spontaneous revegetation on abandoned peat extraction areas is a slow and sporadic process. We conducted an open field experiment to clarify how to promote the revegetation of abandoned extracted peatlands. Two extracted peatlands in East Estonia with three treatments and control were analysed two, three and five years later. Our aim was to elucidate if fertilising with alkaline oil-shale ash promotes revegetation of bare peat fields; whether it speeds up establishment of plant species characteristic of natural mires; and whether the closeness to vegetated areas near the peatland edge has an effect on the formation of plant species composition.

Our results showed that application of oil-shale ash and straw mulch, as well mulch alone promote clearly revegetation in studied extracted peatlands (mean plant cover 57% and 40% on fifth year, correspondingly), but at the same time quadrats with oil-shale ash alone were sparsely vegetated (4%) and similar to plots without any treatment (2%). Oil-shale ash alone did not speed up the establishment of plant species, but oil-shale ash combined with straw mulch facilitated the establishment of some species typical of natural mires. Closeness to the peatland edge increased the number of species and their cover because of the location and proximity to naturally vegetated areas. Consequently, oil-shale ash combined with straw mulch or straw mulch alone facilitated plant growth on extracted peatlands, while the effect of oil-shale ash alone was unimportant.

1. Introduction

In the European Union, due to the extensive drainage mostly for agriculture and forestry only about 2.8% of the land area is covered with peatlands of peat thickness of more than 30 cm (Joosten, 2008). Mostly raised bogs are used for industrial peat mining because they have a several metres thick homogeneous *Sphagnum* peat layer. In former times, peat was traditionally hand-cut from bog margins or extracted without extensive drainage as block-cut peat. Such peat-exploiting methods had mostly only local impact and these areas revegetated spontaneously rather well. In the middle of the 20th century the situation changed remarkably with the introduction of peat milling and the vacuum-mining techniques that rapidly increased the extent of peat extraction areas. These techniques require removal of the existing vegetation, deep drainage and division of peatlands with ditches into peat fields of approximately 20 m width. After completion of the extraction of peat, some mined areas have been used for agriculture, forestry or agricultural purposes, but usually they were abandoned without any restoration activities, especially in the 60–70 s (Karofeld et al., 2017). As the original vegetation and the viable propagule bank on extracted peatlands have been destroyed (Huopalainen et al., 1998; Price et al., 2003; Salonen, 1987) the spontaneous revegetation of extracted peatlands is a very slow and unpredictable process (Lavoie et al., 2003; Triisberg et al., 2011, 2013a) driven by the various environmental factors, mainly defined by the used peat extraction method (Poulin et al., 2005) and properties of residual peat (Girard et al., 2002). Influx of propagules from the surrounding areas can support the revegetation, but the establishment of new arrivals is held back by many critical environmental factors and ecological filters (Salonen, 1987; Campbell et al., 2003; Beleya, 2004), peat mineralisation, wind erosion (Campbell et al., 2002) and frost heaving (Groeneveld and Rochefort, 2002).

Estonia is rich in peatlands, covering *ca* 22% of the territory in total (Orru and Orru, 2008), but the majority of them are affected by different human activities and mires in a natural state are estimated to cover only 5.5% (245 000 ha) (Paal and Leibak, 2011). Peat is actively extracted on more than 20 000 ha (Ramst and Orru, 2009), and the total area of extracted abandoned peatlands is *ca* 9 400 ha. The area of exploited peatlands will increase considerably soon due to the exhaustion of peatland reserves for excavation. Abandoned and poorly

* Corresponding author.
E-mail address: edgar.karofeld@ut.ee (E. Karofeld).

http://dx.doi.org/10.1016/j.ecoleng.2017.10.006
Received 11 April 2017; Received in revised form 4 October 2017; Accepted 6 October 2017
0925-8574/

vegetated peatlands are a threat to the environment not only locally but also globally, being a substantial source of greenhouse gas emissions (Paavilainen and Päivänen, 1995; Laine and Minkkinen, 1996; Salm et al., 2009). Therefore, the recovery of vegetation on extracted peatlands is crucial to hinder destructive environmental influences. The restoration of abandoned peatlands should support the vegetation succession towards the self-sustainable near-natural state resembling mire habitats, where the accumulation of new peat could start (Clarke and Rieley, 2010; Rydin and Jeglum, 2006).

To promote the revegetation of extracted peatlands the active restoration method involving the spreading of plant fragments from a donor site was developed in Canada (Quinty and Rochefort, 2003). Under favourable conditions, the moss layer transfer method has given good results in the restoration of bog vegetation and functioning over large areas in Canada (Gonzáles et al., 2013) and also on test areas in North European conditions (Järveoja et al., 2016; Karofeld et al., 2016). Early monitoring of the revegetation has led to the development of techniques to predict the outcomes of restoration and to make adjustments to achieve the desired results (Poulin et al., 2013; González and Rochefort, 2014). However, this method cannot be used for all types of extracted peatlands and it is important to find out the possibilities to favour their spontaneous revegetation aggravated by the unfavourable moisture conditions, substrate quality and lack of viable propagules (Triisberg et al., 2013a). There are several studies showing the positive effect of liming and application of ashes on plant growth on extracted peatlands (Paal et al., 2011; Kikamägi et al., 2013, 2014). Therefore, we were interested to discover whether the application of oil-shale ash combined with straw mulch can promote the vegetation recovery of extracted peatlands and can be recommended for application in the restoration of larger areas.

The main aim of the current study was to find out how to promote the revegetation of abandoned extracted peatlands. For that purpose we have conducted experiments on two extracted peatlands to test the effects of different treatments: 1. no activities (control), 2. straw mulch, 3. oil-shale ash and straw mulch, and 4. oil-shale ash. We were searching for answers to questions whether (i) the fertilising with alkaline oil-shale ash and/or mulching with straw promote formation of vegetation in bare peat, (ii) does it speed up establishment of plant species characteristic for natural mires? and (iii) does the closeness to vegetated bog areas have an effect on the speed and character of revegetation compared to central parts of abandoned peat areas?

2. Material and methods

2.1. Study sites

The field studies were carried out in Tähtvere (58° 23' 57" N, 26° 38' 25" E) and Keressaare (58° 50' 40" N, 27° 02' 29" E) extracted peatlands in East Estonia, *ca* 32 km apart from each other (Fig. 1). Both peatlands were abandoned after peat extraction with milling technique *ca* 30 years ago, but their total vegetation cover is still only a few percentages. In Tähtvere bog (total area 291 ha, max. thickness of peat layer 4.4 m; Orru, 1995) peat was extracted on 61.5 ha in the years 1968–1982. The average depth of the residual peat layer is 2.75 m (Ramst et al., 2006). The topmost peat layer (0–0.60 m) is slightly decomposed (16%) and consists of *Sphagnum* peat (mainly *fuscum* peat). In Keressaare bog (871 ha, max. thickness of peat layer 6.2 m; Orru, 1995) peat was extracted on 67.3 ha in the years 1965–1980. The average depth of the residual peat layer is 2.5 m (Ramst et al., 2006). The topmost peat layer (0–1.50 m) is well-decomposed (27–30%) and consists of *Sphagnum* peat (mainly *Sphagnum*–*Eriophorum* peat).

2.2. Experiment design

In July 2009 two study sites were selected in both peatlands: one site by the edge close to a vegetated area and the second in the centre of

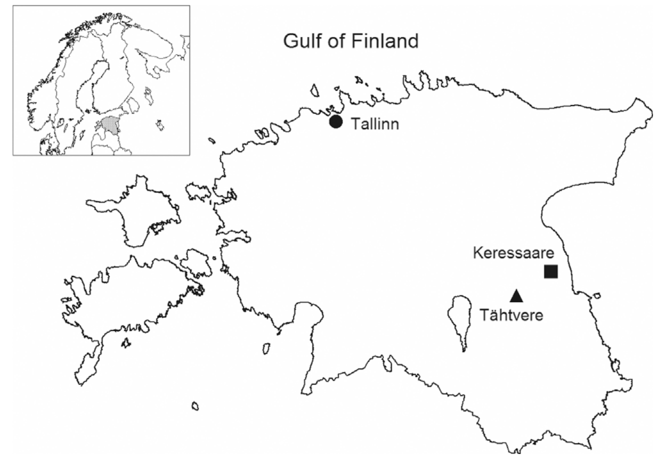

Fig. 1. Locations of Estonia in northern Europe (left up) and the two studied peatlands: Tähtvere (black triangle) and Keressaare (black square) in East Estonia.

a former peat extraction area, both at least 3 m from ditches. Study sites were prepared for experiment by removal of existing sparse vegetation and scraping the topmost *ca* 10 cm of the oxidised loose residual peat layer to create more suitable moisture conditions for germination of propagules. Consequently, revegetation of study sites would start from a zero baseline after the treatments. Every study site consisted of 40 permanent sample quadrats with an area of 1 m^2; n = 10 for control and each treatment. Quadrats were arranged in four rows, with a distance of 1.0 m between rows. Every row consisted of 10 quadrats; the distance between quadrats was 0.7 m. There were control quadrats and quadrats with three different treatments: 1 – sample quadrats without the treatment (Control), 2 – quadrats covered with straw mulch (Mulch), 3 – quadrats covered with oil-shale ash and straw mulch (Ash + Mulch) and, 4 – quadrats covered with oil-shale ash alone (Ash).

Sample quadrats treated with ash (treatments 3 and 4) received *ca* 350 g m^{-2} of ash from Ahtme power plant ash hill. Before application, the ash was dried in an oven at 90 °C for 48 h and sieved to remove propagules and for more even manual spreading. The oil-shale ash mainly consists of CaO, SiO2, FeO, MgO, Al2O3, Fe2O3 (Data on the chemical composition of fly ash and fossil fuels, 1995), with pH in water of *ca* 12. The ash from Estonian oil-shale power plants corresponds with the quality and safety standards in terms of fertiliser requirements established by law (Certificate of compliance, 2000). To improve the moisture conditions half of the quadrats (2 and 3) were covered by a *ca* 10-cm-thick fluffy layer of straw mulch (Quinty and Rochefort, 2003), and in the first summer were also covered by fishing net to avoid straw dispersal by wind. To raise the water table, peat dams were built in ditches alongside the study sites. Water-table depth (WTD) was measured in the centre of each study site from permanent perforated pipes during site visits in growing periods during 2009–2014 (n = 10).

2.3. Vegetation and environmental analysis

In every sample quadrat the vegetation was analysed in July 2011 (two years later), (ii) in August 2012 (three years later), and (iii) in July 2014 (five years later). In every quadrat the overall list of plant species, the total plant cover as well as the cover of every species (vascular plants and bryophytes) was estimated. The botanical nomenclature for vascular plants follows Leht (2010) and for bryophytes Vellak et al. (2015).

From each quadrat peat cores were taken using a plastic tube with a diameter of 6 cm from the topmost 0–10 cm in November 2011. Peat samples were held at 4–5 °C until the next day, afterwards they were dried at 60 °C (24 h) and weighed. For determining the pH and EC of peat solution distilled water was added at a weight ratio of 1:5. The