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Short-term Effects of Shallow *Sphagnum* Moss Biomass Harvesting on the Runoff Water Quality

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Abstract: White horticultural peat is proven to be a superior growing medium. It is microbiologically active, it binds nutrients and water significantly due to its favorable cation exchange capacity and porosity. Unfortunately, horticultural peat is a very slowly renewable biomass, and good quality horticultural peat is not so common even in peatland-rich countries. Therefore, good-quality and simultaneously renewable growing media alternatives are needed. A new growing medium introduced in recent years is based on *Sphagnum* moss biomass. According to our results, shallow *Sphagnum* moss biomass harvesting extended down to a depth of not over 30 cm did not cause any harmful effects on watercourses during the short-term period after harvesting. On the contrary, it is well-known that traditional peat extraction increases the leaching of suspended solids, dissolved organic carbon and nutrients, especially nitrogen and phosphorus into watercourses located downstream. The leaching of SS, DOC and nutrients from peat extraction areas is a significant local problem, since the nutrient leaching may cause enhanced eutrophication and decreased biodiversity, especially in vulnerable headwaters. Because of the probably negligible harmful effects on the water quality, *Sphagnum* moss biomass can be considered as a truly environmental-friendly growing medium compared with the conventionally extracted white horticultural peat.

Keywords: Renewable Growing Medium, *Sphagnum* Mosses, *Sphagnum* Moss Biomass Harvesting, Water Quality

1. Introduction

Nowadays, the two primary growing media used in greenhouse cultivation are rockwool and white horticultural peat (formed from *Sphagnum* mosses), from which white *Sphagnum* peat is by far the most widely used around the world [1-3]. Unfortunately, horticultural peat is a very slowly renewable biomass. In addition, good quality horticultural peat is diminishing even in the peatland-rich countries. Therefore, good-quality and simultaneously renewable growing media alternatives are needed. A novel growing medium studied in this study is based on the living *Sphagnum* moss biomass and it is introduced in the studies of Silvan *et al.* and Kämäräinen *et al.* [4, 5]. *Sphagnum* moss biomass is planned to harvest and regrow within ca. 30 years on the same site of the peatland, and it will be harvested from the mire surface down to the maximum depth of 30 cm [4].

Moderate industrial scale *Sphagnum* moss biomass harvesting for horticultural purposes has also been carried out for instance in North America, Australia and Chile for many

decades with promising results of recovery [6-9]. *Sphagnum* moss biomass harvesting has been carried out both during winter in snow and frost conditions (in North America) and during summer as well (in Australia) [6-8, 10]. During summertime, machinery used for *Sphagnum* moss biomass harvesting have to be equipped with extremely broad tracks (≥ 140 cm), and the normal tractor pulled carts cannot generally be used for *Sphagnum* biomass transportation instead of caterpillar type transporting machinery [4]. Despite the challenges, *Sphagnum* moss biomass harvesting is likely to be carried out successfully with appropriate machinery in summer too.

For growing medium purposes, hummock-forming and some lawn species (for instance *Sphagnum fuscum*, *S. rubellum*, *S. magellanicum* and *S. papillosum*) are the most applicable [5, 11]. The most successful habitats for these species are pristine nutrient-poor treeless or sparsely wooded bogs [12]. On many of forestry drained nutrient-poor and unprofitable peatlands there also exist adequate amounts of *Sphagnum* for harvesting purposes [12]. Due to the public

opinion, *Sphagnum* moss biomass harvesting should be directed to these drained peatland areas, for which there may not be any other profitable land-use options than *Sphagnum* moss biomass harvesting. This is not a significant dilemma in Finland where approximately one million hectares of unprofitable drained peatlands with low forest growth remain out of the wood production. It is estimated that ca. 300 000 ha from these almost million hectares could be utilised for *Sphagnum* moss biomass harvesting [4].

It is well-known that peat extraction with a conventional milling method highly increases the leaching of suspended solids (SS), dissolved organic carbon (DOC) and nutrients, especially nitrogen (N) and phosphorus (P), into watercourses located downstream, mainly due to the intensive drainage and milling of the surface peat e.g. [13-16]. The leaching of SS, DOC and nutrients from peat extraction areas is a significant local environmental problem, since the nutrient leaching may cause enhanced eutrophication and decreased biodiversity, especially in vulnerable headwaters [15, 17-20]. However, fortunately, *Sphagnum* moss biomass harvesting cannot be compared to peat extraction as a method. Since the very low ash and nutrient concentrations in living, undecomposed *Sphagnum* moss biomass, the shallow harvesting depth not reaching decomposed, nutrient-rich peat layers or mineral soil, and no need of drainage during *Sphagnum* moss biomass harvesting [4, 21], it is probable that the harmful effects on watercourses will remain very moderate.

The aim of this study was to: monitor and quantify the short-term effects of *Sphagnum* moss biomass harvesting on watercourses. We hypothesized that the effects caused by *Sphagnum* moss biomass harvesting on the watercourses will remain relatively small and only short-term.

2. Methods

2.1. Study Site Characteristics and *Sphagnum* Moss Biomass Harvesting

The study was carried out at Tunkiosalonneva, in Central Finland (62°19'N, 22°80'), over a one year from October 2009 to October 2010. Tunkiosalonneva was the first demonstration *Sphagnum* moss biomass harvesting area in Finland with ca. 2 hectares and ca. 2000 m³ harvested *Sphagnum* moss biomass (Figure 1) [22]. The study site was constructed so that the effects on water quality caused by *Sphagnum* moss biomass harvesting were possible to monitor, i.e. the catchment area was small with no remarkable external SS or nutrient loads (Figure 1). Tunkiosalonneva was a typical nutrient-poor forestry drained peatland in Central Finland. Ditch network at Tunkiosalonneva was sparse and partly deteriorated allowing the rise of water table level and thus favoring the recovery of *Sphagnum* mosses. The original mire site type of the study site was a low sedge *S. papillosum* pine fen [12]. The long-term (1987-2017) annual mean temperature of the site is ca. 3.0°C, the annual mean precipitation is approximately 605

mm and the accumulative temperature sum (+5°C) is ca. 1050 degree-days.

Sphagnum moss biomass was harvested in August-September 2009 from the mire surface down to a maximum depth of 30 cm [22]. The best harvesting period in central Finland and in normal weather conditions has been shown to be during early autumn, when the depth of water table level is the lowest, and therefore the carrying capacity of the peat soil is the highest.

2.2. Water Quality Monitoring and Analyses

Runoff (l s⁻¹ ha⁻¹), pH, suspended solids (SS), dissolved organic carbon (DOC) (mg l⁻¹), total nitrogen (N_{tot}), ammonium-nitrogen (NH₄⁺), nitrate-nitrogen (NO₃⁻), total phosphorus (P_{tot}) and phosphate-phosphorus (PO₄³⁻) (µg l⁻¹) concentrations were monitored at the study site during October 2009-October 2010. Runoff rates were measured using triangular Thomson's (90°) measuring weir (introduced by James Thomson first time in 1859) equipped with an automatic water level recorder allowing continuous measurements. The runoff rates were measured only below of the harvesting area (lower weir), and they were assumed similar to above of the harvesting area (upper weir) (Figure 1). Water samples were taken approximately biweekly from both upper and lower measuring weirs during summertime (May-October). During winter (November-April), water samples were taken ca. monthly if there was existing runoff.



Figure 1. The schematic map of the study site.

The inflow water was discharged from a small, mainly forestry drained peatland containing catchment area upstream from the study area. We used the load from the upper catchment area (inflow water) as a background load. SS and nutrient loads from the site were determined by subtracting background load from outflow load. In this study, load from the *Sphagnum* moss biomass harvesting area was therefore considered as an input-output balance or as a surplus in the

load caused by *Sphagnum* moss biomass harvesting.

Water samples were taken directly into 500 ml plastic bottles from the upper and lower measuring weirs (Figure 1). Water pH was analysed from fresh water samples within 24 hours after sampling with Philips PW 9422 pH meter. Prior to SS analysis, the samples were stored at +5°C, and prior to other analyses at -20°C. SS concentration was determined by filtering the water samples (fibre-glass, pore size 1.2 µm), and then weighing the tared filters dried at +60°C. The concentrations of DOC were analysed from filtered water with a Shimadzu TOC-5000 carbon analyzer, the concentrations of dissolved N_{tot} , NH_4^+ and NO_3^- with a Foss Tecator Fiastar 5000 FIA-analyzer, the concentrations of P_{tot} with a plasma emission spectrophotometer (Iris AP HR-DUO-ICP), and the concentrations of PO_4^{3-} spectrophotometrically with UV-240 JPC Shimadzu-spectrophotometer. All water chemistry analyses were performed in the accredited laboratories of the former Finnish Forest Research Institute (presently Natural Resources Institute Finland). Statistical differences between

the SS and nutrient concentrations and loads from inflow and outflow water were analyzed with paired t-tests, which were performed using the SPSS 22.0 statistical tool package (SPSS Inc.). Test results were considered significant if $p < 0.05$.

3. Results and Discussion

The mean annual temperature at Tunkiosalonneva during 2009-2010 was only slightly lower than the long term average of 1987-2017 (3.0 and 3.8°C, respectively). However, the temperature of July in 2010 was clearly higher than the long term average of 1987-2017, but on the other hand, the temperature of January in 2010 was clearly lower than the long term average of 1987-2017 (Figure 2). The annual cumulative precipitation during 2009-2010 was nearly same than the long term average of 1987-2017 (46.8 and 50.5 mm, respectively). However, the precipitation in June 2010 was clearly higher than the long term average of 1987-2017, but in January oppositely clearly lower than the long term average of 1987-2017 (Figure 2).

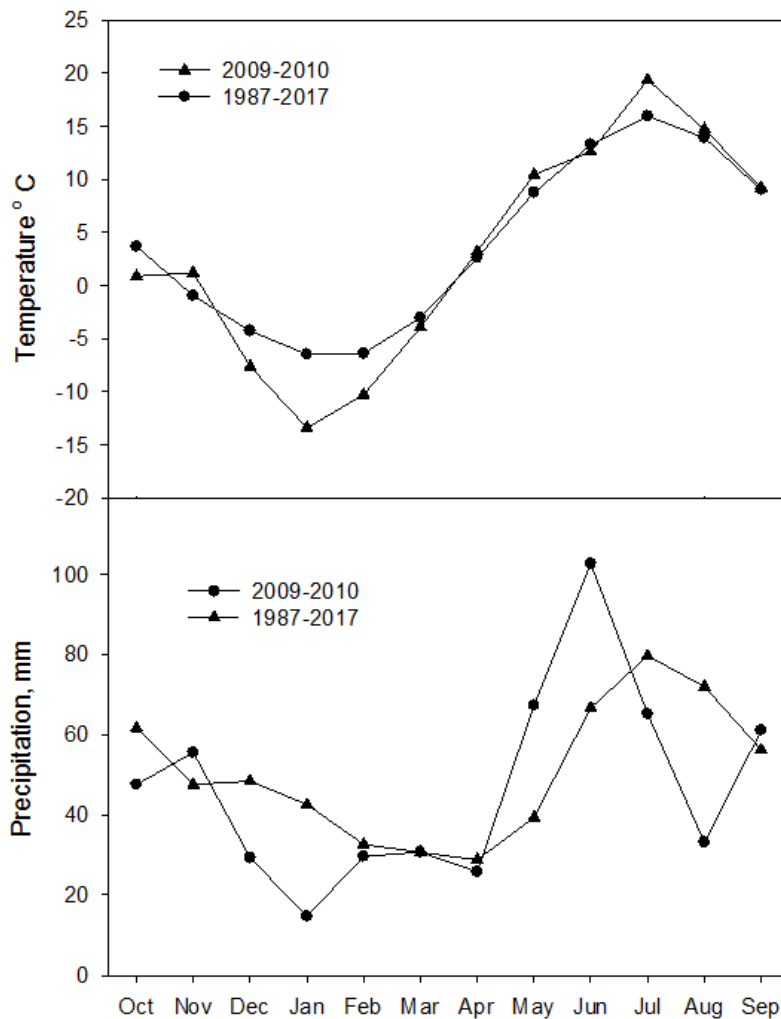


Figure 2. Mean air temperature and monthly precipitation at Tunkiosalonneva from October to October in 2009-2010 and as 30-year average 1987-2017.

Runoff rates varied rather largely within the study year (Figure 3), which is the normal phenomenon in the middle boreal climate type. The observed peak runoff rate was rather

high, $3.2 \text{ l s}^{-1} \text{ ha}^{-1}$, and occurred during the spring flood season in early April (Figure 3). On the other hand, in midwinter there was no existing runoff from the site (Figure

3). Also some thunderstorm occasions with high precipitation in June caused rather high runoff rates, $1.9 \text{ l s}^{-1} \text{ ha}^{-1}$. However, in general, weather conditions during the study period can be considered as rather normal for Central Finland, and therefore there were observed no severe

anomalies in the runoff data. Since the runoffs from the study site were rather normal, and since the study site was a typical middle boreal, nutrient-poor peatland, the results could probably be well generalized over the whole Southern and Central Finland.

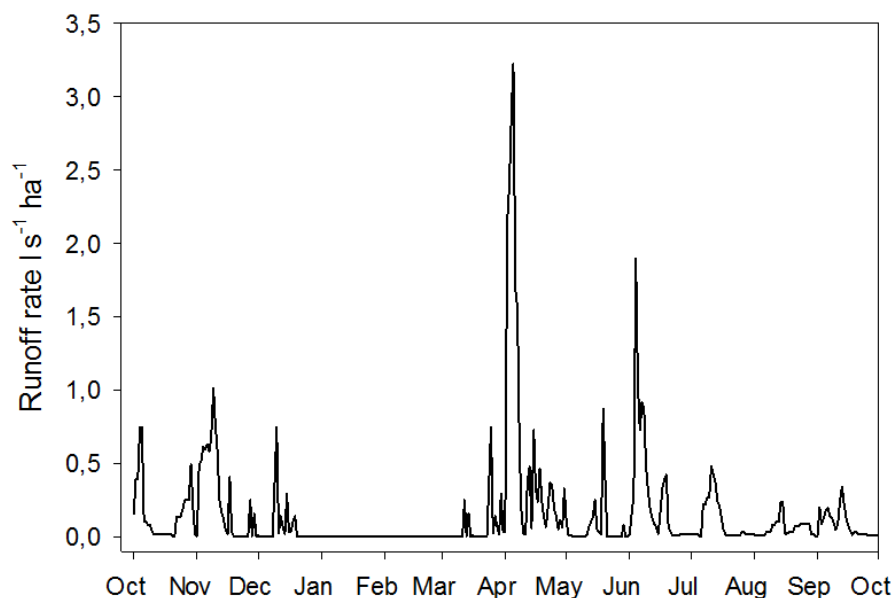


Figure 3. Runoff rates ($\text{l s}^{-1} \text{ ha}^{-1}$) at Tunkiosalonneva during October 2009-October 2010.

In this study, no significant differences ($p < 0.05$) between the concentrations of SS, DOC and nutrients in the inflow and in the outflow water were observed (Table 1). Because of the clear peak in runoff rates in springtime, also maximum SS, DOC and nutrient loads occurred during spring flood in early April. However, average annual loads of SS, DOC and nutrients followed the concentration of SS, DOC and nutrients in runoff water (Table 2), and therefore we observed no significant differences ($p < 0.05$) between the loads nor the concentrations of SS, DOC and nutrients.

Table 1. Average total concentrations of SS and DOC (mg l^{-1}) and nutrients ($\mu\text{g l}^{-1}$) in the inflow and in the outflow water during October 2009-October 2010.

	Inflow	Outflow
SS, mg l^{-1}	3.0	3.2
DOC, mg l^{-1}	5.2	5.2
N_{tot} , $\mu\text{g l}^{-1}$	540	545
NH_4^+ , $\mu\text{g l}^{-1}$	72	68
NO_3^- , $\mu\text{g l}^{-1}$	18	13
P_{tot} , $\mu\text{g l}^{-1}$	14	16
PO_4^{3-} , $\mu\text{g l}^{-1}$	3	3

Table 2. Average annual loads of SS and DOC ($\text{kg a}^{-1} \text{ ha}^{-1}$) and nutrients ($\text{g a}^{-1} \text{ ha}^{-1}$) caused by *Sphagnum* moss biomass harvesting during October 2009-October 2010.

Load	
SS, $\text{kg a}^{-1} \text{ ha}^{-1}$	1.0
DOC, $\text{kg a}^{-1} \text{ ha}^{-1}$	0.0
N_{tot} , $\text{g a}^{-1} \text{ ha}^{-1}$	9.6
NH_4^+ , $\text{g a}^{-1} \text{ ha}^{-1}$	0.0
NO_3^- , $\text{g a}^{-1} \text{ ha}^{-1}$	24.0
P_{tot} , $\text{g a}^{-1} \text{ ha}^{-1}$	-24.0
PO_4^{3-} , $\text{g a}^{-1} \text{ ha}^{-1}$	-19.2

In general, observed runoff rates in this study were of the rather similar magnitude as in the earlier studies from Finnish pristine mires, and also from peatlands drained for forestry [14, 23-27]. However, peak runoff rates may be higher on peatlands drained for forestry compared to the peak runoff rates of pristine mires [14, 23-27]. In this study, the observed peak runoff rate was $3.2 \text{ l s}^{-1} \text{ ha}^{-1}$ while the annual mean runoff rate was $0.2 \text{ l s}^{-1} \text{ ha}^{-1}$, thus the peak runoff rate was only approximately 21-fold compared to the annual mean. Also the concentrations of SS and nutrients observed in the runoff water in this study chiefly corresponded to the very low concentrations observed in pristine mires in Central Finland [14, 23, 24]. Although Tunkiosalonneva can be defined as a forestry drained peatland, the ditch network of the area was sparse and deteriorated, and therefore Tunkiosalonneva functioned hydrologically chiefly as a rather normal pristine mire in Central Finland [28]. Additionally, *Sphagnum* moss biomass harvesting without any kind of drainage before or during the harvesting operation did not cause any peak runoffs increasing bypass flows from the area, on the contrary of peat extraction or of forest drainage [14, 26, 27, 29]. It is known that the major part of SS and nutrient load from peatlands occurs during the peak runoffs [14, 23, 24]. Thus, the rareness of large peak runoffs from the *Sphagnum* moss biomass harvesting area due to the lack of new ditches is a one reason for the negligible effects on water quality. Probably the most important reason, however, is that during *Sphagnum* moss biomass harvesting only the uppermost, nutrient-poor 30 cm layer of the soil is harvested, and without drainage. Therefore only the very low amounts of SS and nutrients leached into

the runoff water compared to the other land-uses of the peatlands [14, 16, 23, 26, 29], thus resulting only negligible effects on water quality.

4. Conclusions

Although the peat reserves in Finland are very large, under high demand conditions the lack of good-quality horticultural peat may become a reality in the near future. The best areas for extraction of good-quality horticultural peat are large pristine raised bogs, which are also very valuable as nature sanctuaries. In southern Finland and, especially, in central Europe, the pristine mires that are large enough for extraction of horticultural peat are protected for nature conservation. *Sphagnum* biomass harvesting provides a renewable alternative constituent for growing media with negligible environmental effects in comparison to conventional production of horticultural white peat. For the most part, *Sphagnum* biomass harvesting is more closely comparable with sustainable forestry than with white peat production. However, this preliminary study was based on the only one intensively investigated study site and on the one study year after shallow *Sphagnum* moss biomass harvesting. Thus, the further research with more study sites and with the longer study period is needed in the near future achieving the more generalized results.

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