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Effect of stockpiling time on donor-peat hydrophysical properties: Implications for peatland restoration

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ABSTRACT

Northern peatlands are an important global climate regulator storing approximately one-third of the global carbon pool, however the degradation of these ecosystems from land-use change can switch peatlands to persistent and long-term sources of atmospheric carbon dioxide. Active restoration is often required to return degraded peatlands to a net carbon sink. The peat-block restoration technique, where intact peat blocks are extracted from a donor peatland and transferred to restore peatlands where the remnant peat is non-existent, contaminated, and/or undergoes seasonal flooding is increasingly being adopted as a peatland restoration technique given the carbon sequestration that can occur immediately post-restoration. However, donor peat blocks often need to be temporarily stockpiled during the restoration process due to logistical constraints. The dewatering of the peat blocks during this stockpiling period may alter hydrophysical peat properties that sustain critical peatland ecohydrological functionality and ultimately affect peatland restoration success. Yet, the hydrophysical evolution of stockpiled peat blocks remains unknown. Here, we examine how peat block stockpiling time (3, 7, 11, and 14 months and a reference site) impacts peat hydrophysical properties and sphagnum moss photosynthesis, both of which are critical for peatland restoration success. Stockpiling peat differentially impacted the hydrophysical properties between the shallower and deeper peats, where little to no impact from stockpiling was observed in the shallower peats, regardless of stockpiling time. Rather, as stockpiling time increased, there was a marked decrease in macroporosity (pores >75 μm) and mobile porosity (drainable porosity at approximately −100 hpa) at depths below 20 cm but the water conducting matrix porosity (defined as mobile porosity minus macroporosity) was not significantly different than the reference samples. However, stockpiling created inhospitable conditions for sphagnum mosses., as chlorophyll fluorescence ratio was below 0.3, indicating little to no photosynthesis of the stockpiled peat during summertime drought conditions. Taken together, we suggest limiting stockpiling time as much as possible would be advantageous for using the stockpiled peat blocks for the peat-block restoration technique or other restoration efforts, such as floating mat creation.

1. Introduction

Northern peatlands represent a globally important climate regulator and freshwater resource, storing approximately one-third of the global soil carbon pool (Turunen et al., 2002; Yu, 2012; Gorham, 1991) and accounting for approximately 10% of global surface fresh water (Holden, 2005). These ecosystems are also considered key refugia capable of extended resistance to environmental change (Stralberg et al., 2020) and play important roles in maintaining local and regional biodiversity (Chapman et al., 2003) by providing critical habitat (Markle et al., 2020). However, the degradation of these ecosystems due to peatland drainage for forestry or agriculture, road construction, atmospheric pollution deposition, peat extraction, and natural resource extraction can critically degrade these ecosystem services (Davidson et al., 2021; Andersen et al., 2013; Waddington and Price, 2000). For example, peat extraction not only results in the loss of "irrecoverable carbon" (Harris et al., 2021) but also switches the degraded peatland to a net carbon source (e.g., Rankin et al., 2018; Waddington et al., 2002). Given that over 20 Mha of northern peatlands have been mined or drained for forestry alone (Joosten, 2004), it is important to develop mitigation

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strategies to reduce the carbon losses from these managed ecosystems (Paustian et al., 2019). In some cases, land-use change (e.g., agriculture, road construction, natural resource extraction, reservoir construction) can result in the complete removal of peatlands from the landscape leading to a concomitant decline in critical ecosystem services. As such, from a global climate mitigation, regional water storage and local habitat perspective the restoration of degraded peatlands and the construction of new peatlands represent important nature-based solutions (Drever et al., 2021).

Peatland restoration as a nature-based solution not only can shift degraded peatlands from a net source of CO_2 to a net sink within approximately 20 years (Nugent et al., 2019; Nugent et al., 2018; Strack and Zuback, 2013) but recent studies have also identified that peatland restoration can have a biophysical climate mitigation potential (Helbig et al., 2020), increase water storage (Liu et al., 2022) and reduce wildfire burn severity (Granath et al., 2016). The moss layer transfer technique (MLTT) (Quinty and Rochefort, 2003) is the most commonly adopted approach for degraded peatland restoration and has been shown to return critical peatland vegetation (Chimner et al., 2016), CO_2 dynamics (Nugent et al. 2019) and some ecohydrological functionality (Waddington et al., 2011; McCarter and Price, 2013; McCarter and Price, 2015) within relatively short timescales. Briefly, this method consists of blocking drainage ditches and building peat berms to retain more water in the peatland followed by the application of donor peatland sphagnum moss fragments and straw or wood mulch to the surface of the degraded peatland. However, the MLTT is often unsuitable in areas where the remnant peat is non-existent (Daly et al., 2012; Price et al., 2010), contaminated and/or the degraded peatland is located in a basin where seasonal flooding is likely (Wilhelm et al., 2015). An alternative peatland restoration method, known as peat-block restoration technique, also referred to as an acrotelm transplant or wet harvesting, involves the transfer of extracted peat blocks (usually the upper few decimeters) from a donor peatland and directly placing them on the degraded peat surface (Cagampan and Waddington, 2008a), flooded peat surface (Tomassen et al., 2003; Kooijman et al., 2016) or on a constructed landscape (Daly et al., 2012). The thickness of the peat block reduces the likelihood of surface moss flooding (Wilhelm et al., 2015) and attenuates the upwelling of contaminants from underlying peat/sediment (Price et al., 2010), whilst allowing surface moss growth and CO_2 sequestration (Cagampan and Waddington, 2008b; Wilhelm et al., 2015). Where possible (and feasible) the transfer of extracted peat blocks from the donor peatland onto the restoration site should be done immediately to preserve the ecohydrological properties inherent within the peat block required for successful sphagnum growth.

The logistics of peatland restoration does not always allow for the immediate use of the extracted peat block, thus requiring the stockpiling of peat blocks. During stockpiling, the peat block dewaters resulting in peat and moss desiccation, potentially leading to the fundamental changes in the peat pore structure, such as collapse of the large pores resulting in peat surface subsidence, peat block compaction and the shrinking of peat, that sustains key ecohydrological processes (McCarter et al., 2020). This leads to an increase in peat bulk density and a decrease in specific yield and saturated hydraulic conductivity (Kettridge et al., 2013; Price et al., 2003). Long-term dewatering can lead to irreversible peat deformation that can reduce the compressibility of peat and result in irreversible losses in pore volume (Kennedy and Price, 2004). This not only reduces the water storage capacity of the peatland but also increases the likelihood of wetland flooding during wet conditions and the likelihood of sphagnum moss moisture stress during dry periods. Stockpiling peat also enhances peat nutrient mineralization (Nwaishi et al., 2015a) and together with the aforementioned changes in peat hydrophysical properties has the potential to impact sphagnum moss photosynthesis (Thompson and Waddington, 2008), vegetation growth and restored peatland trajectories and ecohydrological function (Nwaishi et al., 2015b). Despite the importance of peat stockpiling time on peat hydrophysical properties we are unaware of any studies that have examined this important aspect of peatland restoration. Here we examine how peat block stockpiling time (3, 7, 11, and 14 months) impacts peat hydrophysical properties that are critical for peatland restoration success.

2. Methods

2.1. Study area and experimental design

This study was conducted in peatlands located at the Henvey Inlet Wind Energy Centre (HIWEC), in the eastern Georgian Bay region approximately 80 km south of Sudbury, Ontario, Canada. The HIWEC landscape is comprised of flat to gently rolling exposed gneissic shield bedrock ridges with peatlands varying in depth from tens of centimeters to several meters in bedrock depressions (Markle et al., 2020; Wilkinson et al., 2020). The peatlands are dominated by *Sphagnum* spp., ericaceous shrubs (*Ericaceae*), taller willows (*Salix*), alders (*Alnus*), peatland forbs, sedges (*Carex*), ferns (*Polypodiopsida*), and trees including black spruce (*Picea mariana*), tamarack (*Larix laricina*), jack pine (*Pinus banksiana*) and eastern white pine (*Pinus strobus*). The region has an annual precipitation of 1090 mm, of which 327 mm is snowfall (Environment Canada, 2018). The mean annual temperature is 5.8 °C (Environment Canada, 2018).

During the construction of the HIWEC, several dozen peat blocks (~1 m × 1 m × 0.5 m, L x W x H) were extracted from two donor peatlands in June 2018 (stockpile A) and September 2018 (stockpile B) due to road construction and stockpiled on open rock barrens until the fall of 2019 for use in future peatland restoration efforts. Peat cores (n = 3–4) were extracted from peat blocks in stockpile B in December 2018 and August 2019 and stockpile A in January and August 2019. Extracting peat cores from the two different stockpiles on two different occasions, provided donor peat samples with stockpiling times of 3-, 7-, 11- and 14-months following extraction. Peat cores were also extracted from hollow (n = 3), lawn (n = 3) and hummock (n = 3) microforms in nearby undisturbed natural reference sites in August 2019.

2.2. Peat sampling and hydrophysical properties analysis

For the December and January peat sampling, a sharp metal wedge and sledgehammer were used to cut frozen stockpiled peat into 30 × 40 × 50 cm cubes in the field, which were thawed and subsampled into 10 cm interior diameter PVC casing to a depth of 40 cm in the lab. Roots were cut around the edge of the PVC casing in order to not compress any portion of the sample. For the August peat sampling peat was cored directly into 10 cm diameter PVC casings to a depth of 40 cm whilst being cautious to minimize peat compression. The peat in the PVC casings were then frozen and later cut into 5 cm sections or "pucks" with a bandsaw. Recently, Golubev et al., (2021) illustrated that a 5 cm section effectively captured the hydrophysical properties of sphagnum moss and peat.

Prior to analysis for peat hydrophysical properties, peat pucks were thawed and saturated for 24 h in deionized water. The volume of the saturated peat was measured with a caliper, by measuring the height of the peat at four locations relative to the height of the PVC, and the diameter of the peat relative to the PVC. This method was used to track changes in the peat volume with shrinking and swelling. The peat samples were placed onto a 56 cm diameter porous ceramic pressure plate (Soil Moisture Equipment Corp, Santa Barbara, CA) with an air entry pressure of −1 bar. The mass and volume of the peat pucks were measured after 24 h of suction. Evaporation was limited by keeping the ceramic plates in a plexiglass enclosure. Open water baths were kept in the enclosure and chamber walls were misted every time after opening for measurements in order to maintain a high relative humidity within the chamber. For each pressure step the volumetric water content (VWC $m^3\ m^{-3}$) was calculated as the ratio of water volume to sample volume for both stockpiled and reference site peat.

Measurements were made at pressure steps of −10, −20, −30, −40, −50, −75, −100, −150, −200 and − 500 hPa to construct the soil moisture retention curve (SMRC). Volume measurements and re-saturation of the pressure plates were conducted at each pressure step as these are major causes of error for accurate determination of the SMRC (Bittelli and Flury, 2009). At pressure steps of 200 and 500 hPa, the samples were placed on the pressure plates for 48 h before being removed and weighed to account for slow tortuous flow through smaller pores. The bulk density of the peat was determined after all other pressure steps were completed by oven drying samples at 65 °C for 48 h. The bulk density was then calculated as the mass of oven dry peat (not including the mass of the PVC puck), divided by the volume of peat. The macroporosity and mobile porosity were determined by the drainable porosity at approximately −25 hPa (Soil Science Society of America, 2008) and − 100 hPa (McCarter et al., 2019), respectively. The difference between the macroporosity and mobile porosity represents the majority of pores that will conduct water, represented here as the "water conducting matrix porosity". Under typical field conditions (e.g., soil water pressures above −100 hPa), the macroporosity and the water conducting matrix porosity would contribute the majority of vertical water flow.

A Kruskal Wallis test and post hoc Dunn test were performed in R Statistical Software (R Development Core Team, 2021) to evaluate if the bulk density of stockpiled peat differed between stockpiling durations and between stockpiled and reference site peat. Since individual microform identification was not available for the stockpiled peats, the different reference site microforms were lumped into one "reference" category to capture the natural range of bulk density.

2.3. Chlorophyll fluorescence

To quantify the moisture stress and photosynthetic ability of stockpiled samples, chlorophyll fluorescence was measured using an OS30p+ chlorophyll fluorometer (Opti-Sciences, Hudson, New Hampshire, U.S. A) for sphagnum moss capitula during drought conditions in the summer of 2019 (stockpile time of seven months) and compared to the reference site. The optimal quantum yield of photosystem II as represented by Fv/Fm was measured and reported Fv/Fm values represent the average of the three replicate capitula. The Fv/Fm is the ratio of variable fluorescence divided by the maximal fluorescence emitted when light of specific intensity and wavelength is directed at photosynthetic tissue (Hájek and Beckett, 2008). This ratio has been shown to be an indicator of plant photosynthetic performance (Baker and Oxborough, 2004; Hájek and Beckett, 2008). This measurement represents the efficiency of photosystem II and values between 0.79 and 0.89 represent theoretical maximal values for bryophytes in an unstressed state (Adams and Demmig-Adams, 2004). Values that fell below the minimum threshold for measurement of approximately 0.3, were assigned an Fv/Fm value of zero. Before measurement, samples were dark adapted for 20 min to progressively close photosystem II reaction centers, to have maximal fluorescence upon exposure to light (Baker and Oxborough, 2004). A Wilcoxon rank-sum test was performed to evaluate if there were differences in the Fv/Fm between stockpiled and reference peat.

3. Results

Bulk density increased with depth from peat surface (Fig. 1) and increased the greatest over longer stockpile times and at greater peat depths, almost doubling after 14 months in the deepest peat (Fig. 1). The reference peat had significantly lower mean bulk densities for the top 15 cm than the newer stockpiled peat ($Z = -3.99$, $p < 0.01$, $n = 81$), and older stockpiled peat ($Z = -3.37$, $p < 0.01$, $n = 81$) (Fig. 2). While at depths greater than 15 cm, the older stockpile peat had significantly higher bulk density than the new stockpiled peat ($Z = 2.77$, $p < 0.05$, $n = 81$) and the reference peat ($Z = -3.67$, $p < 0.01$, $n = 81$) (Fig. 1b).

Soil water retention followed the same pattern as bulk density, where the shorter stockpiled times and shallower peats did not substantially increase in VWC at most pressure steps (Fig. 3). Over the pressure range tested, the shallower peats had a greater change in VWC relative to the deeper peats (Fig. 3). Since the relative change in VWC for a given decrease in pressure was lower in the deeper and longer stockpiled peats (14 months), there would be a more uniform theoretical pore size distribution in these peats compared to the reference and upper stockpiled peats (Fig. 3). The change in pore size distribution was likely driven by an initial increase in macroporosity that began at as little in 3 months of stockpiling, peaking at 7 months (Fig. 4a). After which, there was a marked decline in macroporosity with longer stockpiling times, reaching 0% macroporosity by 14 months of stockpiling and were similar to reference lawn and hollow but not the hummock (Fig. 4a). The total mobile porosity followed the changes in macroporosity with depth and time of stockpiling (Fig. 4b). However, the resulting change in the primary water conducting matrix pores was negligible due to stockpiling regardless of stockpiling time or sample depth (Fig. 4c).

During the drought conditions in summer 2019, mean chlorophyll fluorescence was found to be significantly lower in stockpiled peat ($W = 821$, $p < 0.01$) than reference peat (Fig. 5). Most of the observations of stockpiled peat fell below the 0.3 threshold for measurement for Fv/Fm and can be assumed to be photosynthetically inactive. In contrast, the reference peat remained within or below (0.68 +/− 0.19) theoretical maximal values (0.79–0.89) for bryophytes in an unstressed state (Adams and Demmig-Adams, 2004).

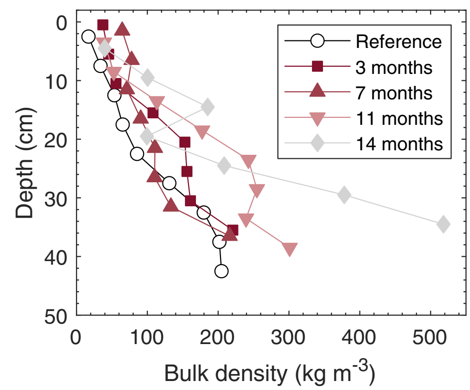

Fig. 1. Mean bulk density (kg m-3) for stockpiled peat (3, 4, 7 and 14 months) and the reference pristine peatland. Plotted depths are offset by up to 2 cm for visual clarity.

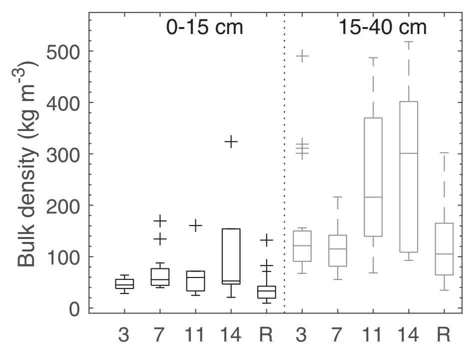

Fig. 2. Bulk density between reference (R) wetlands and stockpiled peat (3, 7, 11, and 14 months) for the top 15 cm and 15–40 cm from the peat surface.

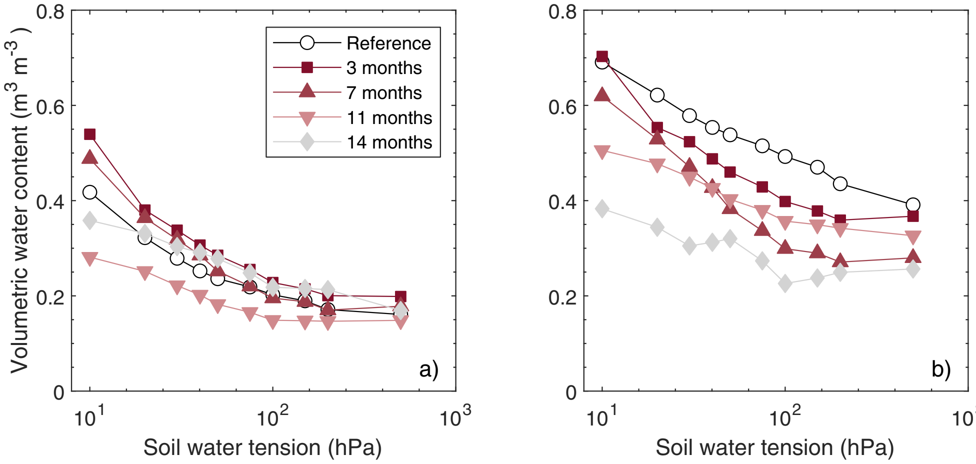

Fig. 3. Soil water retention curves for the top 15 cm (a) and 15–40 cm (b) of reference and stockpiled peat.

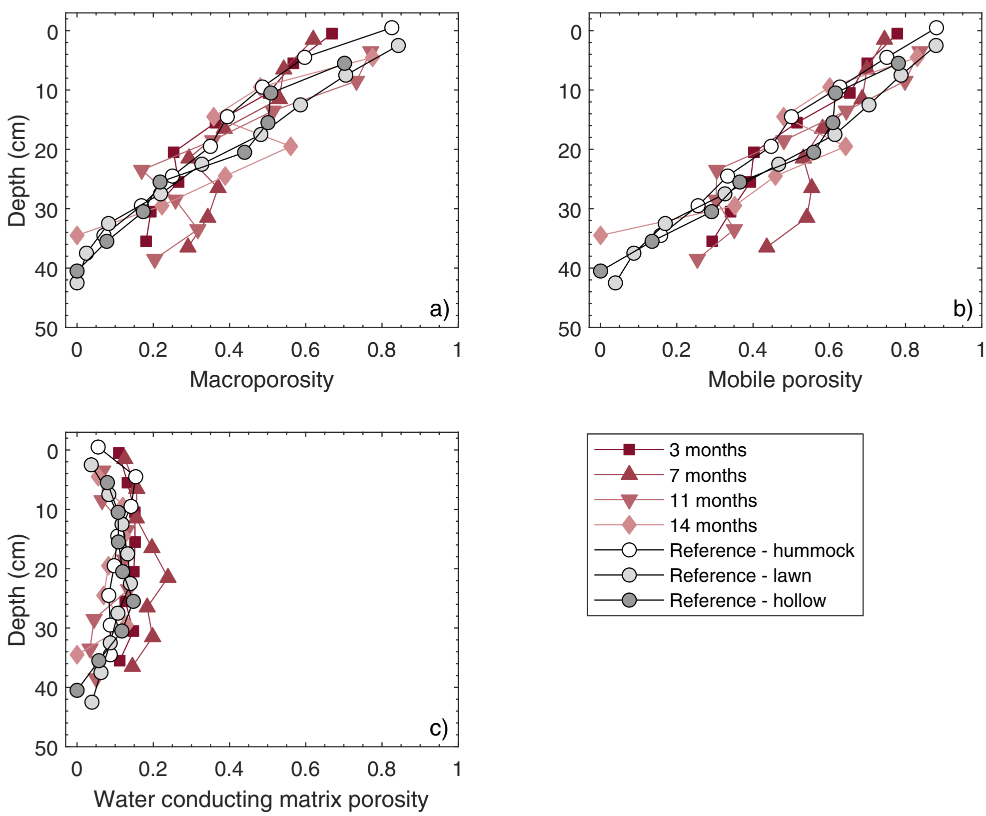

Fig. 4. a) macroporosity, b) mobile porosity, and c) water conducting matrix porosity with depth for stockpiled (maroon) and reference (grey) peat. The macroporosity and mobile porosity were determined by the drainable porosity at approximately −25 hPa (Soil Science Society of America, 2008) and – 100 hPa (McCarter et al., 2019), respectively. The difference between the macroporosity and mobile porosity represents the majority of pores that will conduct water, represented here as the “water conducting matrix porosity”.

4. Discussion

4.1. Peat hydrophysical properties

Stockpiling peat for future restoration or other uses significantly alters the pore structure of the peat, where the longer the peat is stockpiled, the greater the change in peat pore structure. As the stockpiled peat is left without an accessible water source (i.e., the water table), both decomposition of the organic structure (Waddington and Price, 2000) and primary consolidation of the pore network (Price and Schlotzhauer, 1999) can alter the soil hydraulic properties (Price et al., 2005). Given the interactions of the WT – decomposition feedback (Waddington et al., 2015), we would expect that the increase in peat decomposition would result in an increase in surface and near-surface VWC. However, our observation of similar VWC, macroporosity, and mobile porosity for depths of 0–15 cm between our reference and stockpiled peat, suggests that under the relatively short timescales studied here, decomposition is unlikely to be measurable by the hydrophysical measurements. The observed decrease in macroporosity and mobile porosity in the deeper peat over longer stockpiling times was driven by the increase in bulk density, and subsequent decrease in total porosity. Since there was no observable change in the upper peats, the changes in the deeper peat were more likely due to physical consolidation of the peat, rather than the slower decomposition processes.

Primary consolidation of any soil occurs when the water filled pores drain, replacing relatively incompressible water (Freeze and Cherry, 1979) with much more compressible air. In undisturbed peatlands, this often occurs as the water table decreases and results in a mostly

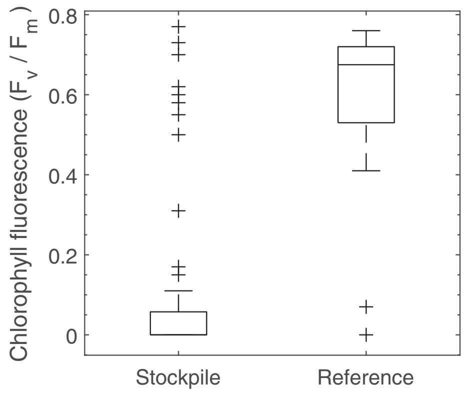

Fig. 5. Chlorophyll fluorescence for stockpiled peat and natural peat during summer drought conditions.

reversible change in pore structures (Price, 2003). While many sphagnum-dominated peatlands can have a relatively large vadose zone (also referred to as an acrotelm in peatland literature), it often retains enough water to prevent substantial deformation of the peat structure (Price, 2003; Kennedy and Price, 2005; Kettridge et al., 2013). The seasonal deformation of the peatland vadose zone is often called mire breathing and can have significant impacts on the hydrological processes that sustain many critical peatland functions (Golubev and Whittington, 2018). When peat is drained and stockpiled for longer time periods, there is no longer enough water to prevent significant consolidation of the peat, resulting in a decrease in the abundance of macropores and a concomitant increase in smaller pore sizes. These processes did not occur throughout the profile equally, rather we observed greater consolidation in the deeper peat as the length of stockpiling increased. Within these longer stockpiled deeper peats the bulk density increased several-fold and the macroporosity decreased by between 20 and 50%. The decrease in macroporosity drove the majority of the decrease in mobile porosity, as the water conducting matrix porosity did not change due to stockpiling. The observed change in bulk density and pore size distribution of these deeper peats was far greater than the seasonal deformation observed in undisturbed peatlands (Price, 2003; Kennedy and Price, 2005; Kettridge et al., 2013; Golubev and Whittington, 2018). Seasonal deformation is thought to occur in the sphagnum and near-surface peat (Golubev and Whittington, 2018) and not in the deeper peat depths as we observed in the stockpiled peats. Such large changes in the pore structure of what is considered relatively "stable" peat may induce irreversible peat consolidation, particularly as little is known about the response of the stress-strain relationship of peat macropores (Kettridge et al., 2013). Further compounding the potential for irreversible peat structural changes is the physical act of extracting the peat-blocks. During the initial few months of stockpiling, macroporosity increased suggesting at least some measurable disturbance of the basal peat due to extraction.

4.2. *Implications for peatland restoration*

The overall success of any potential peatland restoration or reclamation project will depend on the overall management and restoration/reclamation goals (Ketcheson et al., 2016; McCarter et al., 2021). By focusing on retaining the original structure of the peat by extracting the upper few decimeters of the peatland, rather than just placing the peat in a disorganized pile, there are a greater number of uses and restoration/reclamation outcomes. Specifically, the stockpiled peat in this study could be used to return ecohydrological functionality to horticulturally extracted peatlands (Cagampan and Waddington, 2008a) and metal contaminated peatlands, and create floating mats (Wilhelm et al., 2015). In each of these instances the evolution in peat hydrophysical properties due to the length of time the peat is stockpiled could impact the magnitude of intervention and ultimate success of any restoration/reclamation effort.

4.2.1. *Ecohydrological functionality*

Returning critical peatland processes, such as net carbon sequestration, to disturbed and degraded peatlands require the restoration of the hydrological connectivity between the degraded peat and restored sphagnum moss capitula. The hydrological connectivity depends on both the specific pore size distribution of the moss to maintain capillary continuity with the remnant peat and the effectiveness to transmit water from the base of the restored/regenerated moss to the capitula (McCarter and Price, 2015). While stockpiling peat-blocks over longer time periods (e.g., $>$ 1 yr) did not measurably change the near-surface pore distribution and soil water retention, the proportion of macropores decreased at the base of the profile. A shift to a lower abundance of macropores and greater relative abundance of water conducting matrix pores at the interface peat will likely result in greater capillarity between the moss and remanent peat (Gauthier et al., 2018; McCarter and Price, 2015). Once such capillary continuity has been established, the relatively unchanged pore structure in the rest of the moss profile would likely maintain sufficient hydrological connectivity to facilitate minimal hydrological stress of the capitula (McCarter and Price, 2015). This evolution of the basal peat coupled with the minimal change in the existing pore network of the near surface *Sphagnum* would likely result in an overall positive impact on hydrological connectivity, enhancing potential restoration success.

Restoring a sphagnum-dominated peatland by returning ecohydrological functionality requires both the return of key hydrological processes, as discussed above, and the keystone ecosystem engineer sphagnum moss. While stockpiling peat for longer periods creates hydrophysical conditions that would likely enhance the return of key hydrological processes, stockpiling appears to create conditions that are unfavourable to maintain healthy sphagnum moss. Chlorophyll fluorescence is a measure of the photosynthetic capacity of chlorophyll in the capitula and can be directly linked to overall sphagnum health, where lower chlorophyll fluorescence indicates that the sphagnum moss is under physiological stress. During drought conditions in 2019 (7 months of stockpiling time), it was apparent that the stockpiled peat was under a much greater degree of stress than the reference sphagnum moss. Although *Sphagnum* spp. are drought avoidant mosses and can tolerate periodic periods of limited water, such conditions can limit the recovery of the sphagnum moss, particularly if the stress is over a long time period (Bengtsson et al., 2016; Schipperges and Rydin, 1998; Thompson and Waddington, 2008). Since the stockpiled peat is generally unconnected to any water table, this physiological stress was likely due to limited moisture at the capitula, as desiccation of the capitula was evident at the peat stockpiles but not the reference sites during this period. Prolonged physiological stress may induce a greater die-off of the sphagnum moss, even after restoration, which would necessitate further interventions, such as phosphorous fertilization or "over-seeding" with the MLTT, after placement of the peat-block on the degraded peatland. Thus, the time-window for the stockpiling of peat-blocks becomes a balance between operational necessities, changes in hydrophysical properties, and limiting physiological stress of the sphagnum moss. Given the strong likelihood that any natural peat would sustain the critical hydrological processes without stockpiling, we recommend limited stockpiling times to reduce any physiological stress of the sphagnum moss and enhance the likelihood of restoration/reclamation success.

4.2.2. *Creation of floating mats*

The restoration of floating mat vegetation is important for returning the ecological and biogeochemical processes operating in many peatland ponds (Tomassen et al., 2003, 2004; Wilhelm et al., 2015). Tomassen et al. (2004) observed that a peat-block pH:bulk density ratio above 0.05 kg m^{-3} is required to have sufficient buoyancy to ensure the floating mat does not become inundated and host typical floating mat carbon dynamics. Assuming a range of pH from 4 to 6, the longer stockpiled peats (11 and 14 months) were at (pH 6) or below (pH 4 and 5) this critical buoyancy threshold, while shorter stockpiling times resulting in higher pH:bulk density ratios above 0.05 for both pH 5 and 6. In contrast, the average reference peat pH:bulk density ratio was above 0.05 at all pH's, except for the hollows of the reference sites where the ratio was only above at pH 6. This pH-bulk density ratio limitation can be ameliorated by the use of external material to float the peat-block at ratios below the critical threshold (Temmink et al., 2021; Tomassen et al., 2003). Given the relatively low pH waters where the samples were taken (unpublished data), shorter stockpiling times would be advantageous for using stockpiled peat-blocks or the use of external materials to artificially float the peat-blocks to restore floating mats. Thus, there is again an operational trade-off between stockpile time, and associated changes in the physical peat structure, and added cost of external materials, altering the ease of using stockpiled peat blocks for the creation of floating mat.

5. Conclusions

The efficient and effective use of stockpiled peat for restoration requires accounting for not only operational challenges and targeted end-use, but the hydrophysical evolution of the peat block during stockpiling. Decomposition of the stockpiled peat did not appear to measurably impact the hydrophysical properties that govern many critical peatland processes. Rather, physical, and likely irreversible, consolidation of the peat itself led to the greatest changes of the peat blocks. The changes to the peat block pore structure only occurred at the deeper peat depths. The longer the peat was stockpiled, the greater the decrease in macroporosity but no clear change in the water conducting matrix porosity. While this evolution of the macroporosity was clear, the lack of change in the water conducting matrix porosity suggests that the stockpiled peat would be able to maintain hydrological connectivity with the remnant peat regardless of stockpile time. However, the increase in inhospitable conditions on the stockpiles for sphagnum mosses and the increase in the peat block bulk density suggest that limiting stockpiling time as much as possible would be advantageous for using the stockpiled peat blocks for the peat-block restoration technique or floating mat creation. Based on our results, we recommend targeted field-scale trials of varying stockpiling times and in-situ moss photosynthesis, moisture dynamics and CO_2 exchange be undertaken to examine the implications of stockpiling time on restoration trajectory and success. Together with the results of this study the trade-offs of donor peat block stockpile time and long-term restoration success can be better incorporated into peat restoration logistics management.

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Data availability

All data is available upon request.

CRediT authorship contribution statement

K. Lehan: Data curation, Formal analysis, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. **C.P. R. McCarter:** Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **P.A. Moore:** Data curation, Formal analysis, Methodology, Software, Visualization, Writing – review & editing. **J.M. Waddington:** Conceptualization, Funding acquisition, Supervision, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors do not have any conflict of interests.

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