Can peatland restoration enhance drought and flood resilience in boreal forests?

Sara Camiolo[1], Claudia Teutschbein[1], Gustaf Granath[2] and Thomas Grabs[1]

[1]Department of Air, Water and Landscape Science, Uppsala University, Sweden [2]Department of Ecology and Genetics, Uppsala University, Sweden

Introduction

Boreal peatlands have experienced severe anthropogenic disturbances throughout the 20th century. In recent years, their potential for climate change mitigation has been recognized at global level with policies promoting peatland restoration. Successful interventions are difficult to assess due to the long monitoring required to study hydrological feedbacks, and the variable effects given by peatland specific properties.

Material and Methods

A literature review is conducted to analyze the empirical evidence for increased water storage, groundwater recharge, drought buffering and flood control in restored boreal peatlands.

How do peat hydraulic properties mitigate drought and flood events?

What is the relationship between peatland location and its hydrologic function?

How are peatland hydrological functions impacted by high and low flows?

Preliminary results

Previous low- and medium intensity land uses

Evidence from long-term monitoring (≥10 years)

Tab. 1. Peat properties for the top soil (≤ 30 cm) in Finnish peatlands with diverse land uses. Mean values extracted from the long-term monitoring (≥10 years) by Menberu et al. (2021).

Top soil ≤ 30 cm	Drained for forestry	Pristine	Restored from forestry drainage
Bulk density [$g\ cm^{-3}$]	0,15	0,08	0,09
Hydraulic conductivity [$\cdot 10^{-5}\ m\ s^{-1}$]	2,2	5,9	2,5
Porosity [%]	91	93	93
Specific yield	0,21	0,40	0,38

Critical application of rewetting in relation to drainage network and hydraulic gradient

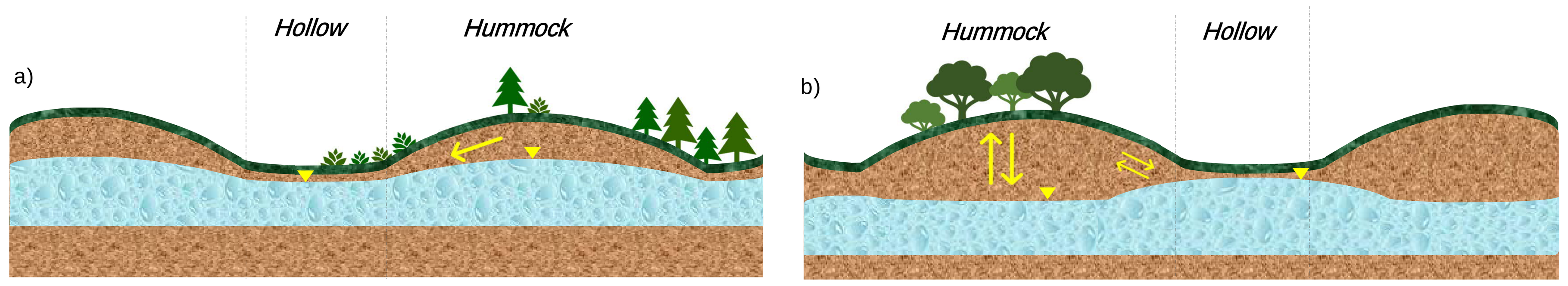


Fig. 1. Water table depth and hydraulic gradient in peatland hummock-hollow microforms following the micro-topography (a) and opposing to it (b). The arrows and their dimension indicate the direction and prevalence of the main water fluxes. The representations are based on the analyses of Haynes et al. (2023) and Hokanson et al. (2020).

Relationship between landform, soil moisture and tree establishment

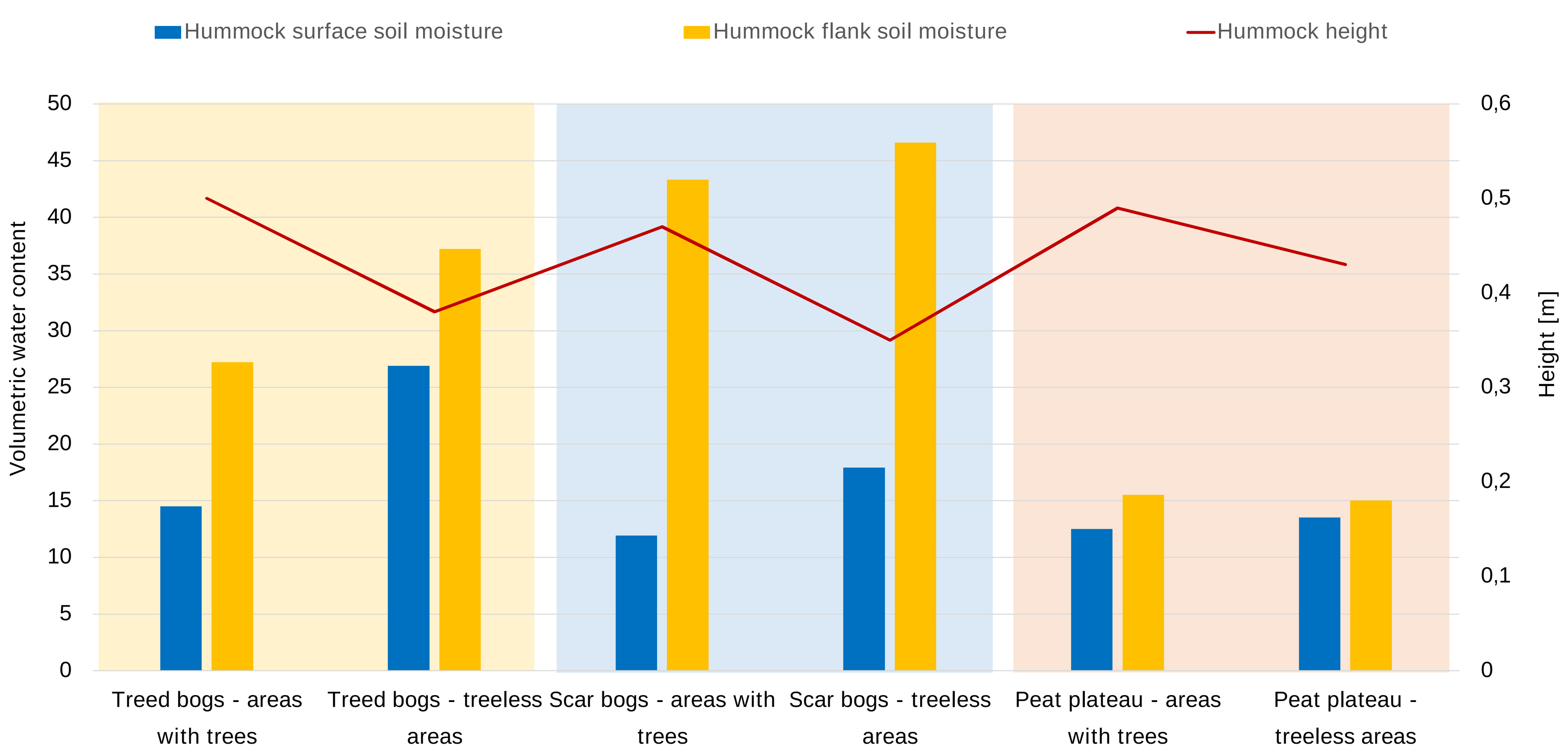
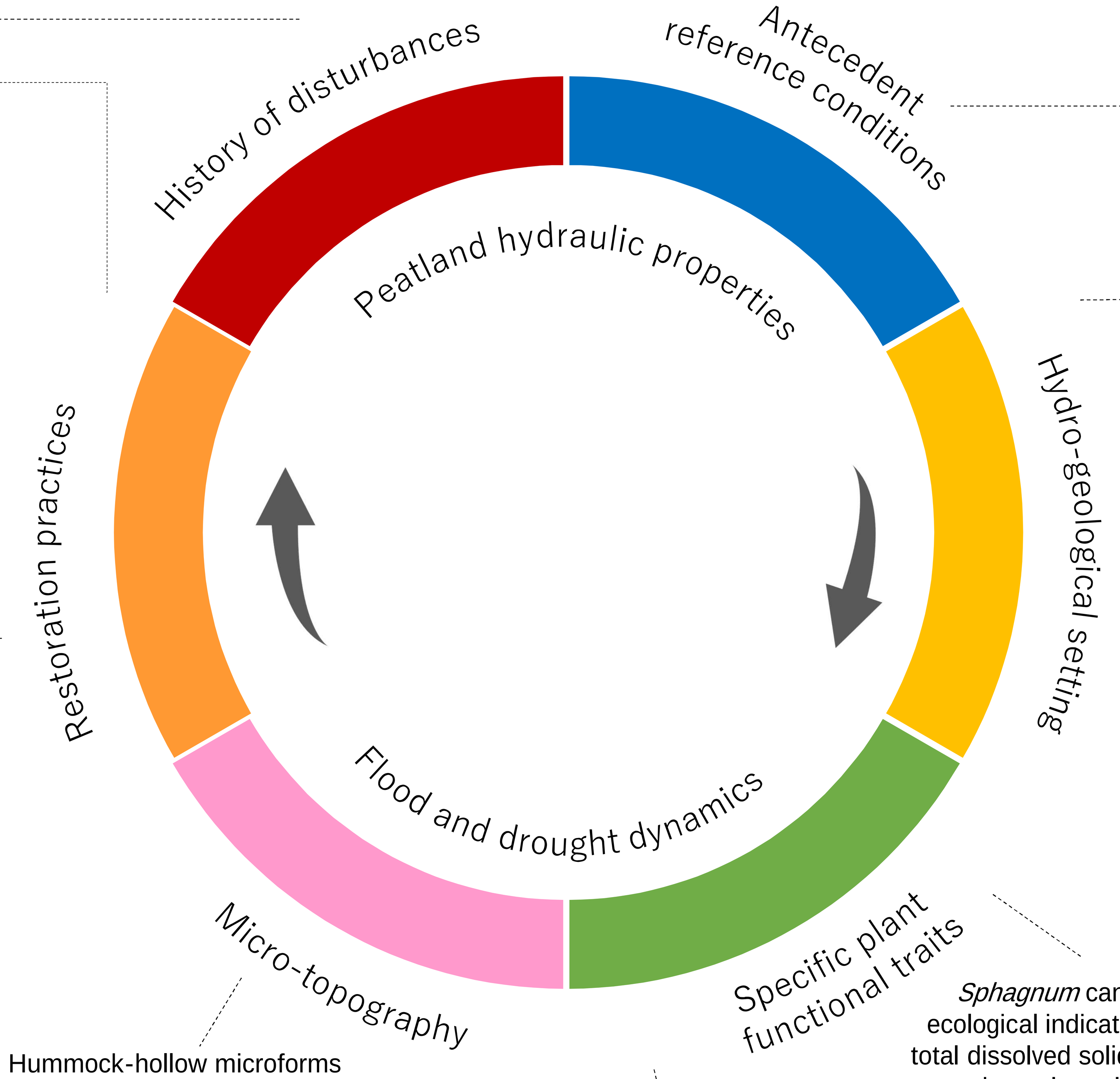


Fig.2 Relationship between hummock height, tree presence (black spruce) and soil moisture (adapted from Haynes et al., 2023). The following correlations have been assessed by the authors: hummock height-tree presence p < 0,01; landform – hummock surface soil moisture p < 0,0001; landform – hummock flank soil moisture p < 0,0001.



Hummock-hollow microforms

Increased flow path tortuosity among gradients of hydraulic conductivity

Increased hydrological connection and downstream runoff

Drier conditions support the hummock formation and aggregation

More efficient drainage of larger hummock aggregates

Reduced volume of water stored in the peatland

Peatland moisture gradient – moss community dynamics: peat depth and catchment directly influence soil water storage and moss water availability

Maximum water holding capacity

Water retention and desiccation avoidance

Soil water pressure and unsaturated hydraulic conductivity

Specific root length and linearity of fine root biomass growth (< 2 mm)

Sphagnum can be used as ecological indicators paired with total dissolved solid concentrations to detect lateral groundwater inflows in preliminary assessments

Event-based analysis ➡ antecedent reference discharge (ARD)

Low ARD + moderate P ⇒ water storage

High ARD + moderate P ⇒ high-flow prolongation

Hydrological year ➡ residual water storage surplus/deficit

Peat margin swamps and transmissivity feedback

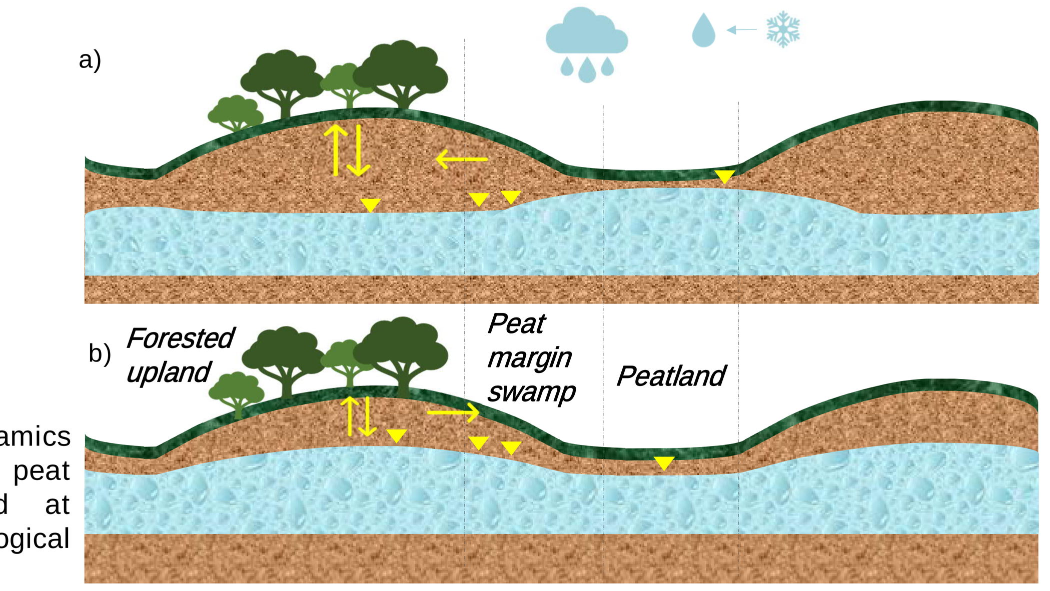


Fig. 3 Lateral groundwater dynamics between a forested upland, peat margin swamp and peatland at different times during a hydrological year.

Tab 2. Prevailing peatland hydrologic function relative to the lateral groundwater flow generating runoff in the catchment. When ∆S/∆t > Qout = sink; ∆S/∆t < Qout = discharge; Qout < Qout-Qin = transmitting; Qout > Qout-Qin = source of runoff (Goodbrand et al., 2019). The sign “>” indicates the prevalent behaviour when different functions are observed in relation to changes in the recharge or hydraulic properties. Cases are compiled from literature where p=pristine, d=drained, and r=restored.

Landscape units	Temporal scale	Peatland function
Sand aquifer → basin peatland[p,d]	7 months	transmitting > source
Esker → peatland[p]	7 months	sink
Peatland[p,d] → esker	1 year	source
Forested upland → peatland[p]	5 months	sink > source
Forested upland → peatland[r]	2 months	transmitting and source > sink
Forested upland → peat margin swamp → peatland[r]	25 years	source
Forested upland → peat margin swamp → peatland[r]	2 years	sink

Take-home messages and next steps

- Lack of **empirical studies** on peatland hydrology, especially flood and drought control
- Very few works making use of **paired sites** and **long-term monitoring** to evaluate water flow dynamics in restored wetlands.
- **Limited evidence** on improved **soil wetness** and **hydraulic properties** after peatland restoration.
- **Shrubification** and hummock-vegetation are favoured by **drier conditions**.
- Self-organized large **hummock aggregates** seem to improve **drainage efficiency** reducing the volume of **stored water**.
- **Hydro-geological setting**, presence of **peat margin swamps**, and **antecedent reference conditions** have large influence on the peatland **hydrological function**.

PREDPEAT project

Monitor and **analyze hydrological dynamics** (2023-2027) for a set of **pristine**, **drained** and **restored peatlands in Northern Europe**.

Integrate hydrology with **ecological** and **water quality assessments** to understand how **boreal peatland ecosystems** respond to high- and low-flows in a **changing climate**.

References

Goodbrand, A., Westbrook, C.J., van der Kamp, G., 2019. Hydrological functions of a peatland in a Boreal Plains catchment. Hydrological Processes 33, 562–574. https://doi.org/10.1002/hyp.13343

Haynes, K.M., Frederick, I., Disher, B., Carpino, O., Quinton, W.L., 2023. Long-term trends in wetland event response with permafrost thaw-induced landscape transition and hummock development. Ecohydrology 16, e2515. https://doi.org/10.1002/eco.2515

Hokanson, K.J., Peterson, E.S., Devito, K.J., Mendoza, C.A., 2020. Forestland-peatland hydrologic connectivity in water-limited environments: hydraulic gradients often oppose topography. Environ. Res. Lett. 15, 034021. https://doi.org/10.1088/1748-9326/ab699a

Menberu, M.W., Marttila, H., Ronkanen, A.-K., Haghighi, A.T., Kløve, B., 2021. Hydraulic and Physical Properties of Managed and Intact Peatlands: Application of the Van Genuchten-Mualem Models to Peat Soils. Water Resources Research 57, e2020WR028624. https://doi.org/10.1029/2020WR028624

Suggestions, thoughts and material welcomed at:
sara.camiolo@geo.uu.se

Find more at:

More about the PredPeat project at:

www.predpeat.com

PREDPEAT

SCAN ME

UPPSALA UNIVERSITET