Rewetting drained boreal peatland forests does not mitigate climate warming in 21st century

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Content

- Atmospheric radiative forcing in brief
- Methods to estimate climate-impact of peatland use change
- Does rewetting drained peatland forests warm or cool the climate?
- Should I rewet?

Photos: Paavo Ojanen & Luke media bank

Atmospheric radiative forcing changes

Peatland use change affects how solar radiation is absorbed in the Earth system

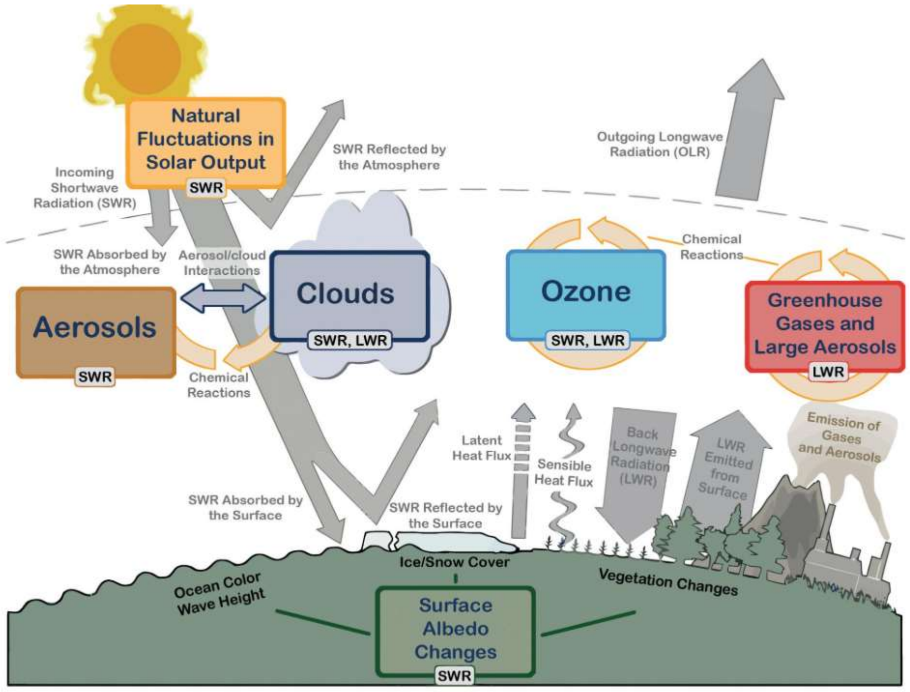
Radiative forcing (RF)

- Measures how Earth's energy budget changes due to e.g. land-use change
- Increased atm. GHG concentrations increase absorption of thermal radiation
- Change in peatland structure can affect albedo

- Metric to compare climate impacts from multiple causes: several GHG's, albedo, …

- **RF's of different GHG's, albedo etc. are additive**

We compare two alternative land-use cases: continued forestry use and restoration



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Radiative forcing of gas *k*

Change in annual surface flux of gas *k* creates cumulative change in atm. concentration of gas *k* over time *t:*

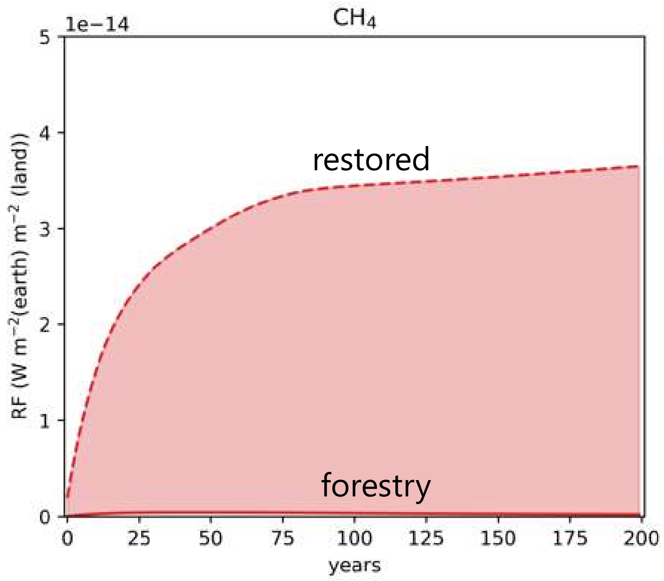
$$\Delta S_{a,k}(t) = \int_{t=0}^{t} \Delta F_{k,d\rightarrow r}(t')\ e^{(t'-t)/\tau_k}\, dt'.$$

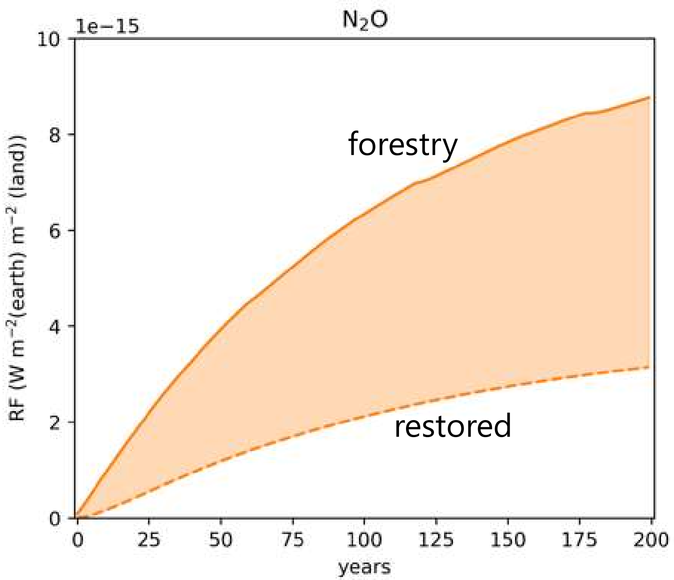
Change in atm. concentration of *k* leads to change in RF:

$$\Delta RF_k(t) = \xi_k E_k \times \Delta S_{a,k}(t).$$

$\xi_k E_k$ depict radiative efficiency of gas *k*

$$\Delta S_{a,co2}(t) = \Delta S_{a,co2}(t_0) \times \left[\beta_0 + \sum_{j=1}^{3} \beta_j e^{-t/\tau_{co\ ,j}}\right].$$





RF's are additive

$$\Delta RF_{tot}(t) = \Delta RF_{co\ ,soil}(t) + \Delta RF_{tree}(t) + \Delta RF_{res}(t) + \Delta RF_{wp}(t) + \Delta RF_{ch4}(t) + \Delta RF_{n2o}(t) + \Delta RF_{alb}(t),$$

Time-varying contribution of

- Different GHG's
- (eco)system components

- **Can climate impact of peatland use be determined based on CO_2 only?**

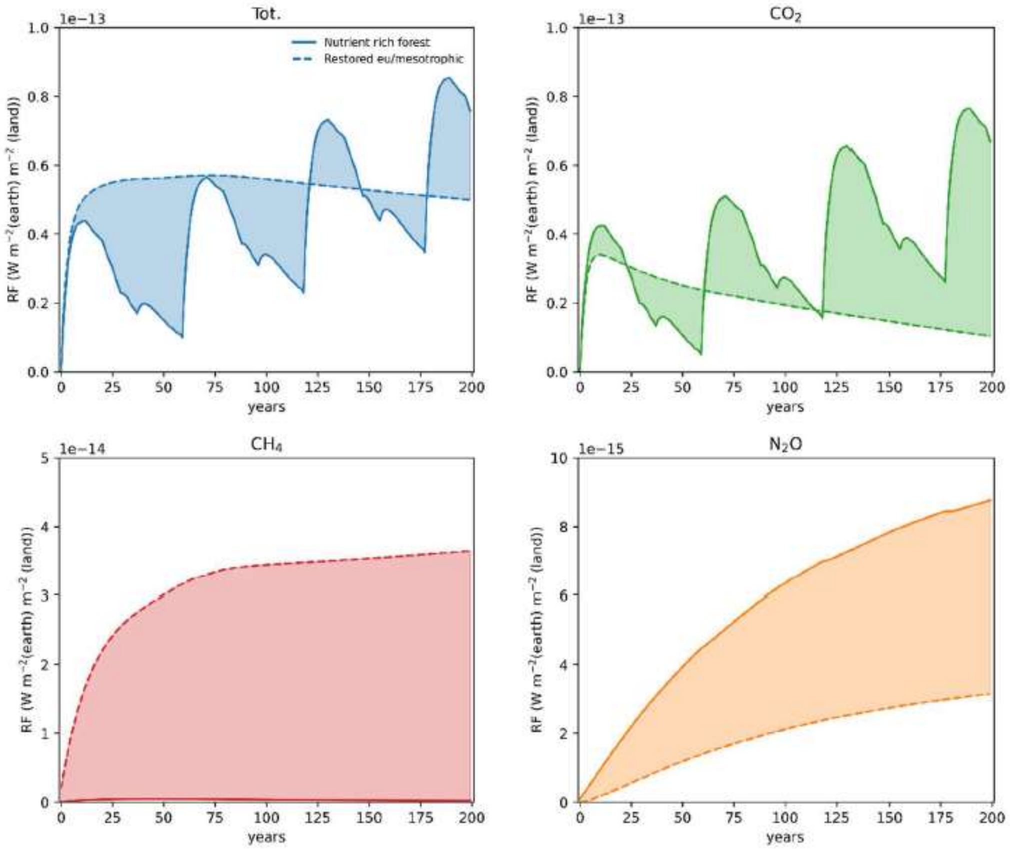


Fig. S5: Radiative forcing (RF) timeseries for nutrient rich forest (FNR, Mtkg in Southern Finland) and restored open eutrophic/minerotrophic peatland (*Case 1*, Fig. 2a,b). Total radiative forcing from greenhouse-gases (GHG's) is the sum of individual GHG's dynamic contributions (Sect. S1.3). The change in radiative forcing (ΔRF) due to restoration is the difference between restored and forestry drained peatland RF; i.e. restoration has a cooling effect when dashed line is below the continuous line. Note that y-axis scale varies between panels.

Bookkeeping model and boundaries

We compute change in system CO_2 storage and CO_2, CH_4 and N_2O fluxes over time (forestry vs. restoration). These change atmospheric GHG concentrations and RF's.

"Use what is out there, in a clever way."

Luke

CO_2 budget

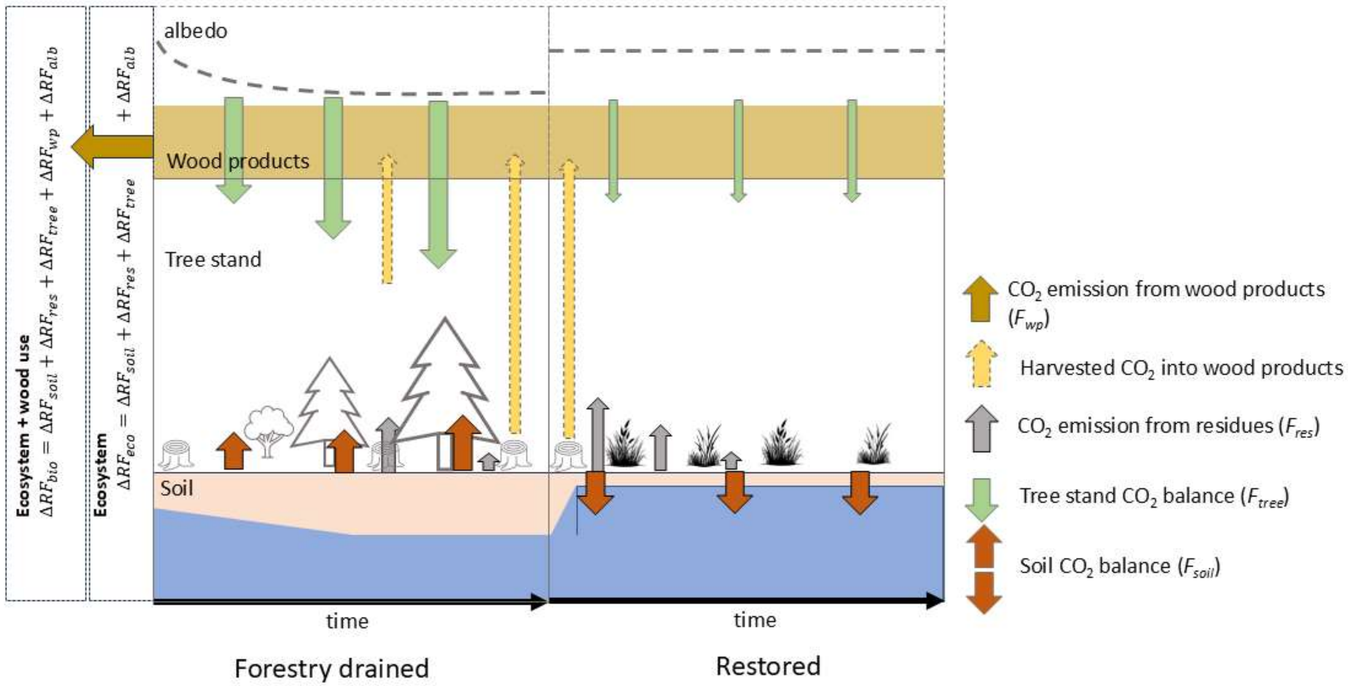
$$F_{c,net}(t) = F_{c,soil}(t) - F_{c,tree}(t) + F_{c,res}(t) + F_{c,wp}(t).$$

CO_2 flux between system and the atmosphere

Growth simulator

- biomass C → NPP
- Harvests → wood products, residues
- Vol.

Empirical soil CO_2 balance = f(Vol.)



System boundaries

- On-site (ecosystem)
- On-site + wood use

$$S_{bio}(t) = S_{soil}(t) + S_{tree}(t) + S_{res}(t) + S_{wps}(t) + S_{wpl}(t).$$

CO_2 storage in the system

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Tree stand growth and CO_2 uptake

Motti growth simulator (Hynynen et al, 200x)

- BAU, Southern (Tampere) and Northern (Oulu) Finland

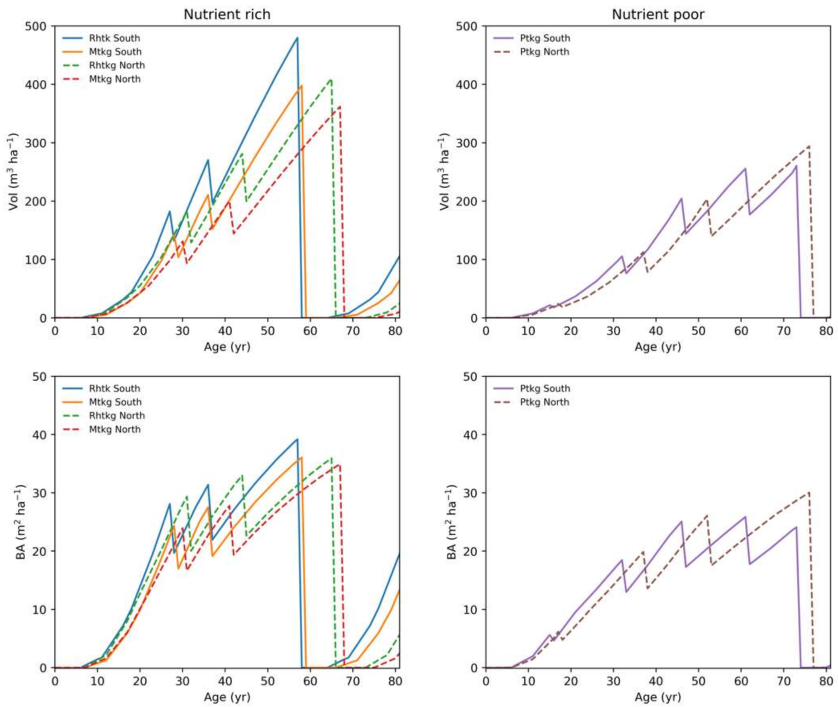
Nutrient-rich peatlands (FNR)

- Herb-rich (Rhtkg), Vaccinium myrtillus-type (Mtkg)
- Rotation ca. 58 / 68 yr, 2 thinnings

Nutrient-poor peatlands (FNP)

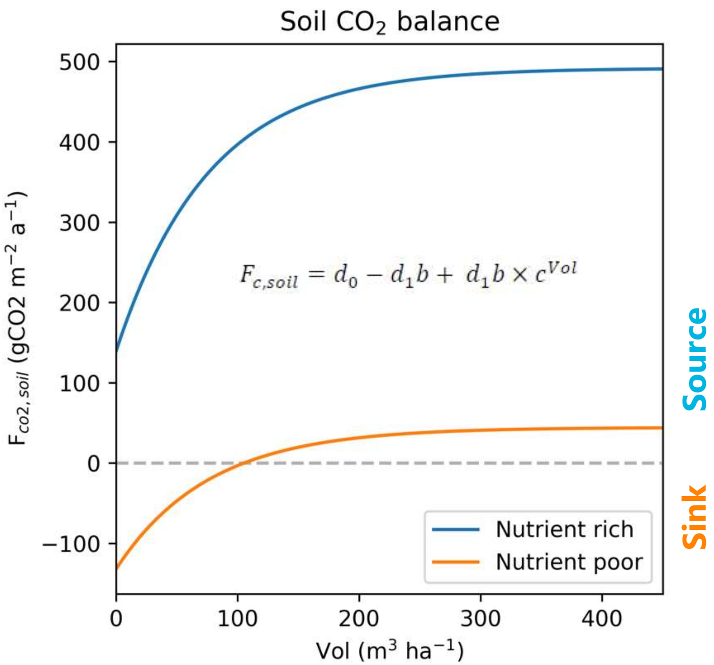
- Vaccinium vitis-idaea type (Ptkg)
- Rotation ca. 75 yr, 2-3 thinnings

- Annual tree NPP from predicted biomass change



Soil CO_2, CH_4 and N_2O

- Forest soil CO_2 balance: f(Vol, fertility)



Based on:
$F_{c,soil}$ = f(WT, fertility), Ojanen & Minkkinen (2019)
WT = f(Vol), Sarkkola et al. (2010)

- Laine et al. 2024 give overview of annual net soil gas balances
- We assume CH_4 and N_2O fluxes from forest & restored, and CO_2 flux from restored, are constant in time (Table 1)

Table 1: Soil GHG balances (g (gas) m^{-2} a^{-1}) used in this study. For CO_2, the rotation-cycle average of eq. S3 (Fig. S4) and range corresponding to young and mature (in parenthesis) are given. Laine et al. (2024) used constant values +265 gCO_2 m^{-2} a^{-1} (FNR) and -45 gCO_2 m^{-2} a^{-1} (FNP).

	Soil gas balance (g (gas) m^{-2} a^{-1})		
Peatland type	**CO_2**	**CH_4**	**N_2O**
Drained nutrient rich (FNR)	+384 (140…490)	+0.34	+0.23
Drained nutrient poor (FNP)	-15 (-130…+40)	+0.34	+0.08
Spruce mire	-91	+1.7	+0.10
Pine mire	-97	+4.8	+0.03
Open eu/mesotrophic	-104	+15	+0.10
Open oligotrophic	-124	+22	+0.03
Open ombotrophic	-95	+9.7	+0.03

Wood products and residue pools

Wood products (removed from site)

- Short-term 2 yr, long-term 20 yr.
- Allocation based on *timber fraction x saw yield*

Residues 3 pools (left to the site)

- Foliage 3 yr
- FWD 7 yr
- CWD forestry (stumps, coarse roots) 30 yr
- CWD (restored) 300 yr (anoxic conditions)

Filled from harvests, decay exponentially

CO_2 storage change $\Delta S_i(t) = \alpha_i H(t) - F(t)_{c,wi}$

CO_2 flux to atm. $F_{c,wi}(t) = S_{wi}(t) e^{-1/\tau_i}$.

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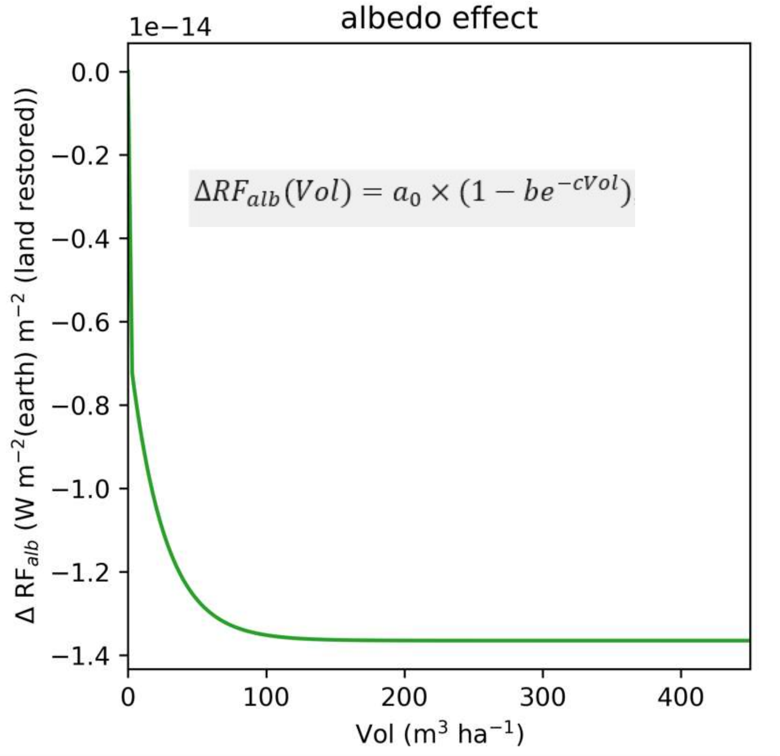
ΔRF from albedo change

- Forest albedo < open peatland albedo
- Effect strongest in mature (high Vol.) stands and during wintertime
- Albedo RF depends on local albedo change, surface area & solar radiation
- On annual scale - a rough approximation:

$$\Delta RF_{alb} = SW_{\downarrow} \times \Delta\alpha \times \tau_{atm} \times \frac{A}{A_{earth}}$$

- We use literature to parameterize ΔRF_{alb} as function of stand Vol. in Southern Finland.



"Restoring to open peatland increases albedo and contributes to cooling (ΔRF_{alb} <0). The effect saturates with stand Vol."

Lohila et a. 2010 JGR; Peräkylä et al.m 2025 BG

Does restoration warm or cool the climate?

Some case-examples

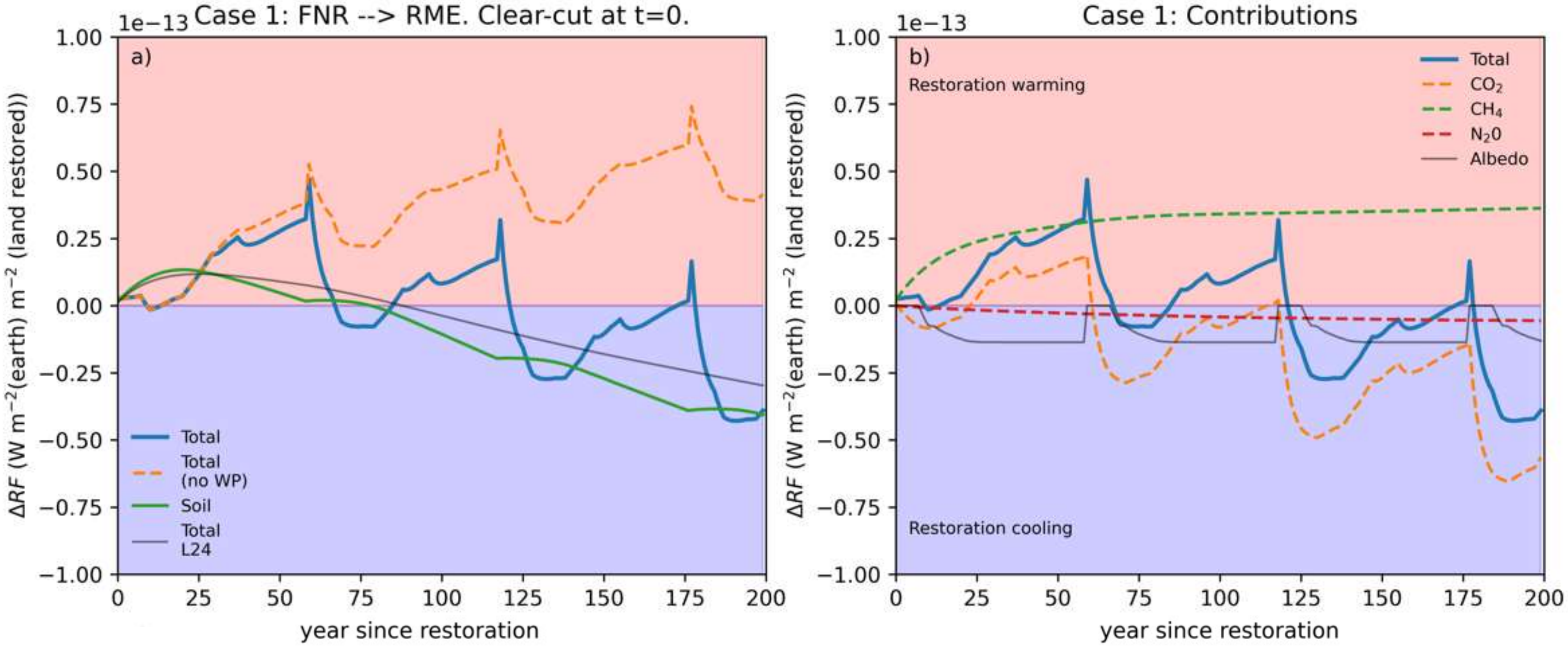
Comparing restoration to continued forestry

- Continued forestry for next 200 years as in the past
- Rewetting and restoration either to i) an open peatland or ii) tree-covered mire

- Restoration takes place after clear-cutting at end of rotation
- Harvest residues and wood products ‘decompose’ in restoration-scenario, while periodically replenished in continued forestry scenario
- We consider change in total radiative forcing and its components

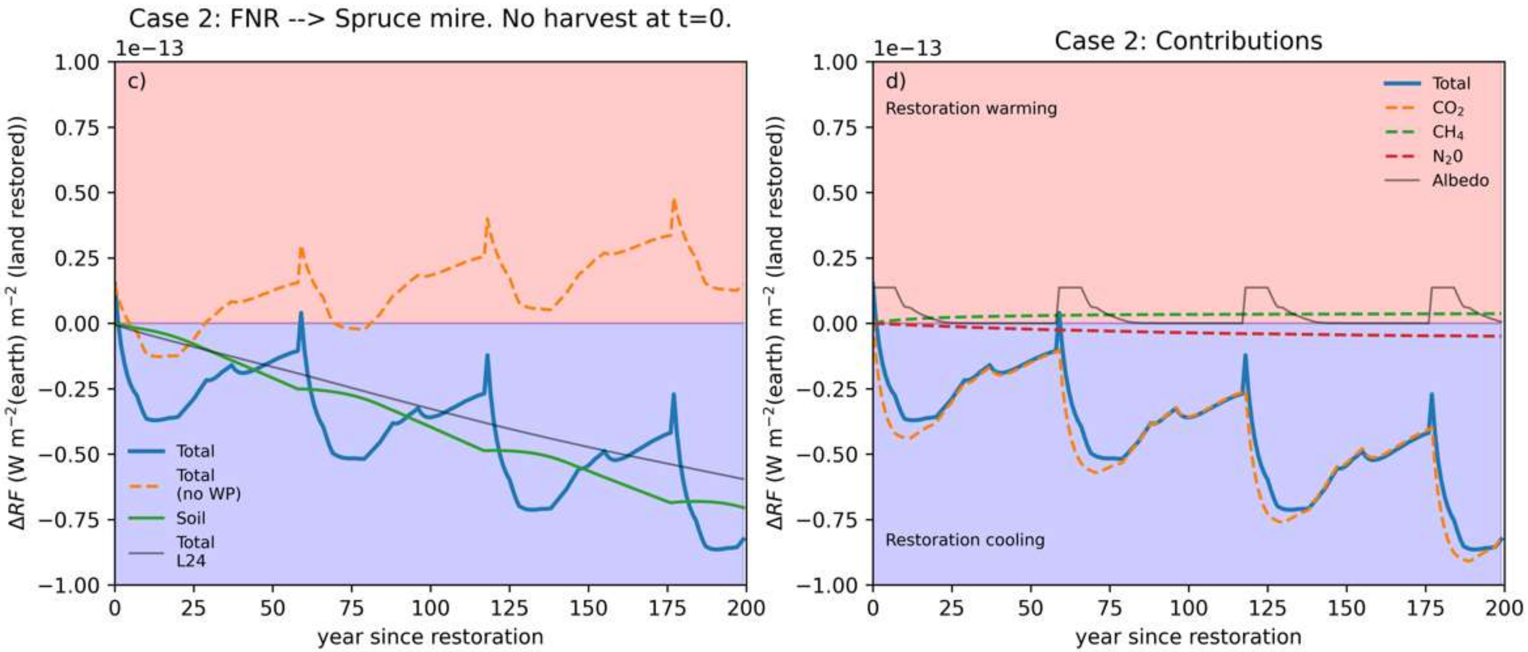
$$\begin{aligned}\Delta RF_{tot}(t) = {} & \Delta RF_{co\ ,soil}(t) + \Delta RF_{tree}(t) + \Delta RF_{res}(t) + \Delta RF_{wp}(t) \\ & + \Delta RF_{ch4}(t) + \Delta RF_{n2o}(t) \\ & + \Delta RF_{alb}(t),\end{aligned}$$

Nutrient-rich forest to open mesotrophic fen



- **Net warming over 2 first rotations**, mainly due to increased CH_4 emissions & strong tree CO_2 sink
- Albedo-change and N_2O provide cooling
- Very different outcomes if only:
  - CO_2 effect is considered
  - part of system considered (soil, no WP, …)
- **Warming effect of rewetting is the stronger the more productive stand is restored**

Restore nutrient rich stand to tree-covered mire



- **We assume tree CO_2 storage is preserved *ad infinitum* in restoration-scenario**
- **Net cooling IF tree stand CO_2 storage is 'locked'**
- Albedo-effect is opposite to *Case 1*
- Small impact of CH_4 and N_2O as fluxes do not change much

- **What happens for climate benefits if restoration does not affect wood demand?**

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Restoring nutrient poor stands

Restoring to open peatland

- Persistent net warming, due to CH_4 emissions
- Soil (CH_4 + CO_2) balance contributes to warming

Restoring to pine mire

- Climate-neutral if tree CO_2 storage preserved
- Small contribution from CH_4

Table 1: Soil GHG balances (g (gas) m^{-2} a^{-1}) used in this study. For CO_2, the rotation-cycle average of eq. S3 (Fig. S4) and range corresponding to young and mature (in parenthesis) are given. Laine et al. (2024) used constant values +265 gCO_2 m^{-2} a^{-1} (FNR) and -45 gCO_2 m^{-2} a^{-1} (FNP).

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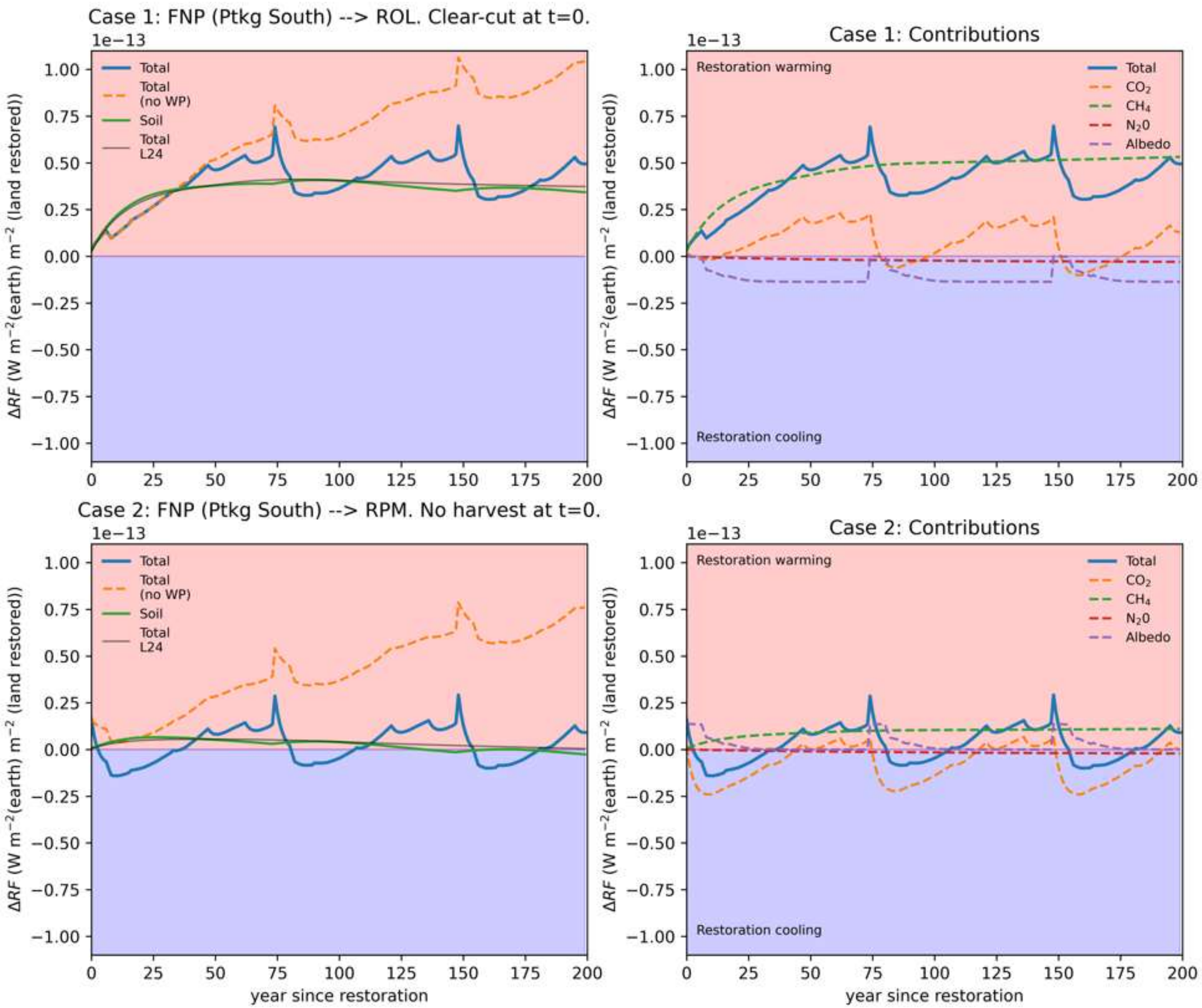
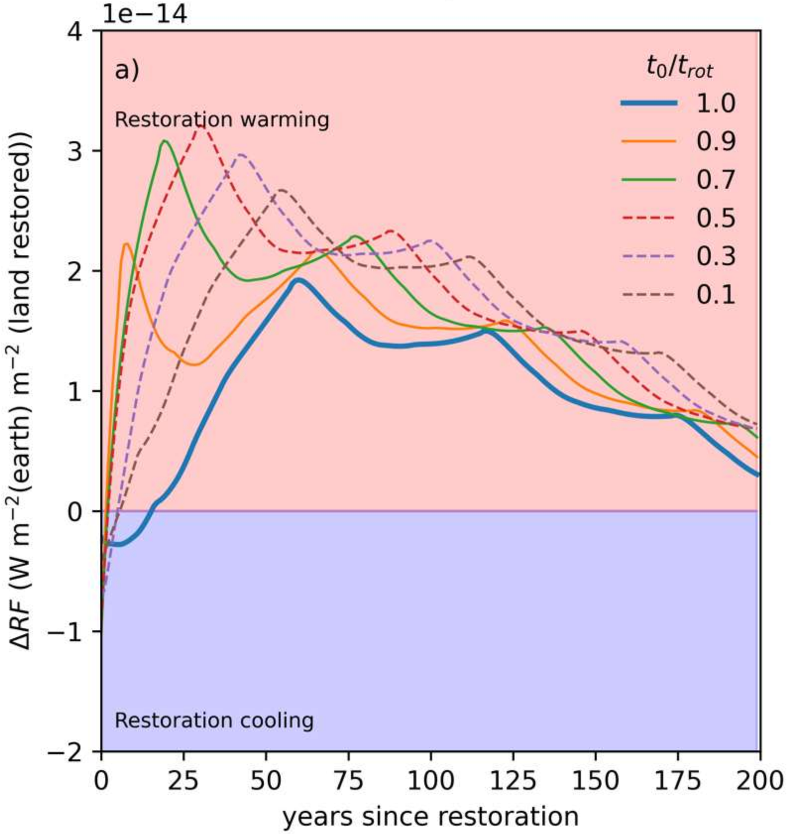


What if one restored during rotation cycle?

Nutrient rich stand → open mesotrophic fen

- Reweting by clear-cutting during rotation period (t_{rot})
- Restore large stand late in rotation
  - earlier large emissions from residues & wood products
- Restore small stand early in rotation:
  - small emissions from residues & wood products but large 'gap' due to lost growth
- **Best if one can restore at rotation end – but not always practicable**

Case 3: FRM --> Open mesotrophic.
Restoration during stand rotation.



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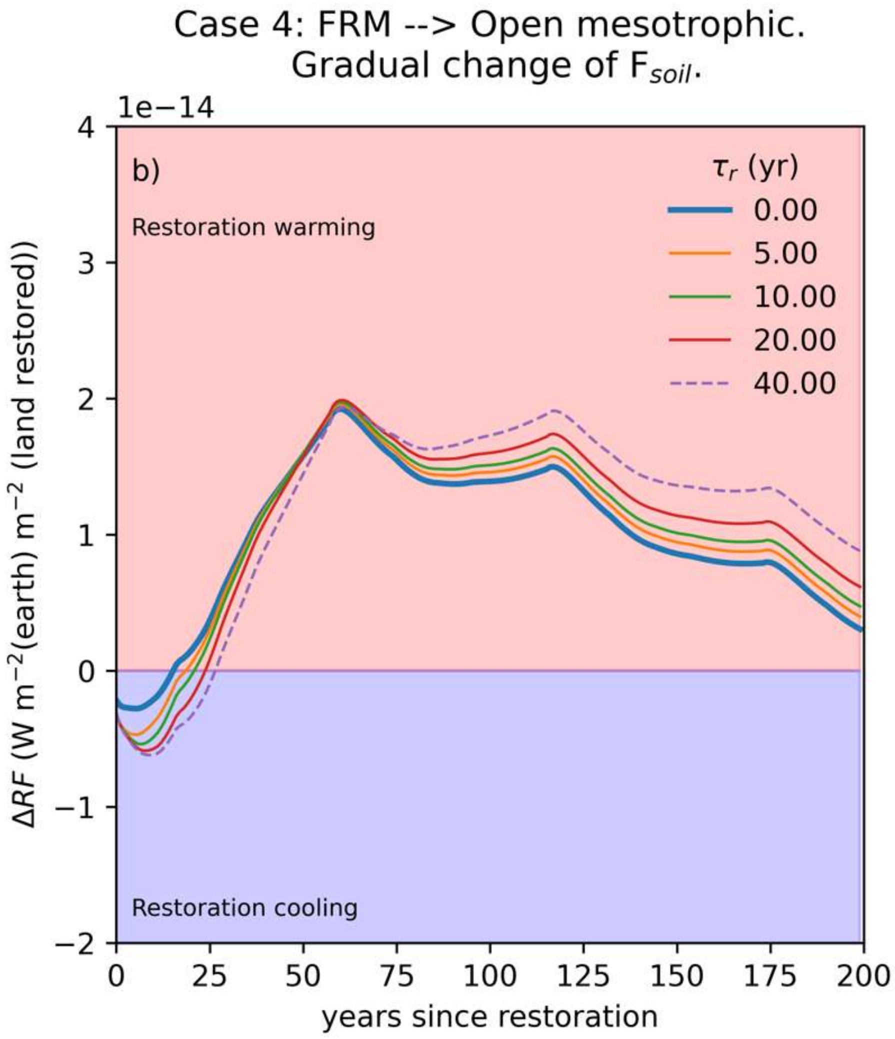
What if recovery takes time?

- After rewetting ecosystem functions recover with delay, except hydrology
- Rate of soil GHG balance recovery is unknown, estimated to take 15 – 30 yr (Escobar et al. 2022)
- Delayed recovery leads to more favorable short-term but more harmfull medium-term climate impact
    - Mainly due to gradual increase of CH_4 emissions



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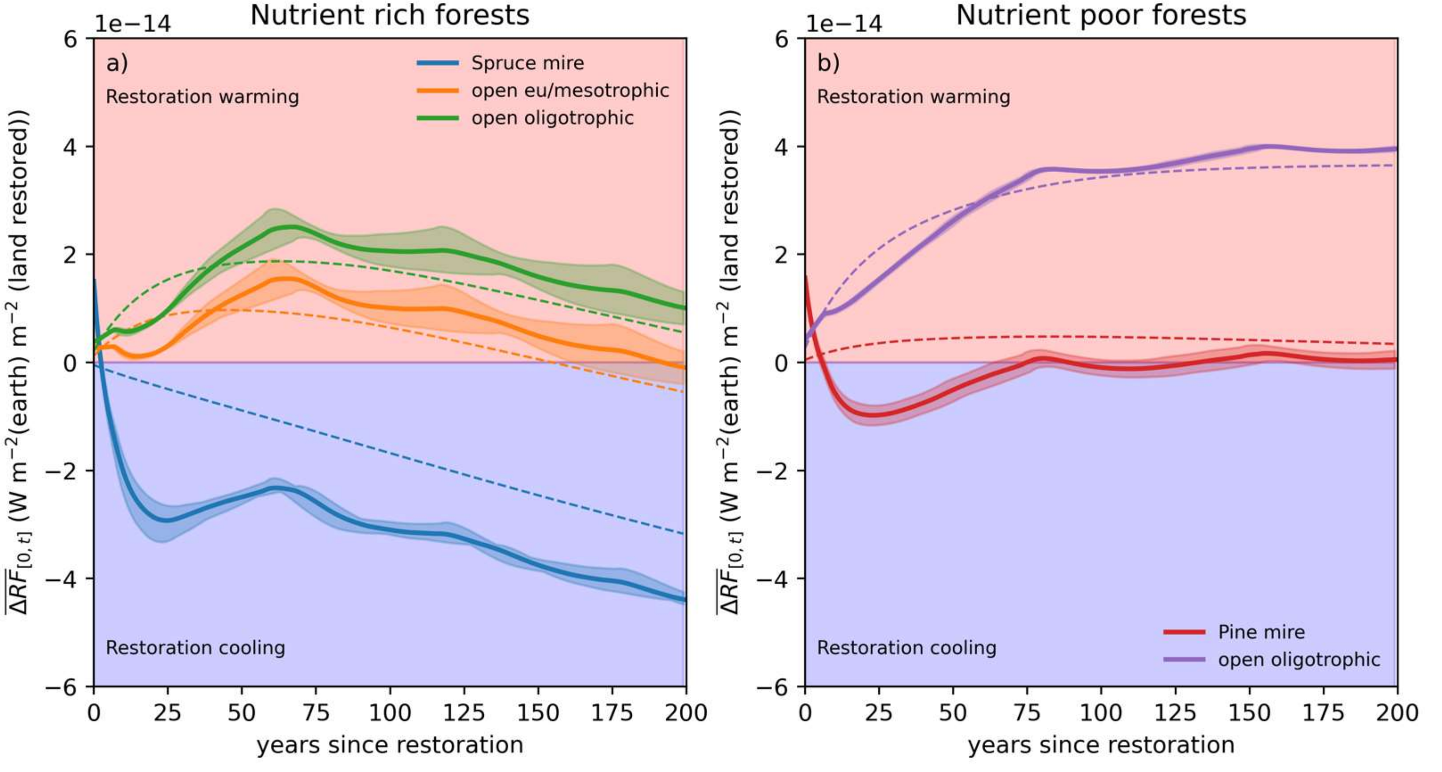
Key message

Should we restore?

Climate impact dynamics of rewetting



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No benefit except if successfully restoring nutrient rich stands to tree-covered mires

Should one rewet forest peatlands?

- For ecological benefits & biodiversity
- For improved water retention
- For better water quality?

- **For climate only in a rare case when tree C storage is preserved**
  - Climate impact of peatland use change can't be assessed by CO_2 only
  - Restoration part of larger toolkit
- Our results are by no means ground-breaking
- **Surprising how knowledge is commonly miss-used**

Research Council of Finland

LS-Hydro (2023-2027): From forest structure to hydrological function – merging dense EO data and process-models

PREFER (2022-2026): Precision nutrient management - a tool for mitigation of climate change and environmental loading in boreal forestry

European Commission
Horizon Europe 2021-2027

GreenFeedBack – Greenhouse gas fluxes and Earth system feedbacks

Thanks!

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References

- Escobar et al. 2022. Front. Env. Sci., doi: 10.3389/fenvs.2022.834371
- Laine et al. 2024. Rest. Ecol., https://doi.org/10.1111/rec.14213
- Launiainen et al. 2025. Ambio (in review), https://doi.org/10.31223/X5H43K
- Lohila et al. 2010 J. Geophys. Res., doi:10.1029/2010JG001327
- Peräkylä et al. 2025. Biogeosci., https://doi.org/10.5194/bg-22-153-2025
- Ojanen, P. and Minkkinen, K., 2019. Mires and Peat, 24(Article 27), p.27.
- Sarkkola et al. 2010. Can. J. For. Res. 40(8), pp.1485-1496.

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