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

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5.3.2024

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Content

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

Photos: Paavo Ojanen & Luke media bank

Atmospheric radiative forcing changes

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

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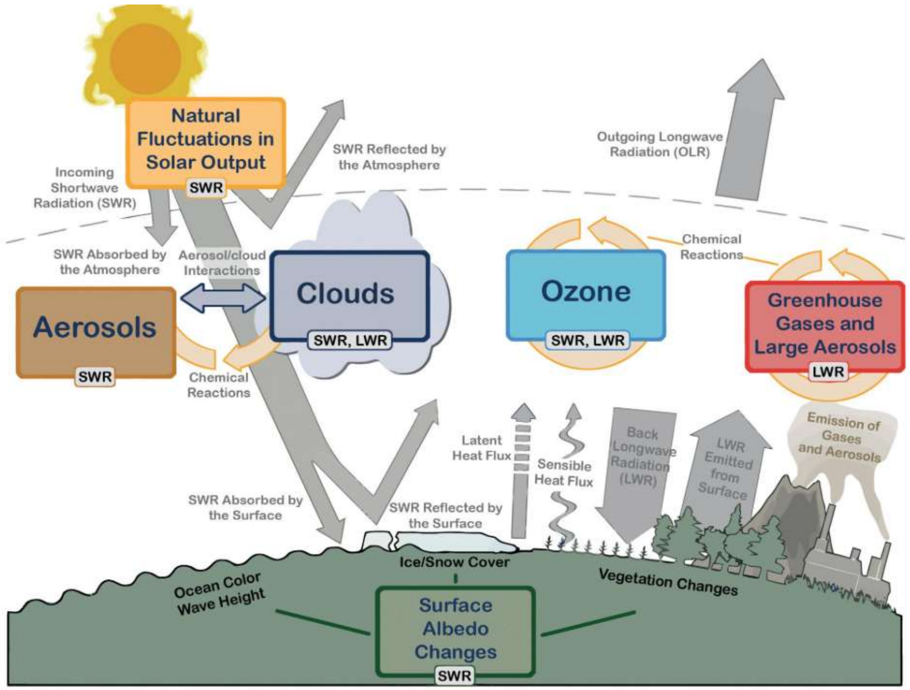
Radiative forcing (RF)

- Measures how Earth's energy budget changes due to e.g. land-use change
- Elevated 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, …

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



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:*

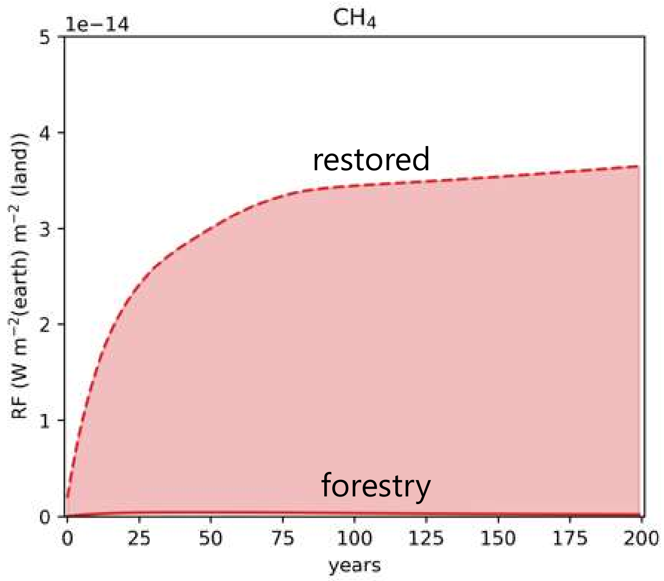
$$\Delta S_{a,k}(t) = \int_{t=0}^{t} \Delta F_{k,d\to r}(t')\; e^{(t'-t)/\tau_k}\, dt'.$$

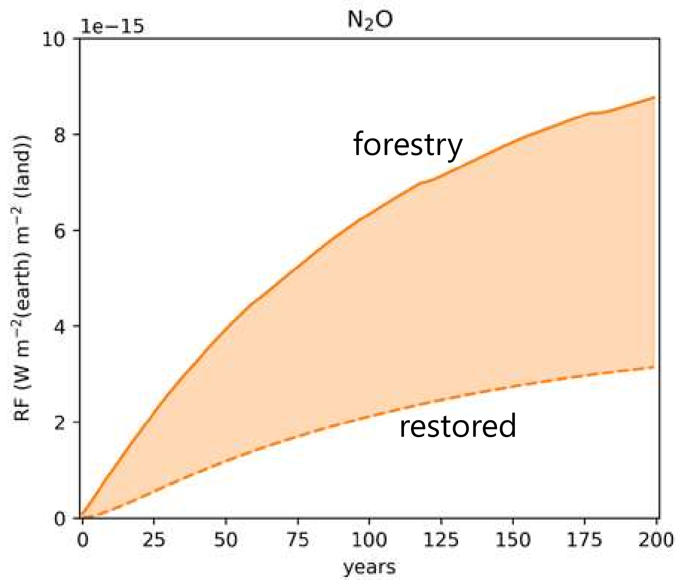
Change in atm. concentration of *k* leads to change in RF:

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

$\xi_k E_k$ 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?**

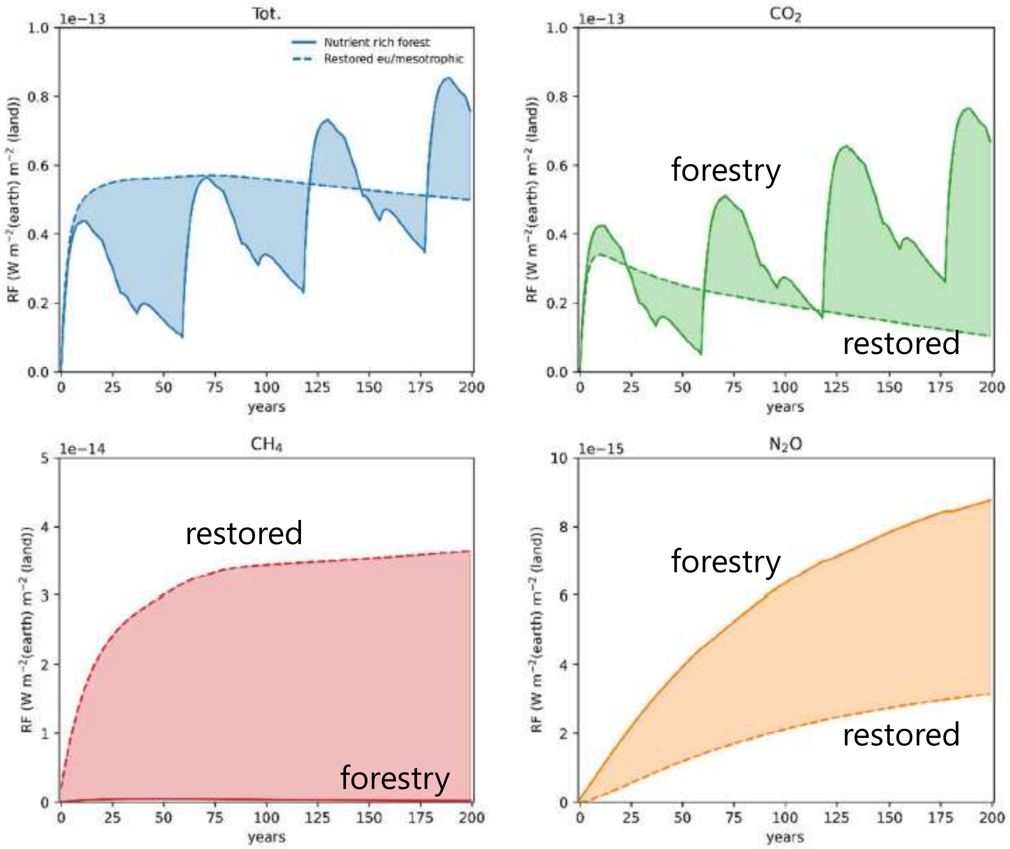


Fig. S5: Radiative forcing (RF) timeseries for nutrient rich forest (FNR, Mtkg in Southern Finland) and restored open eutrophic/minerotrophic peatland (*Case 1*, Fig. 2a,b). Total radiative forcing from greenhouse-gases (GHG's) is the sum of individual GHG's dynamic contributions (Sect. S1.3). The change 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

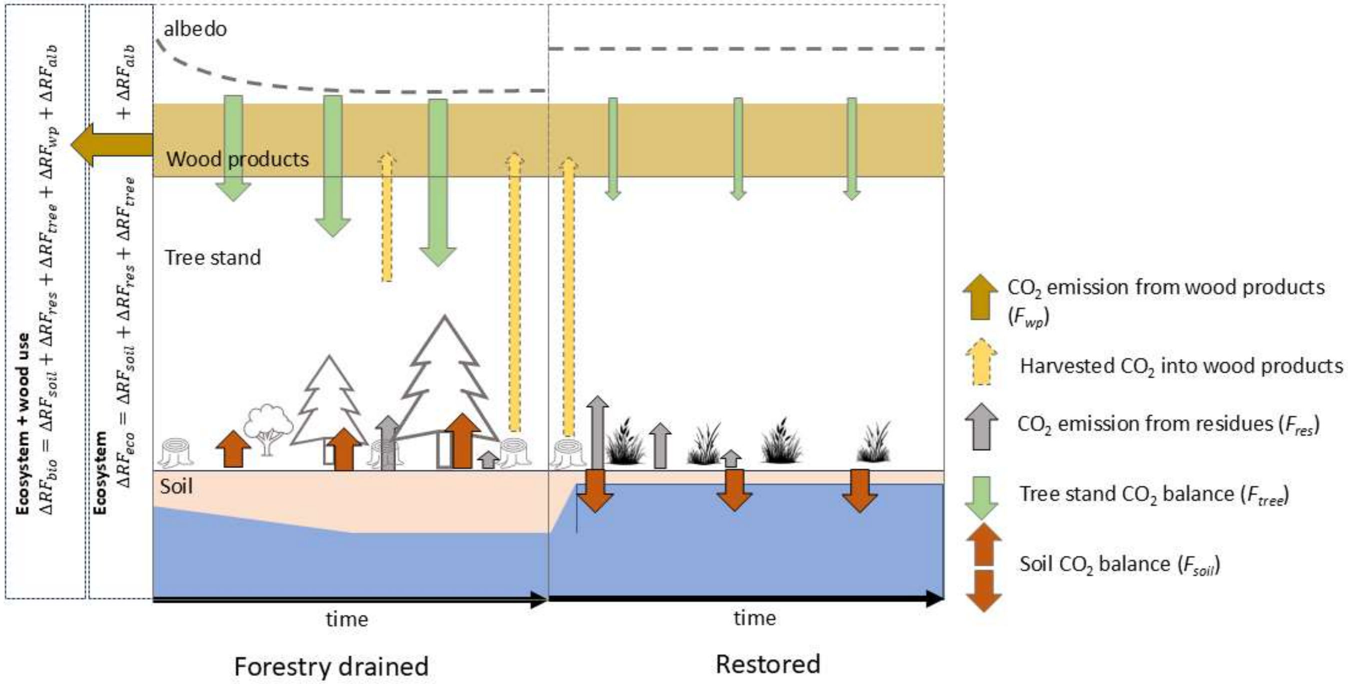
Growth simulator

- 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

Tree stand growth and CO_2 uptake

Motti growth simulator (Hynynen et al, 2005)

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

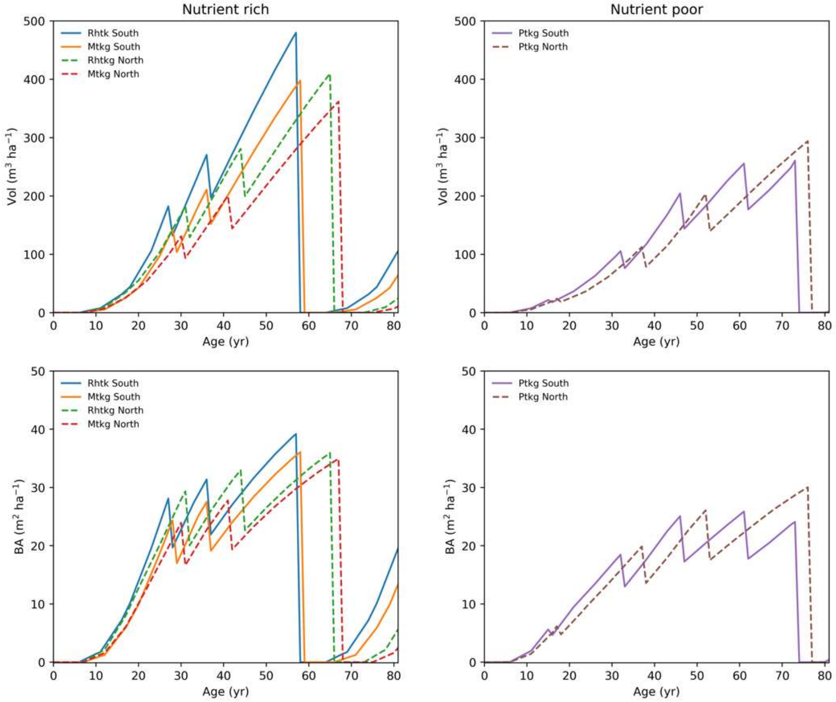
Nutrient-rich peatlands (FNR)

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

Nutrient-poor peatlands (FNP)

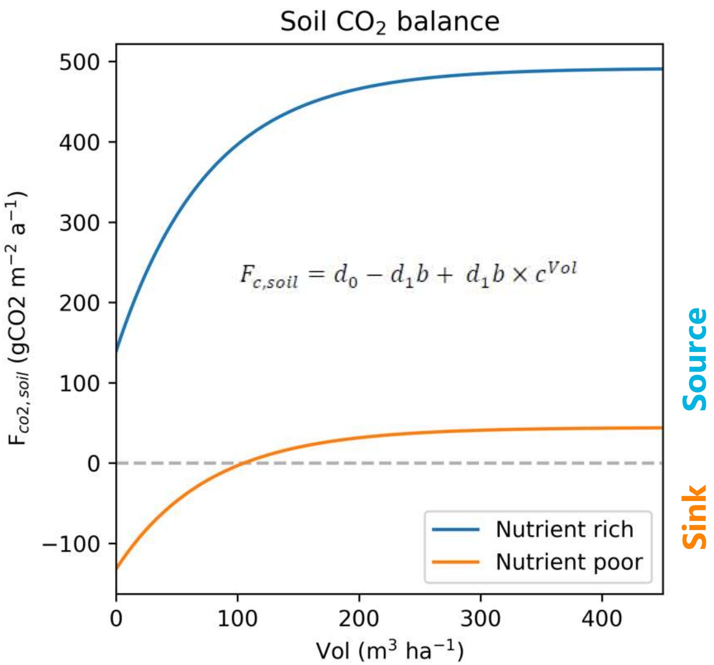
- Oligotrophic V. vitis-idaea type (Ptkg)
- Rotation ca. 75 yr, 2-3 thinnings

- Annual tree NPP estimated from predicted biomass change
- Understory NPP omitted



Soil CO_2, CH_4 and N_2O balance

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

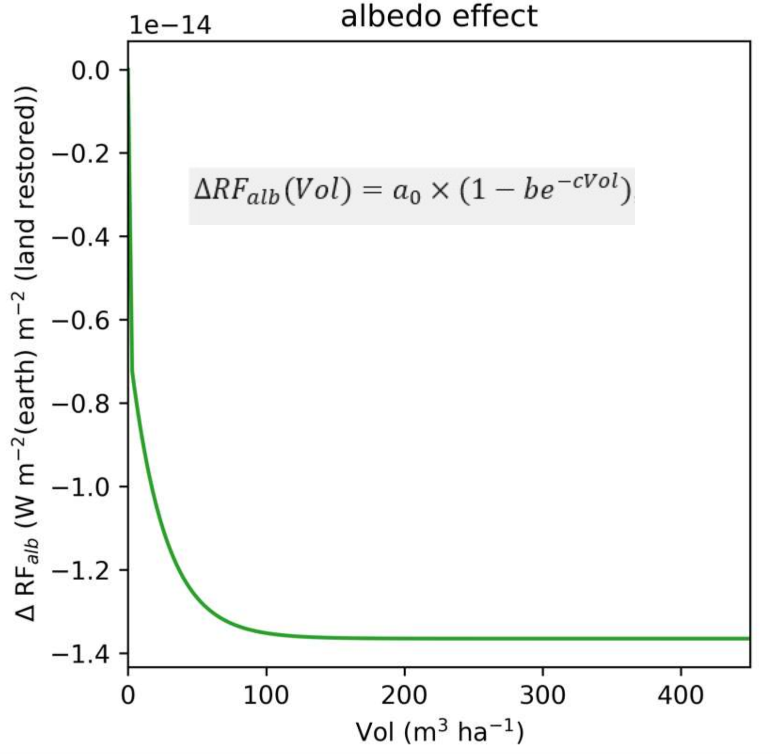
CO_2 flux to atm. $F_{c,wi}(t) = S_{wi}(t)e^{-1/\tau_i}$.

ΔRF from albedo change

- Forest albedo < open peatland albedo
- Difference largest in mature (high Vol.) stands 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."

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

Does restoration warm or cool the climate?

Some case-examples

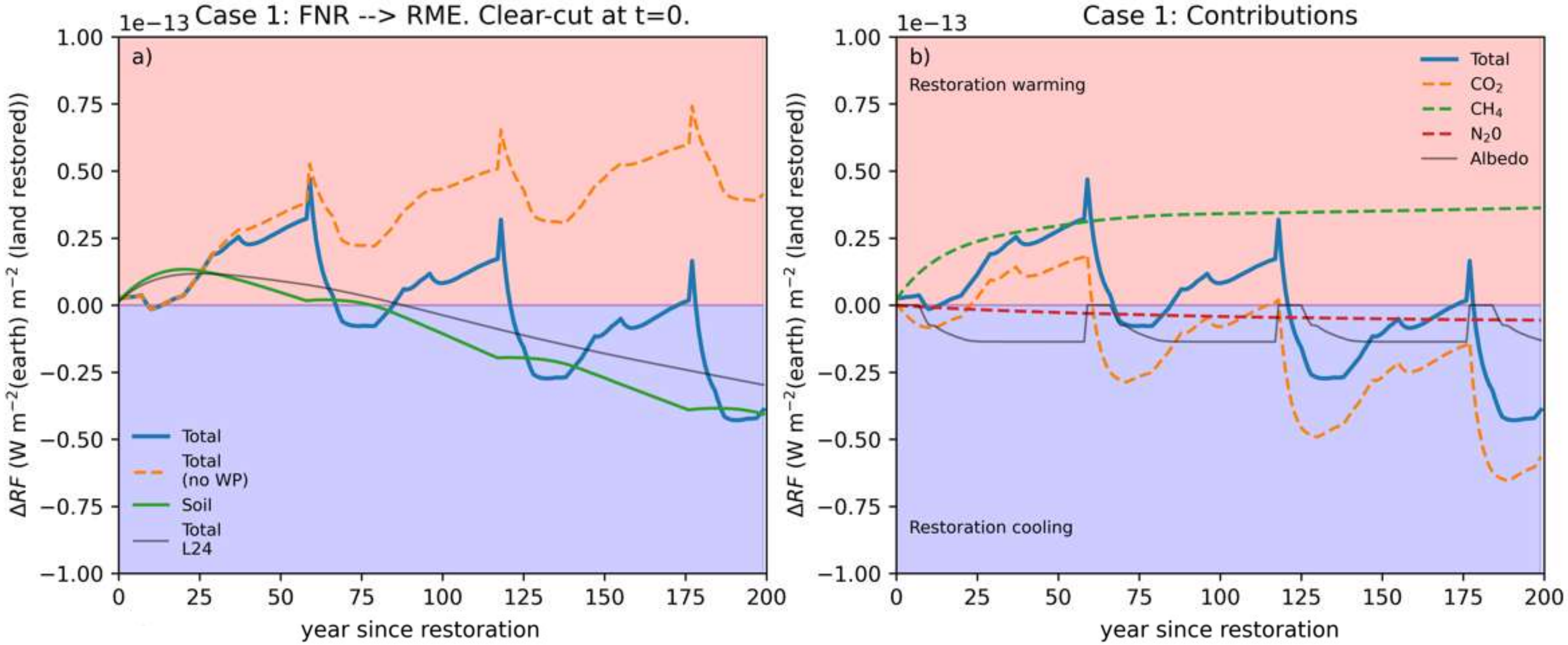
Comparing restoration to continued forestry

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

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

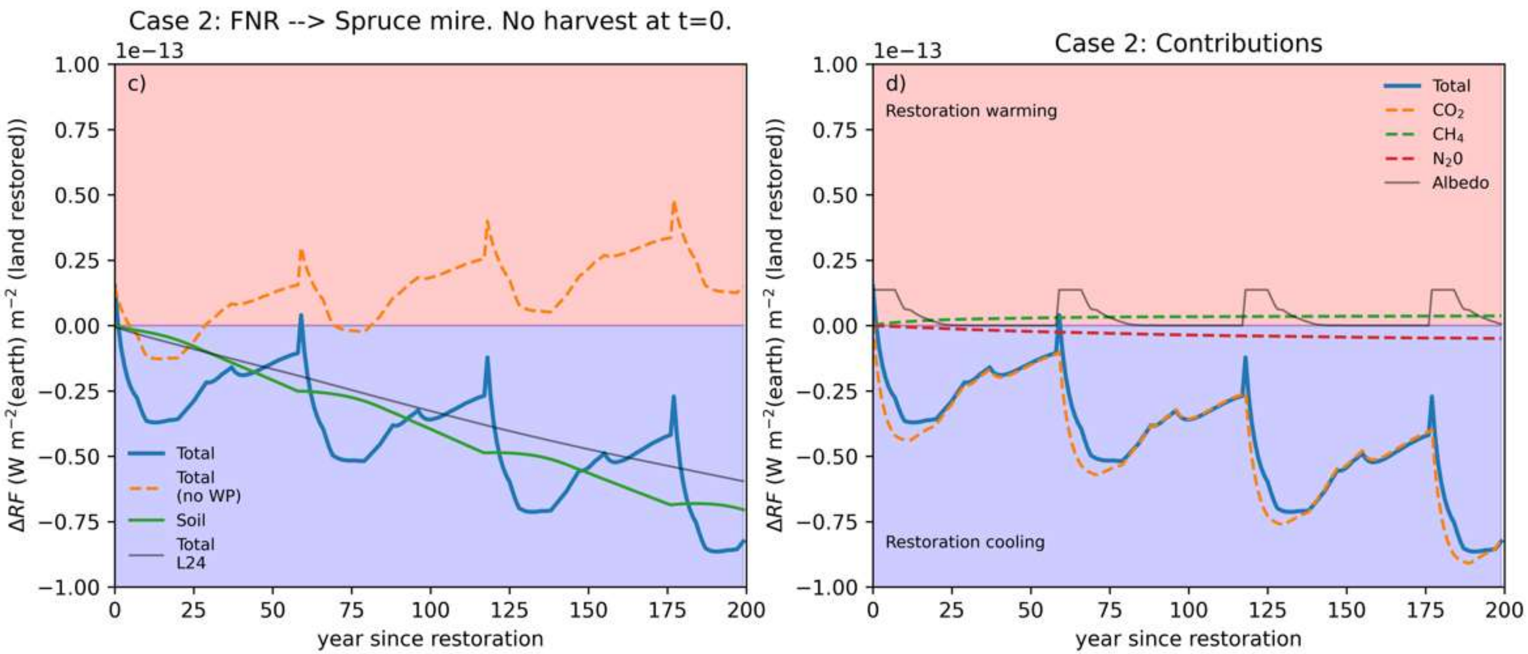
$$\begin{aligned}\Delta RF_{tot}(t) = \; & \Delta RF_{co\;,soil}(t) + \Delta RF_{tree}(t) + \Delta RF_{res}(t) + \Delta RF_{wp}(t) \\ & + \Delta RF_{ch4}(t) + \Delta RF_{n2o}(t) \\ & + \Delta RF_{alb}(t),\end{aligned}$$

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 provide cooling
- Very different outcomes if only:
  - CO_2 effect is considered
  - part of system considered (soil, no wood products, …)
- **Warming effect of rewetting is the stronger the more productive stand is restored**

Restore nutrient rich stand to tree-covered mire



- **Net cooling IF tree stand CO_2 storage is preserved after restoration**
- 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?**

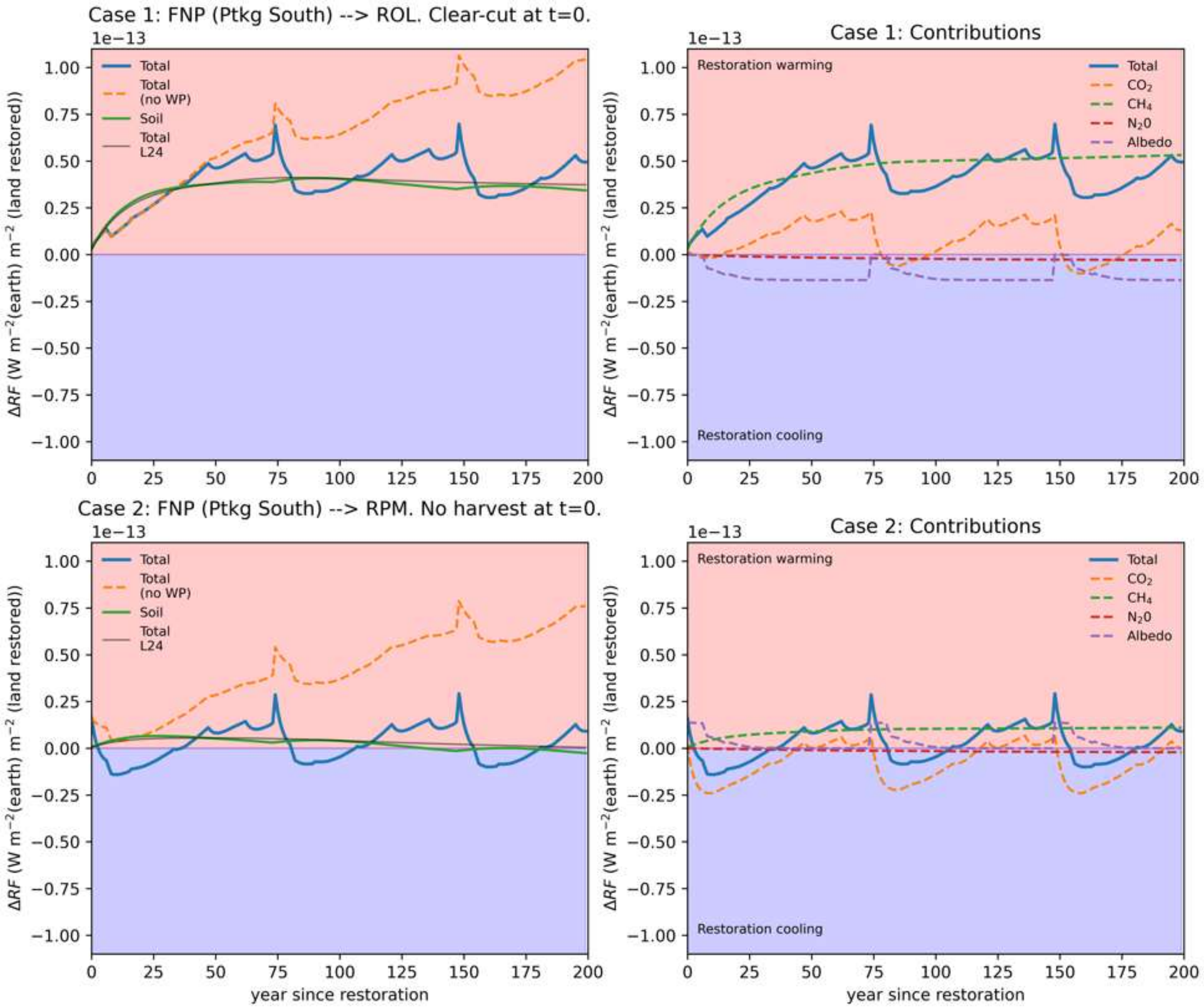
Restoring nutrient poor stands

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



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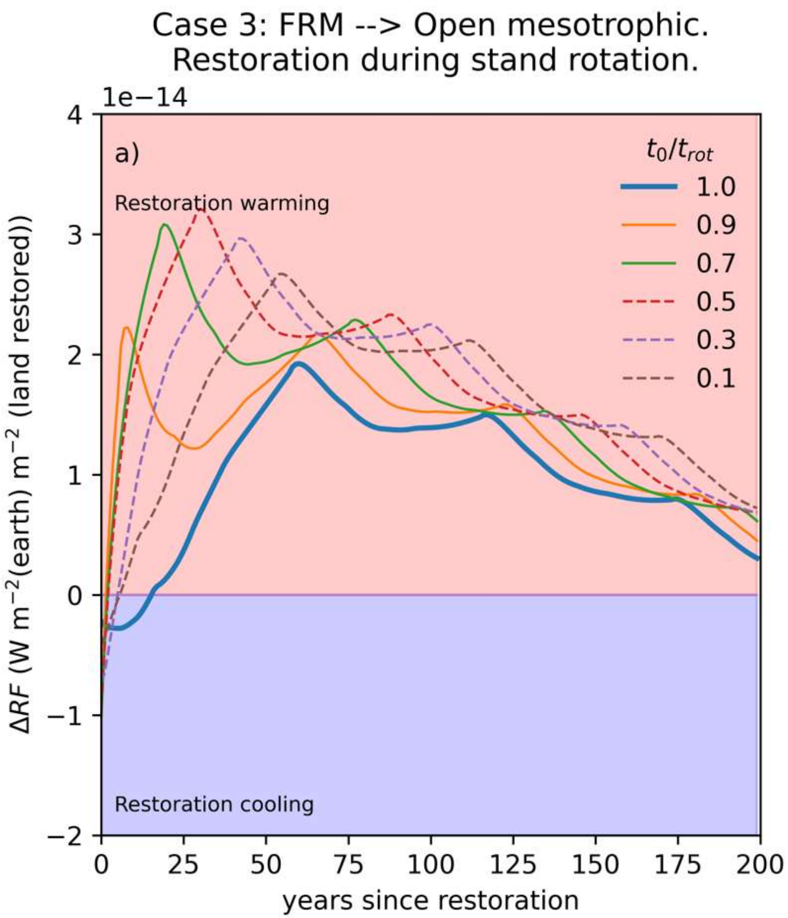
What if one restores during rotation cycle?

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 to restore at rotation end – but not always practicable**



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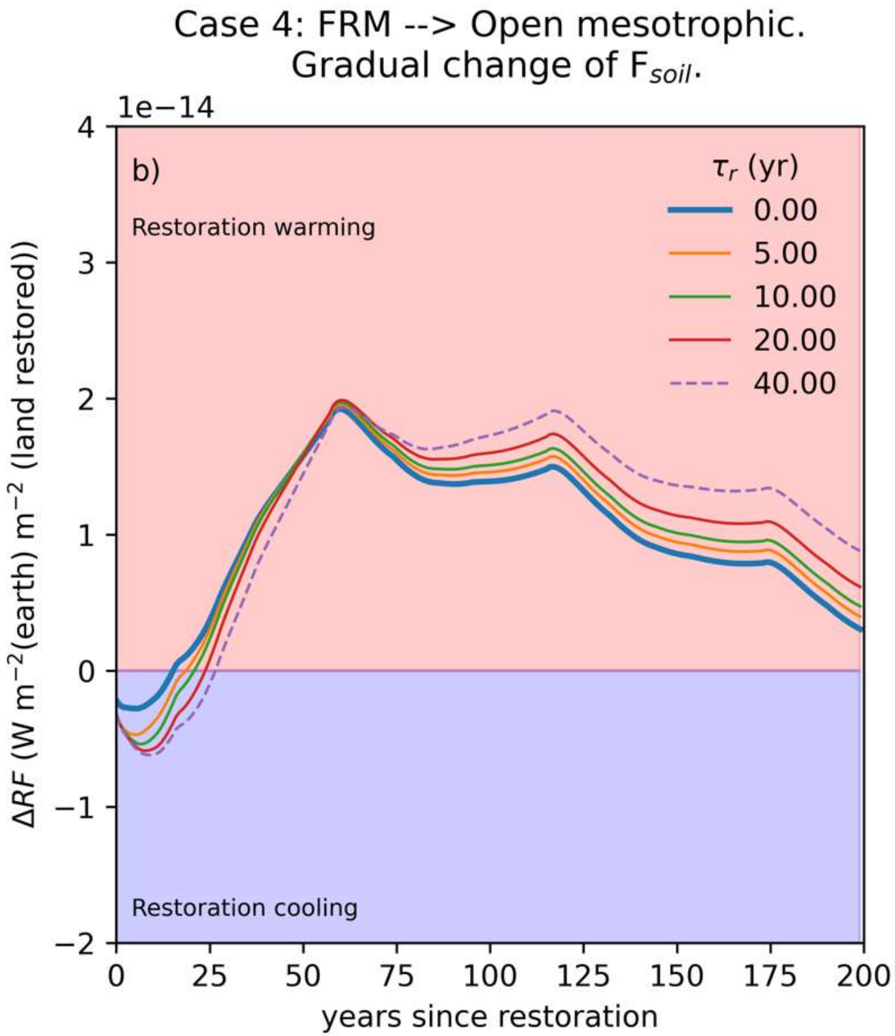
What if recovery takes time?

- After rewetting hydrology recovers fast, other ecosystem functions gradually
- 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

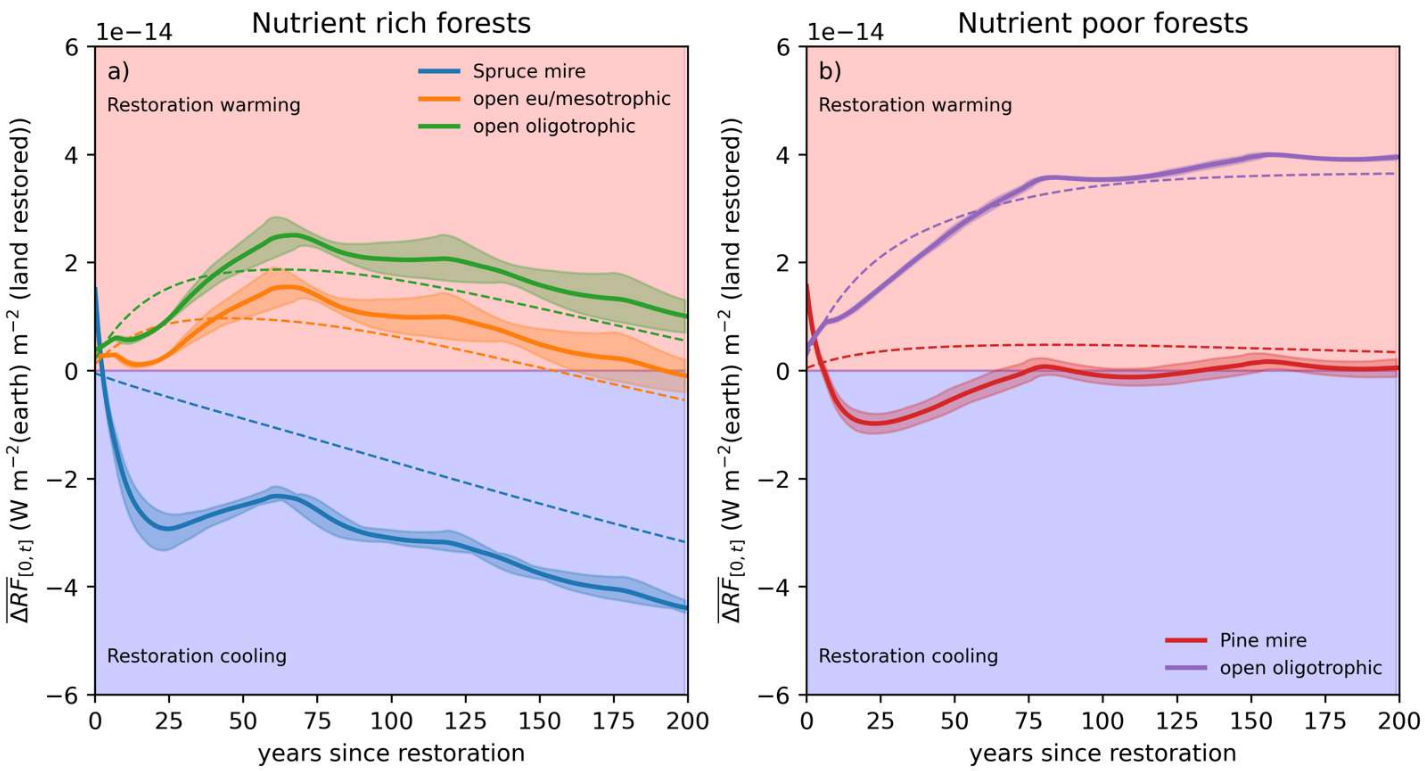
Should we restore?

Climate impact dynamics of rewetting


RESTORATION ECOLOGY
The Journal of the Society for Ecological Restoration
SER
RESEARCH ARTICLE

Climate change mitigation potential of restoration of boreal peatlands drained for forestry can be adjusted by site selection and restoration measures

Anna M. Laine[1,2,3], Paavo Ojanen[4,5], Tomi Lindroos[6], Kati Koponen[6], Liisa Maanavilja[7], Maija Lampela[7], Jukka Turunen[7], Kari Minkkinen[4], Anne Tolvanen[8]



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

Should we rewet forest peatlands?

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

- **For climate – not, except 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 does not provide more of everything
- **Our results are by no means ground-breaking**
- **Is knowledge respected?**

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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RESTORATION ECOLOGY
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Global Biogeochemical Cycles

RESEARCH ARTICLE
10.1029/2019GB006503

Rewetting Offers Rapid Climate Benefits for Tropical and Agricultural Peatlands But Not for Forestry-Drained Peatlands

Paavo Ojanen[1] and Kari Minkkinen[1]

[1]Department of Forest Sciences, University of Helsinki, Helsinki, Finland

Key Points:
- Rewetting of tropical peat soils resulted in immediate cooling
- In temperate and boreal agricultural peat soils, methane emissions offset a major part of the cooling for the first decades

Global Change Biology (2002) 8, 785–799

Carbon balance and radiative forcing of Finnish peatlands 1900–2100 – the impact of forestry drainage

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Forestation of boreal peatlands: Impacts of changing albedo and greenhouse gas fluxes on radiative forcing

Annalea Lohila,[1] Kari Minkkinen,[2] Jukka Laine,[3] Ilkka Savolainen,[4] Juha-Pekka Tuovinen,[1] Lauri Korhonen,[5] Tuomas Laurila,[1] Hanna Tietäväinen,[1] and Ari Laaksonen[1]

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