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FOREST-HUMAN-MACHINE INTERPLAY

How improved forest management practices can contribute on the CRCF?

Aleksi Lehtonen

Research Council of Finland

FLAGSHIP PROGRAMME

UNIVERSITY OF EASTERN FINLAND

Tampere University

NLS FINNISH GEOSPATIAL RESEARCH INSTITUTE FGI

Luke NATURAL RESOURCES INSTITUTE FINLAND

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- Background
- Improved forest management – boreal examples
  - Nitrogen fertilization
  - Water level management in drained peatlands
- European scale – HoliSoils results
- Challenges and research need to implement CRCF regulation
- Conclusions

Background

- Carbon Removals and Carbon Farming
  - Climate-friendly practices implemented by farmers and foresters to enhance carbon sequestration
  - E.g. Rewetting and restoring peatlands & Afforestation and improved forest management

Nitrogen fertilisation

- Microbiology and trees measured from all fertilisation treatmeants (Ca, N, P, …)
- Soil respiration measured from control and N treatment

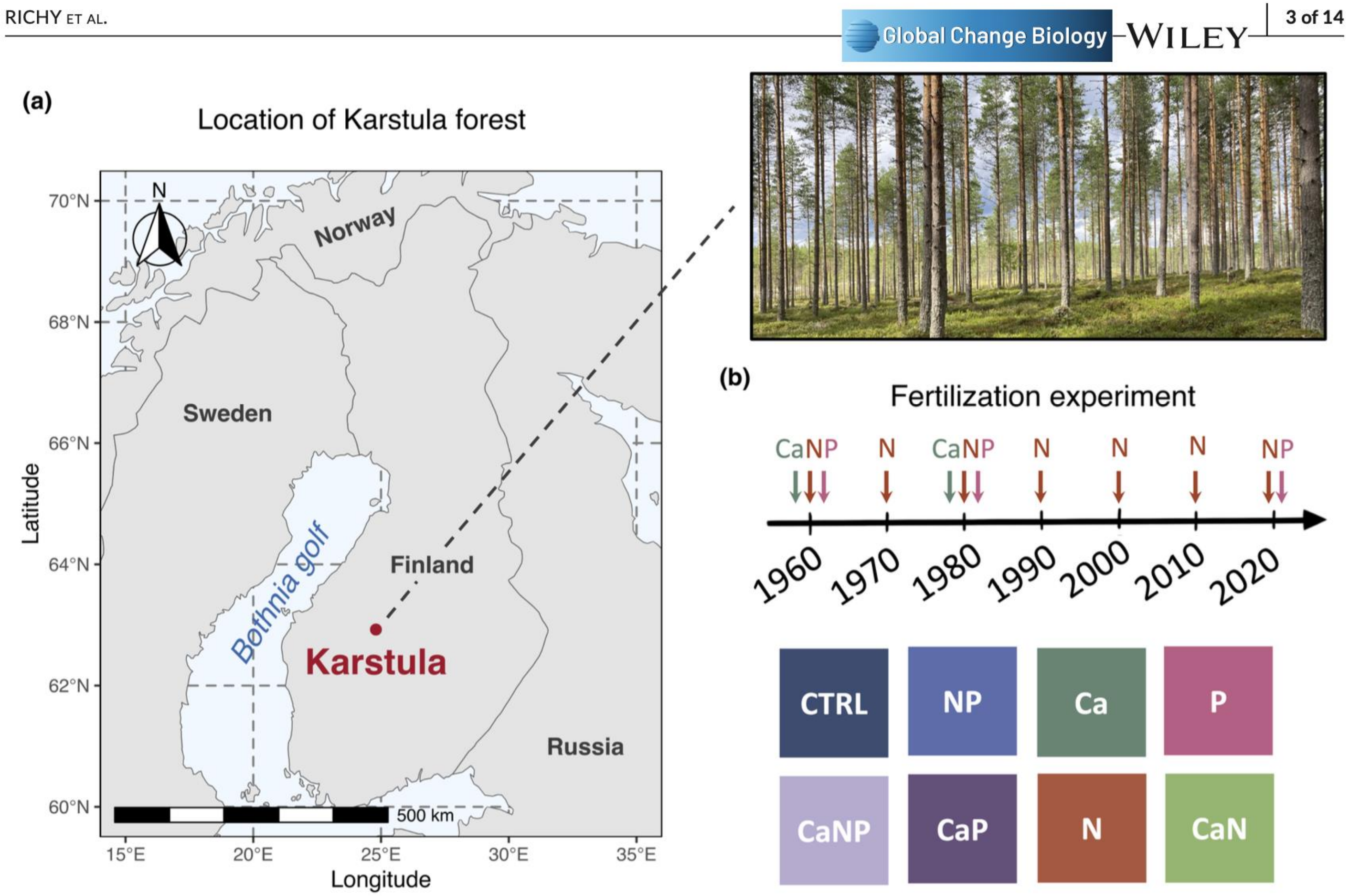

Received: 29 May 2024 | Revised: 28 August 2024 | Accepted: 4 September 2024
DOI: 10.1111/gcb.17516

Global Change Biology WILEY

RESEARCH ARTICLE

Phosphorus limitation promotes soil carbon storage in a boreal forest exposed to long-term nitrogen fertilization

Etienne Richy[1] | Tania Fort[1] | Inaki Odriozola[1] | Petr Kohout[1] | Florian Barbi[1] | Tijana Martinovic[1] | Boris Tupek[2] | Bartosz Adamczyk[2] | Aleksi Lehtonen[2] | Raisa Mäkipää[2] | Petr Baldrian[1]



Nitrogen fertilisation

Boreal forests are nitrogen limited ecosystems

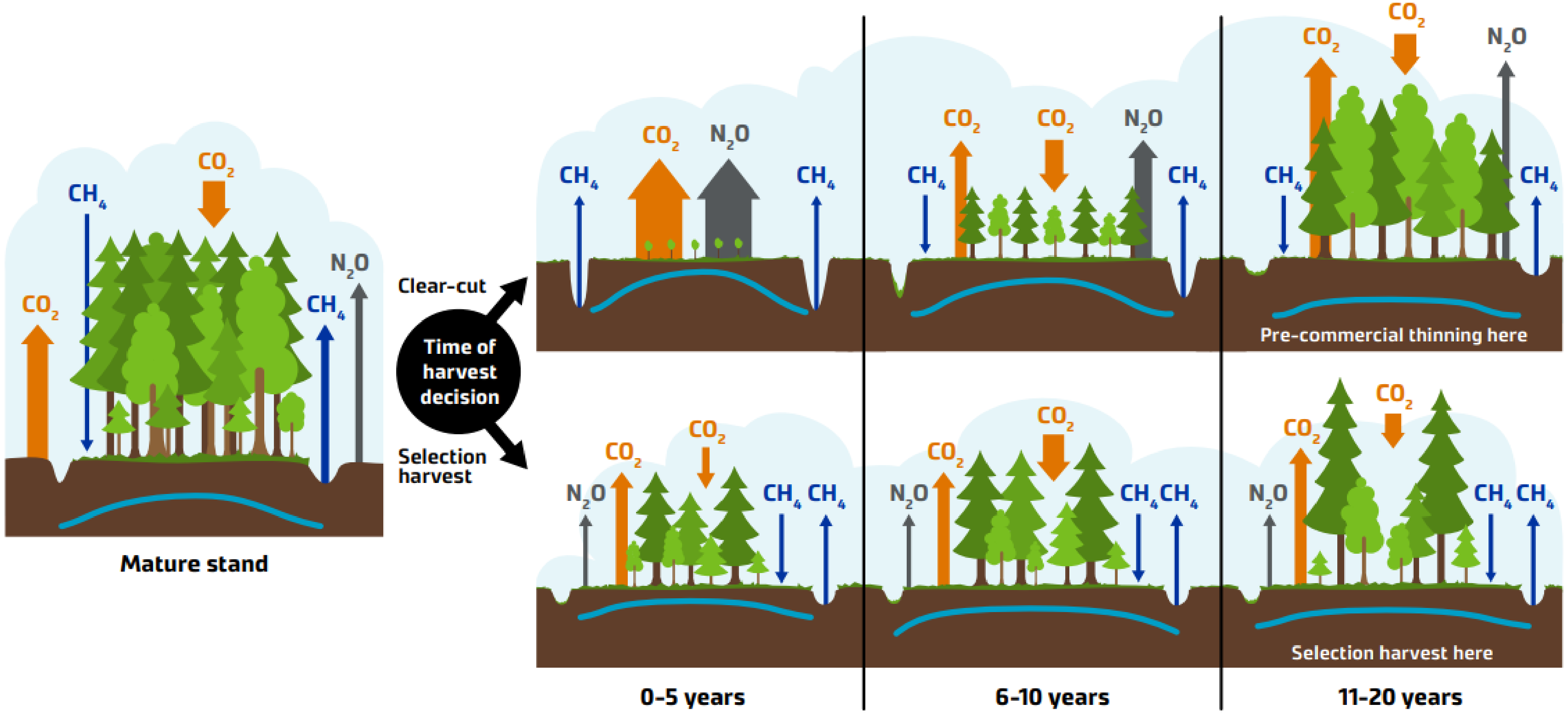
Nitrogen fertilization of Scots pine dominated stand in Finland

- mitigate GHG emissions
- increases soil carbon stock, especially stabile C stock
- increases biomass of fungi (living and dead)
- increase enzyme activity

- Adamczyk et al. *(2025). Nitrogen fertilisation of boreal forest soil increases soil carbon pool through elevated microbial necromass formation but also modifies tree secondary metabolism. Soil Biology and Biochemistry, 109917.*
- Ťupek, B. Et al. *(2025)*. Long-term nitrogen fertilization alters microbial respiration sensitivity to temperature and moisture, potentially enhancing soil carbon retention in a boreal Scots pine forest, Biogeosciences, 22, 5497–5510,
- Richy, E., et al., *(2024)*. Phosphorus limitation promotes soil carbon storage in a boreal forest exposed to long-term nitrogen fertilization. Global Change Biology, 30(9), p.e17516.

Water level management in drained peatlands

- Does transition from rotation forestry and clear-cutting to selection harvesting can mitigate emissions and other negative impacts of forestry?



Water level management in drained peatlands

- Results based on the intensively studied drained peatlands
  - CO_2 and N_2O emissions are substantial after clear-cutting
  - Continuous cover forestry was able to raise water table only by limited amount -> need for more effective water management
  - Moss covered ditched do have much lower CH_4 emissions compared to open ditches, due to CH_4 oxidation
  - Continuous cover forestry has better downstream water quality compared to clear-cuts
  - There are indications that continuous cover forestry on drained peatlands have higher biodiversity than clear-cuts

Martínez-García, E et al. (2026). Short-term effects of harvesting alternatives on soil nitrous oxide fluxes in a boreal drained peatland forest. Geoderma, 465, 117648.

Palviainen, M et al. (2022). Water quality and the biodegradability of dissolved organic carbon in drained boreal peatland under different forest harvesting intensities. Science of the Total Environment, 806, 150919.

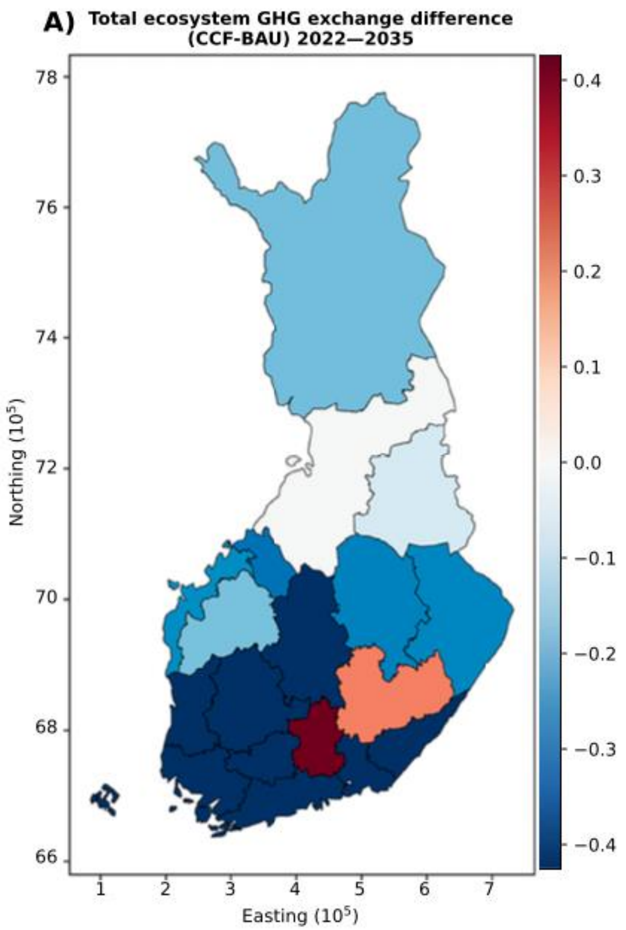
Rissanen, AJ et al (2023). Vegetation impacts ditch methane emissions from boreal forestry-drained peatlands—Moss-free ditches have an order-of-magnitude higher emissions than moss-covered ditches. Frontiers in Environmental Science, 11, 1121969.

Tikkasalo, OP et al. "Eddy-covariance fluxes of CO2, CH4 and N2O in a drained peatland forest after clear-cutting." *Biogeosciences* 22, no. 5 (2025): 1277-1300.

Water level management in drained peatlands

- Simulating for Finland with MELA model and GHG methods
  - Asking is conversion from BAU to continuous cover forestry on drained peatlands provides climate benefits, when harvesting level remains the same?

Component	The difference between CCF and BAU in Tg CO_2 eq.					
	2022–2026	2027–2031	2032–2036	2037–2041	2042–2046	2047–2051
Mineral soils	− 0.17	0.53	0.82	0.91	0.64	0.28
Organic soils (peatlands)	− 0.45	− 1.20	− 1.10	− 1.39	− 0.18	− 0.04
Trees	− 0.47	− 0.62	− 0.76	− 0.82	− 0.71	− 0.40
Total	− 1.09	− 1.29	− 1.03	− 1.31	− 0.25	− 0.15



- Additional sink of -1 to -1.3 Tg CO_2
  - Mainly attributed to increased tree growth
  - Increasing sinks **(blue)** in areas that have mature fertile drained peatland forests

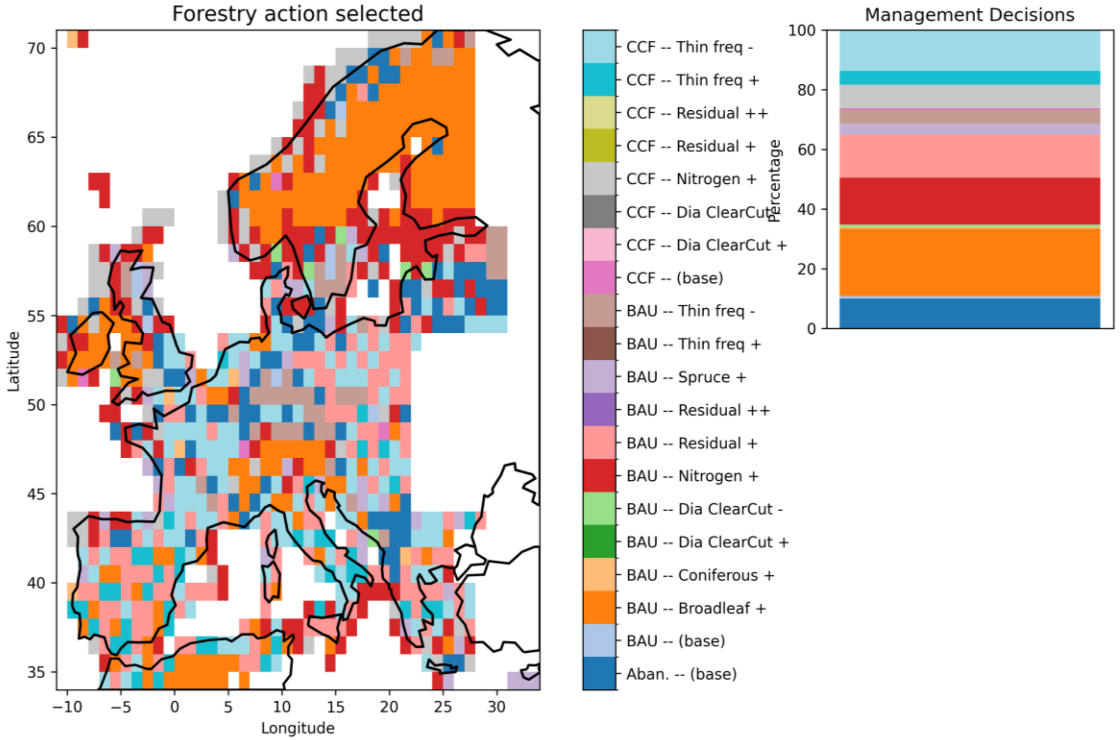
Lehtonen, A., et al. (2023). Potential of continuous cover forestry on drained peatlands to increase the carbon sink in Finland. Scientific Reports, 13(1), 15510.

European scale - preliminary

- In HoliSoils S. Luyssaert et al. simulated different forest management portfolios across Europe looking, what should be done where, when implementing climate smart forestry (CSF)
  - ORCHIDEE model

Climate mitigation:

- Maximise carbon sink
- Minimise N2O emissions
- Maximise evapotranspiration
- Minimise soil temperature
- Maximise albedo
- Time frame: 2015 to 2100



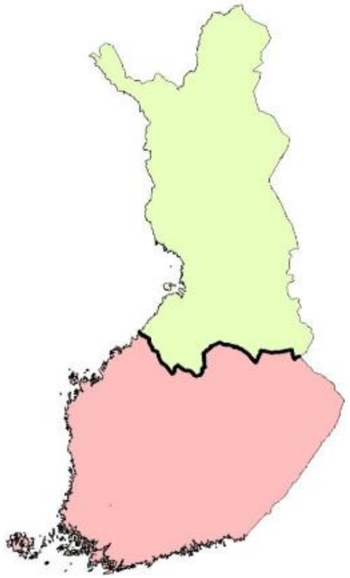
Residuals+
Nitrogen+
Broadleaves
Set-aside

HoliSoils deliverable 6.3: https://holisoils.eu/wp-content/uploads/2025/09/Deliverable-6.3-Atlas-of-optimal-forest-management-strategies.pdf

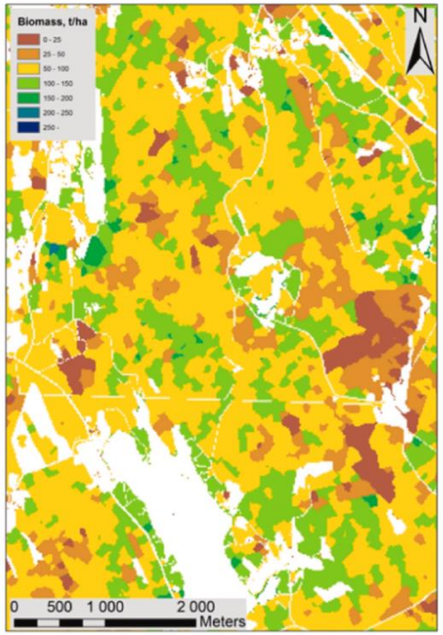
Challenges and research need to implement CRCF regulation

- **Spatial scale**

LULUCF regulation



CRCF regulation



- **Measuring & verifying**
  - Measuring C stocks and their change
    - Expensive, but often existing systems (e.g. NFI)
    - Comes with time delay (not real time)
  - Modelling
    - Model is a model …
    - Reacts fast when inputs change
  - Remote sensing
    - Biomass mapping
      - Biomass change ?
      - Soil carbon, not there yet
  - High resolution soil C maps
    - Provide static estimates for soils
    - How about soil C change ?

Conclusions

- N fertilization provides opportunities for timber and C sink delivery in boreal conditions
- Water management in drained peatlands is needed – continuous cover forestry is way to go especially when accounting biodiversity and water quality benefits
- Large-scale models exist and different forest management portfolios can be evaluated across Europe
- CRCF regulation poses substantial research needs for carbon stock change measurements and verification
  - Need to combine, models, measurements and earth observations to have real time GHG exchange between biosphere and atmosphere
- Gov. Finland funded (HIKET, 8 mill €) "*Holistic infrastructure for knowledge on land-use sector carbon sinks and emissions tracking*". EU could scale it up for the continent together with MS and research community

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Thank you!

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