Afforestation and subsequent restoration of raised and blanket bogs: impacts on water table depth and pore-water quality

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Background

Peatlands are thought to cover 2.84% of the Earth's land mass (Xu *et al.*, 2018)

Responsible for 1/3 of global soil C pool

Historically influenced by land management

Afforestation is one of the most marked land-use changes

100,000 km^2 of Finland, Russia, Norway and Sweden drained for forestry (Simola *et al.*, 2012)

More than half of Finland's peatlands have been afforested, largely between 1960 and 1990 (Strack, 2008)

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Afforested deep peat in the UK

- Deep peat = peat depth > 50 cm in Scotland; 40 cm England and Wales
- ~190,000 ha of deep peat afforested between 1950 and 1980 (Hargreaves, 2003)
- ~51,000 ha in England (Anderson *et al.*, 2014)
- ~18,000 ha in Wales (Vanguelova *et al.*, 2012)
- ~111,000* ha in Scotland

* - Estimated from James Hutton Institute 1:250,000 peat soils data and the National Forest Inventory 2015

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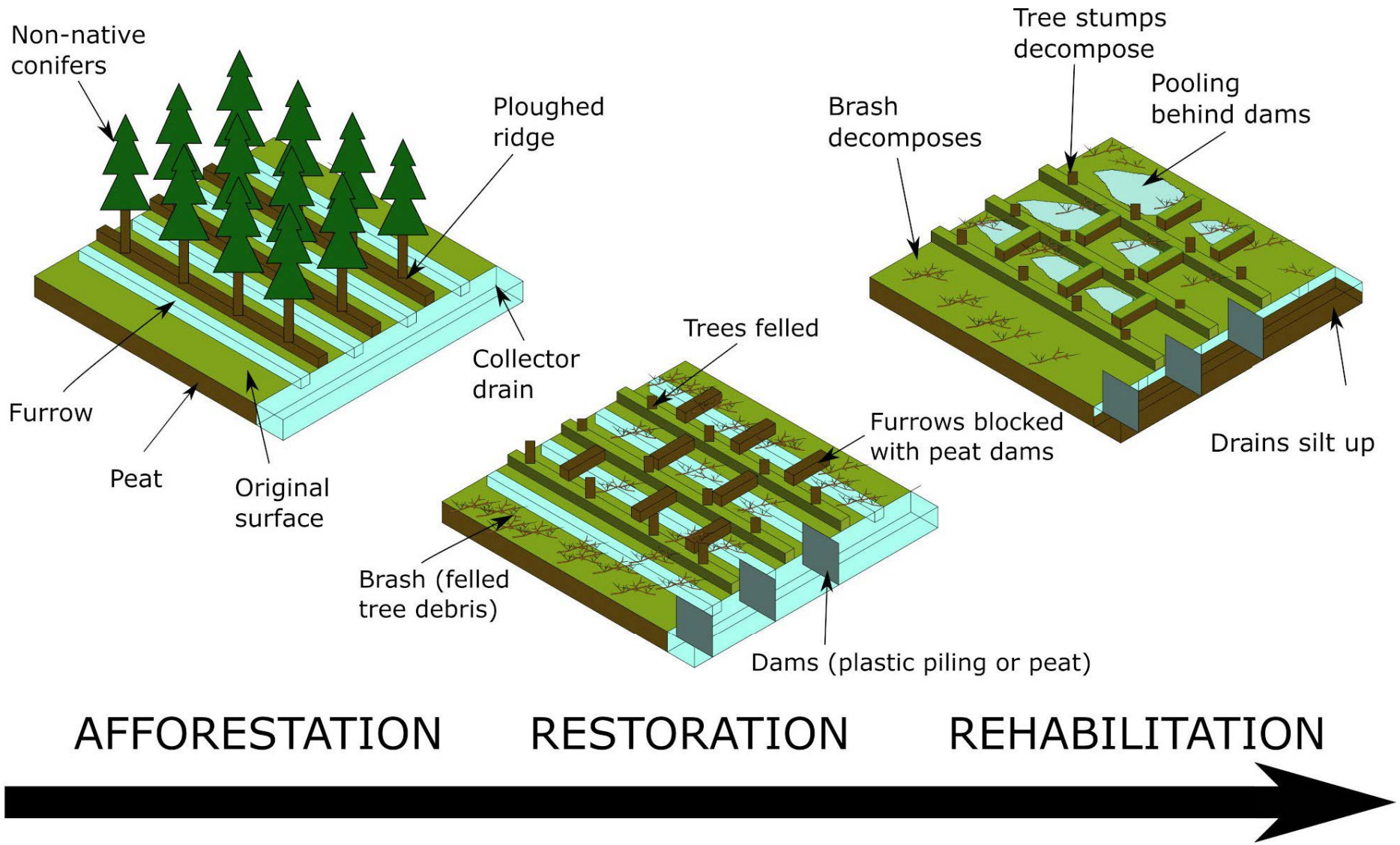

Restoration process

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Objectives

1. Determine whether significant differences in water-table depth (WTD) and pore-water chemistry exist between intact bog, afforested and restored bog sites.
2. Investigate whether differences exist in the response of pore-water chemistry to forest-bog restoration at different depths in the peat (20 to 80 cm).
3. Quantify any seasonal variability in WTD and pore-water chemistry in intact bog, afforested and restored bog sites and determine whether significant differences exist.
4. Infer the rate of recovery of forest-bog restoration at both a raised and blanket bog sites, and if any differences exist.

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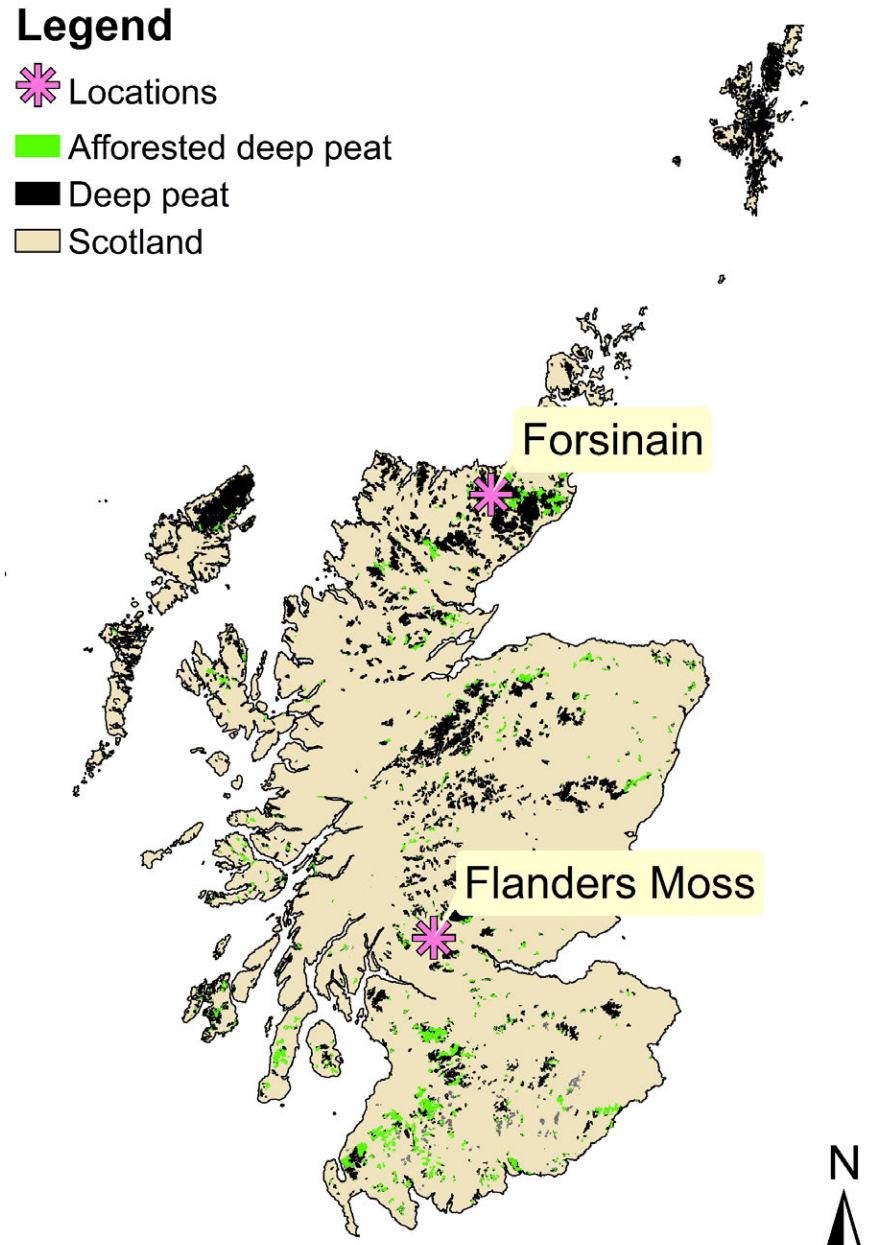
Pore-water sampling

- 2 locations
  - Flanders Moss, Stirlingshire – raised bog
  - Forsinain, Sutherland – blanket bog
- Chemical analysis
  - Dissolved organic carbon (DOC)
  - Dissolved ammonium (NH_4-N)
  - Soluble reactive phosphate (PO_4-P)
  - Total oxidised nitrogen (TON)
  - Nitrite (NO_2-N)
  - Nitrate (NO_3-N)
  - Water colour
  - pH
  - Electrical conductivity (EC)



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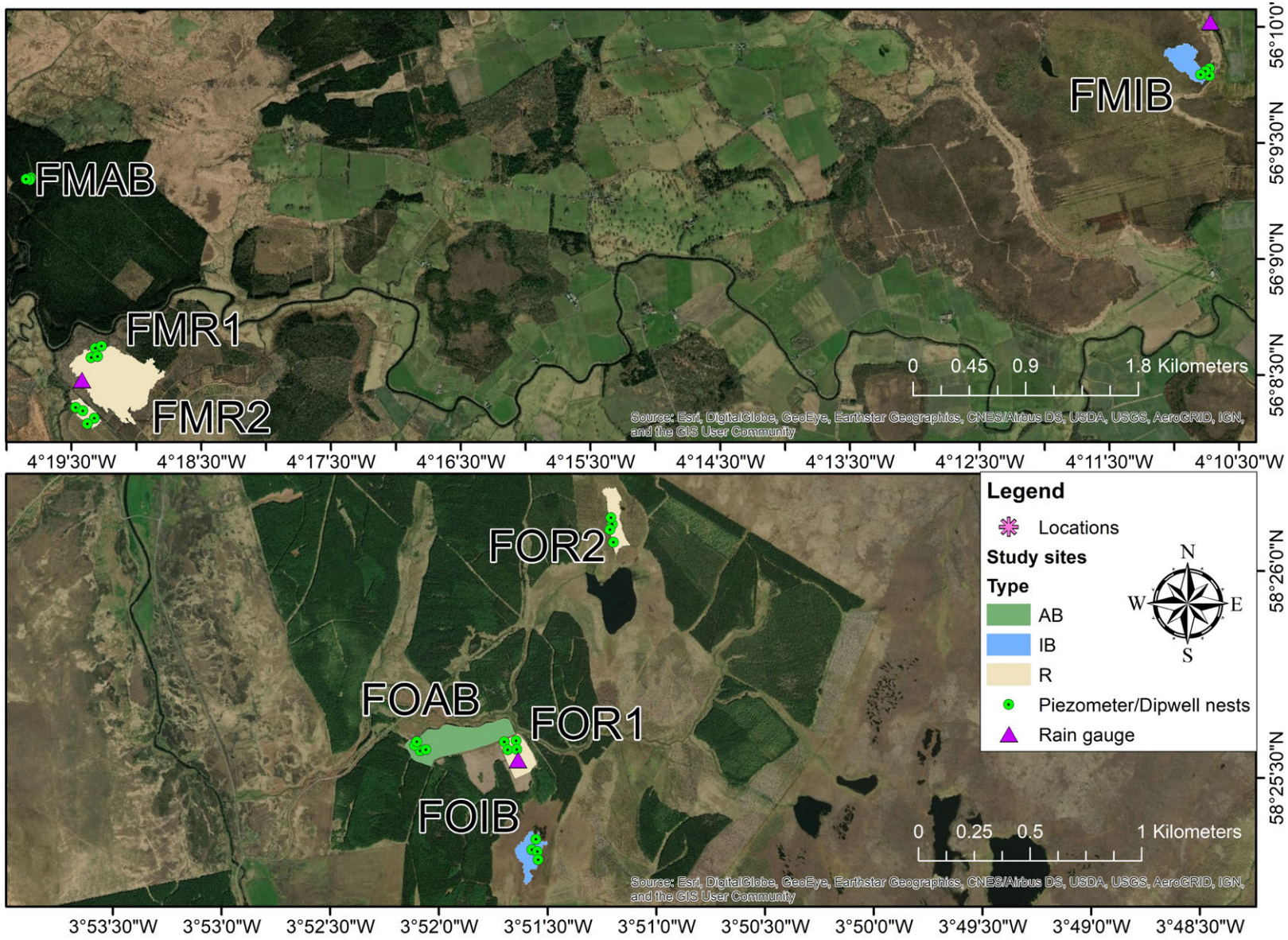
Site codes

- FM – Flanders Moss (raised bog)
- FO – Forsinain (blanket bog)
- IB – Intact bog
- AB – Afforested bog
- R1 – Restored 1 (earliest to be restored)
- R2 – Restored 2 (latest to be restored)



Experimental Design

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Site characteristics

Site	Description	Restoration Dates	Restoration Method	Furrow Spacing	Catchment Area	Catchment Outlet Location	Planting year
FMIB	Flanders Moss intact bog (IB)				6.0 ha	56° 9'47.00"N 4°10'52.29"W	
FMAB	Flanders Moss afforested bog (AB)			1.4 m	0.2 ha	56° 9'10.12"N 4°20'1.54"W	~1965
FMR1	Flanders Moss restored 1 (R1)	01/10/2013 - 31/03/2014	Felled to waste	1.4 m	26.2 ha	56° 8'27.24"N 4°19'19.27"W	~1965
FMR2	Flanders Moss restored 2 (R2)	24/11/2009 - 09/12/2009 01/08/2011 - 18/10/2011	Felled to waste – timber/ brash removed	1.4 m	2.4 ha	56° 8'12.88"N 4°19'35.19"W	~1965
FOIB	Forsinain intact bog (IB)				1.3 ha	58°25'10.32"N 3°51'41.01"W	
FOAB	Forsinain afforested bog (AB)			1.9 m	11.1 ha	58°25'30.85"N 3°52'14.67"W	~1980
FOR1	Forsinain restored 1 (R1)	2014-2015	Mulched – collector drain blocked	2.3 m	1.6 ha	58°25'32.21"N 3°51'44.25"W	~1980
FOR2	Forsinain restored 2 (R2)	2002-2003	Felled-to-waste – furrows & collector drain blocked	1.4 m	1.5 ha	58°25'58.49"N 3°51'18.76"W	~1980

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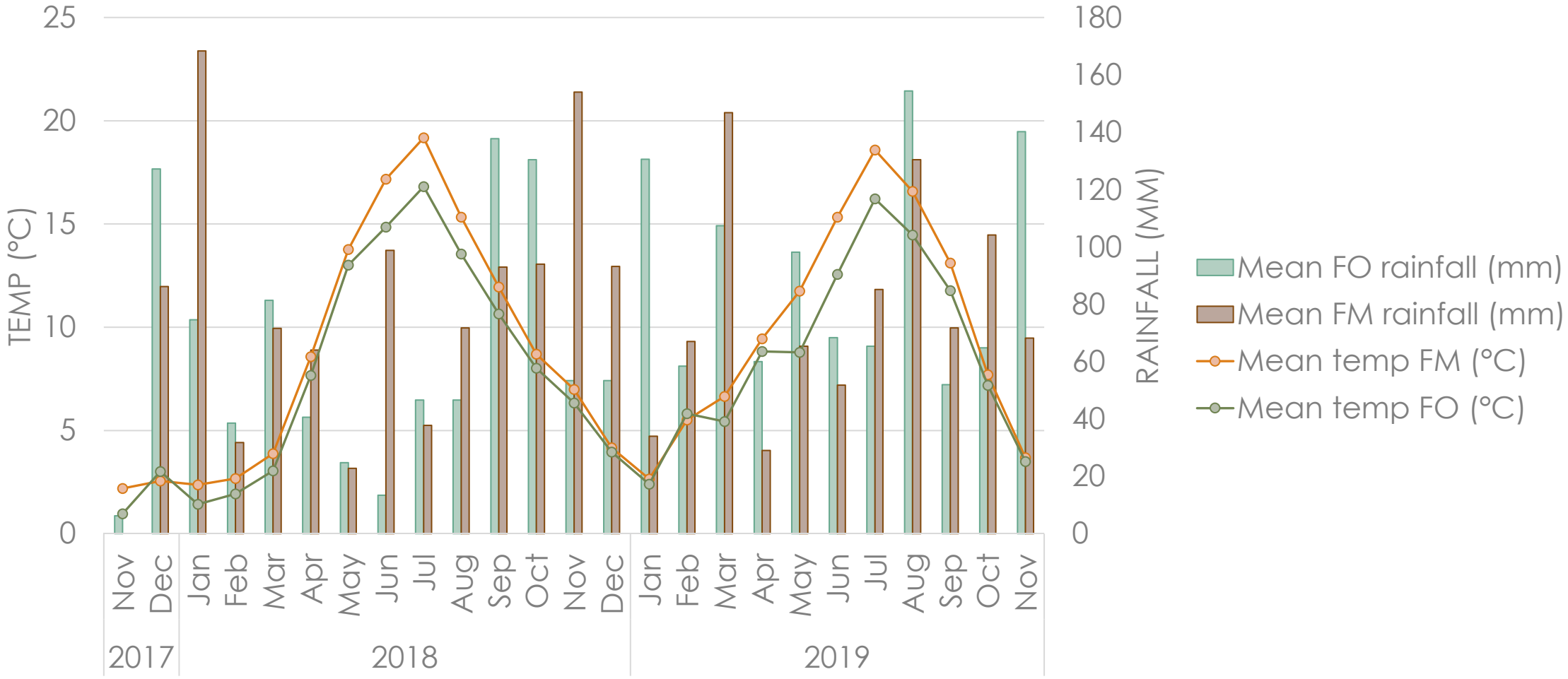

Temperature and rainfall

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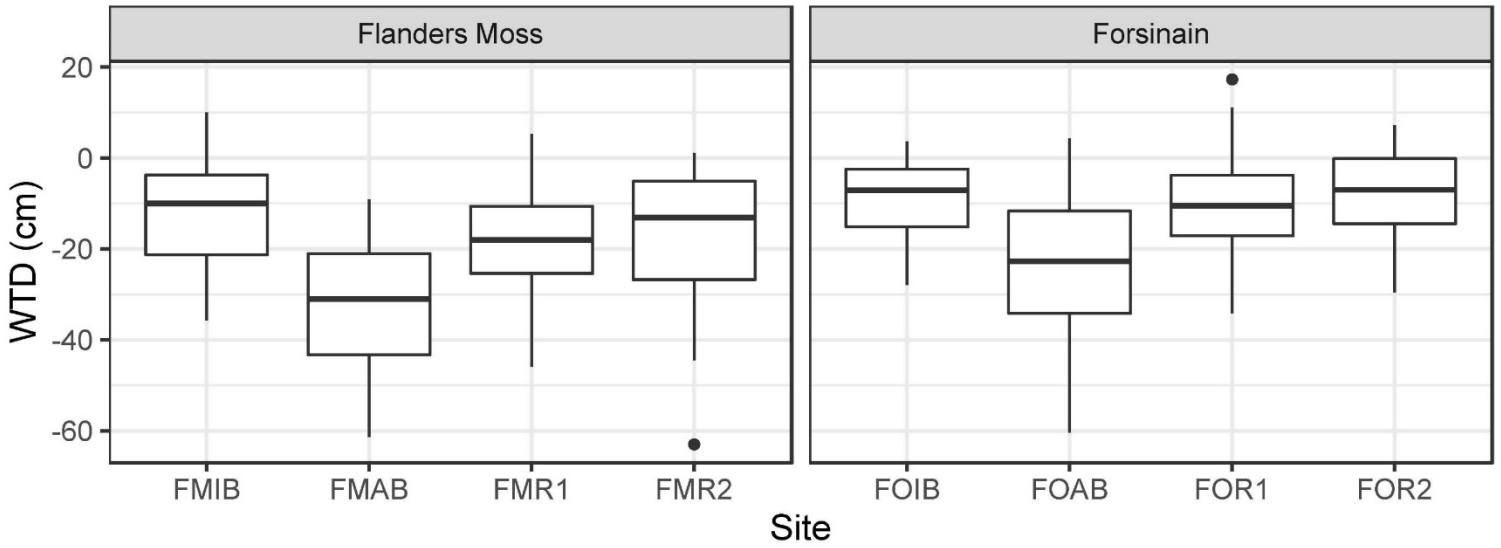
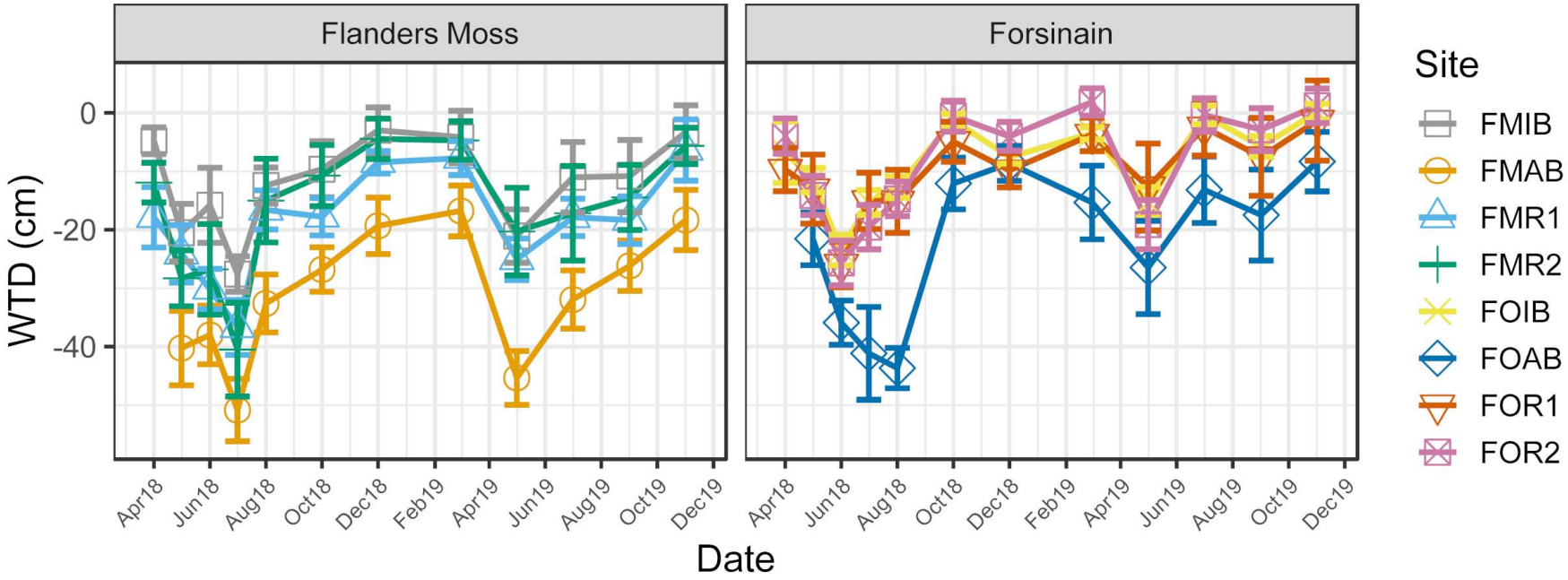


Water table

- Forestry – WT drawdown
- Greater WT drawdown at Flanders Moss
- Restoration recovery



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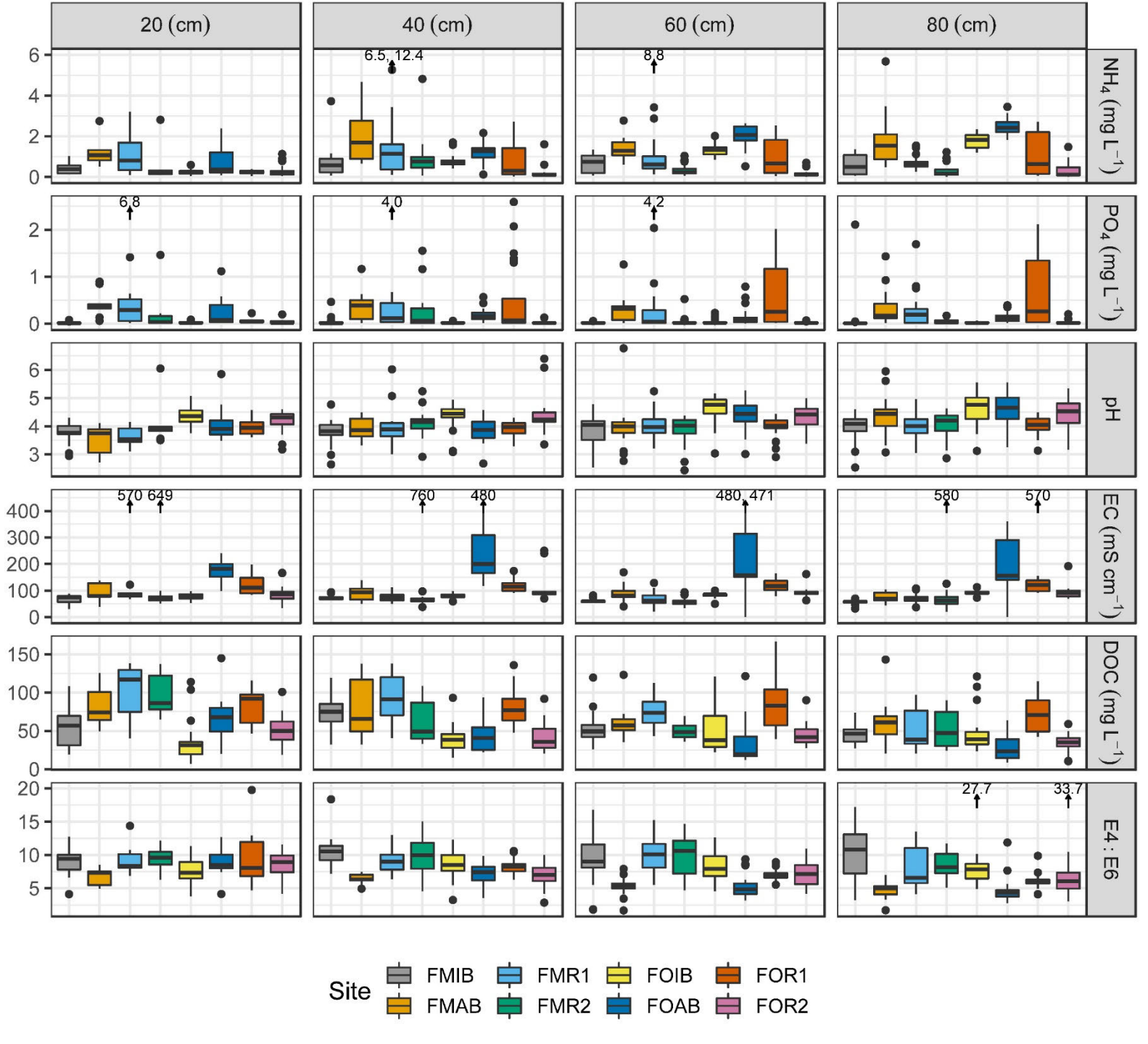
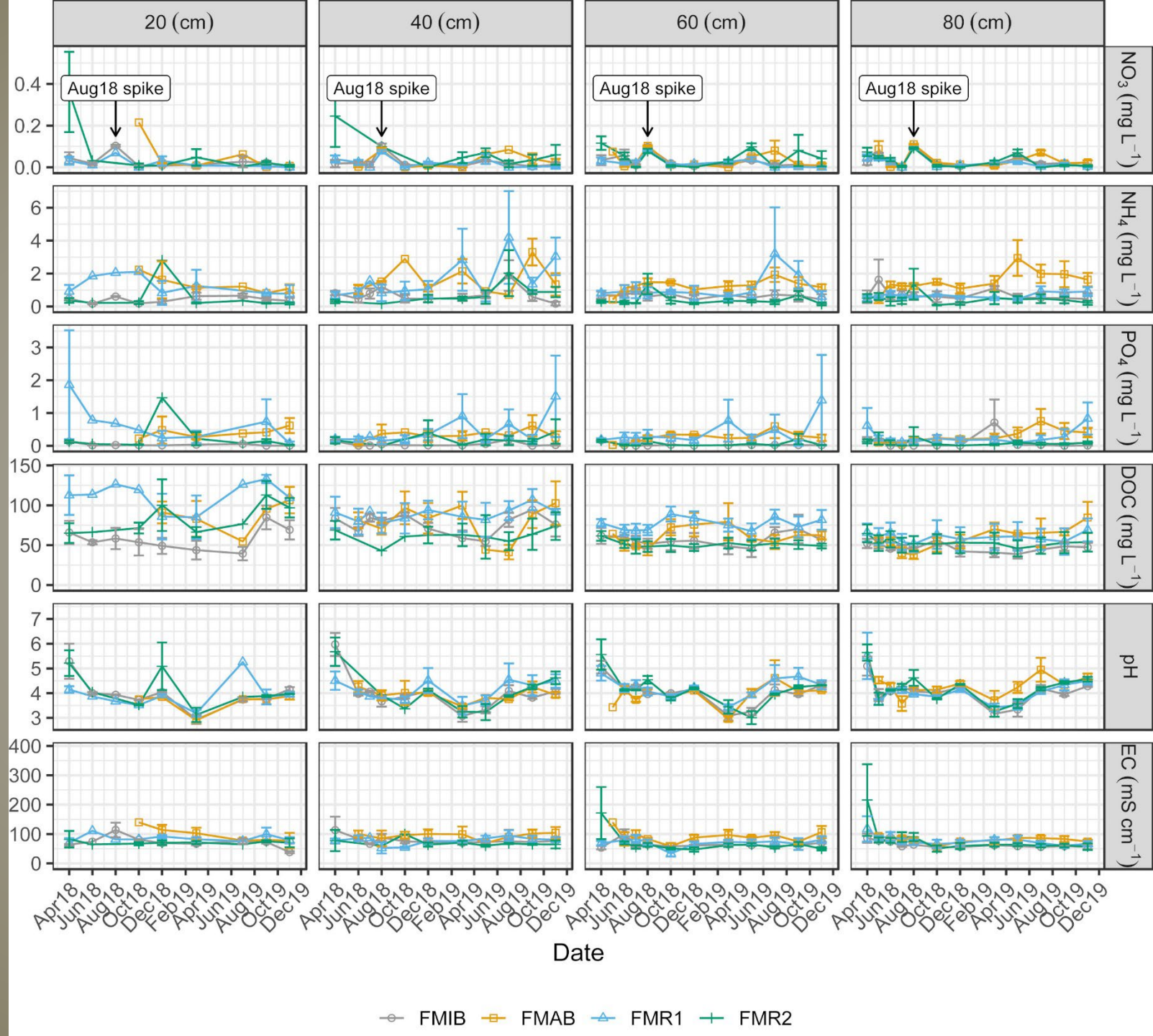
Pore-water chemistry

- DOC higher in the raised bog (FM)
- DOC recovery with restoration
- Higher EC in FOAB
- NH_4-N reduction with restoration
- A change in DOM composition with afforestation and restoration noticeable with E4:E6 ratio



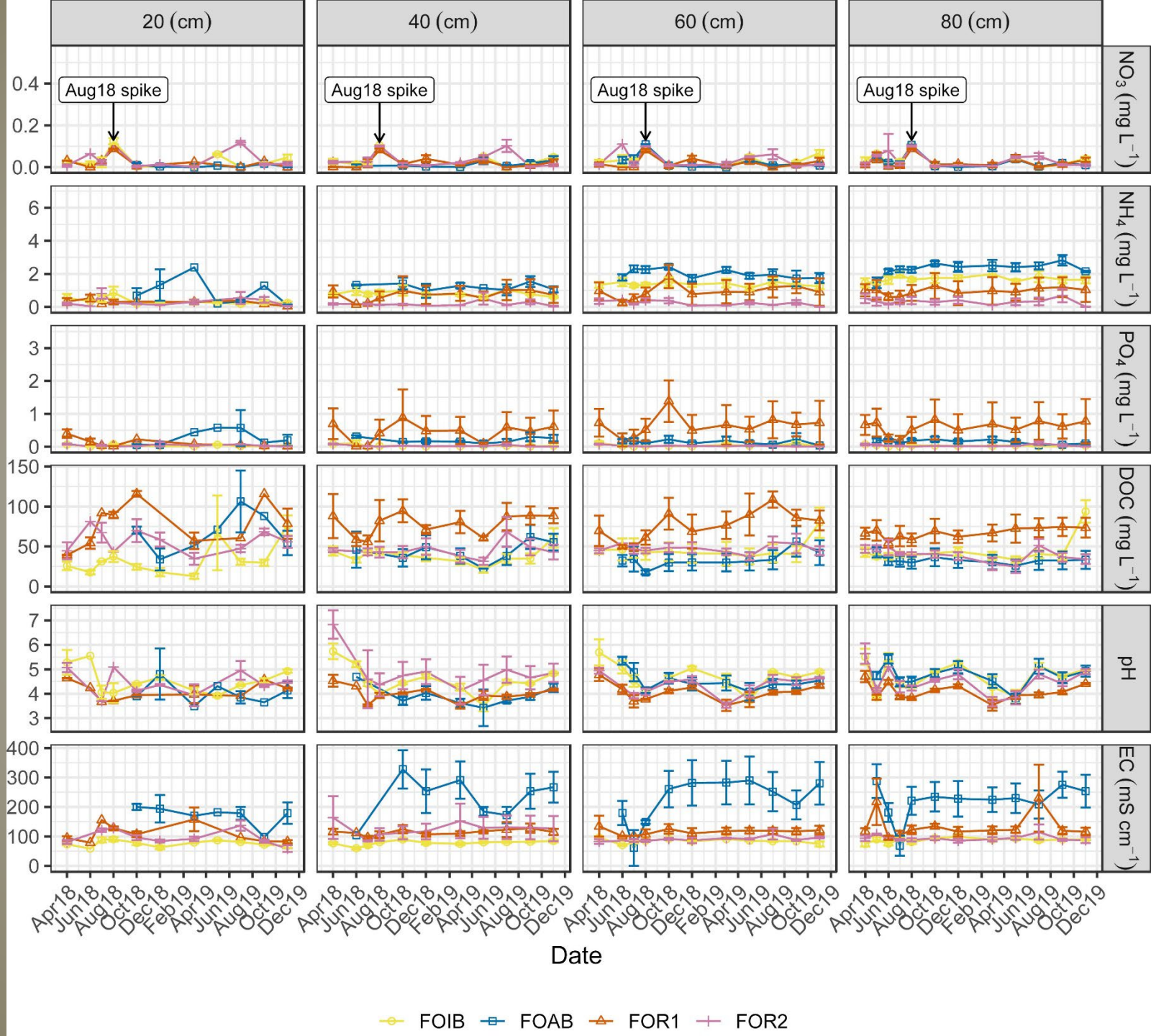
Flanders Moss seasonal variability

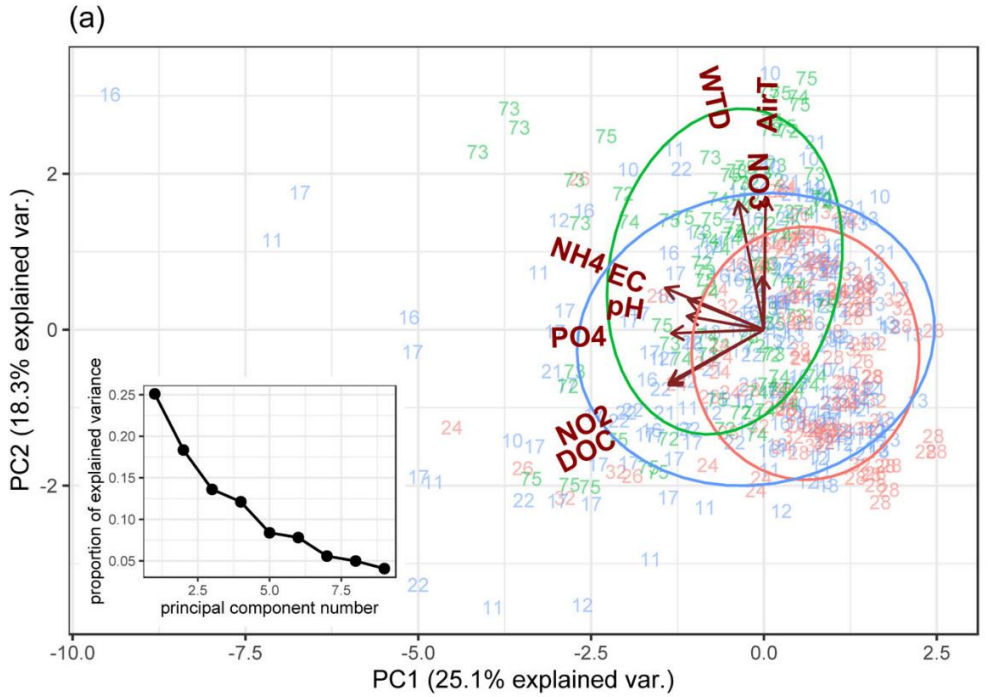
- August 2018 NO_3-N spike
- DOC and pH seasonal variability

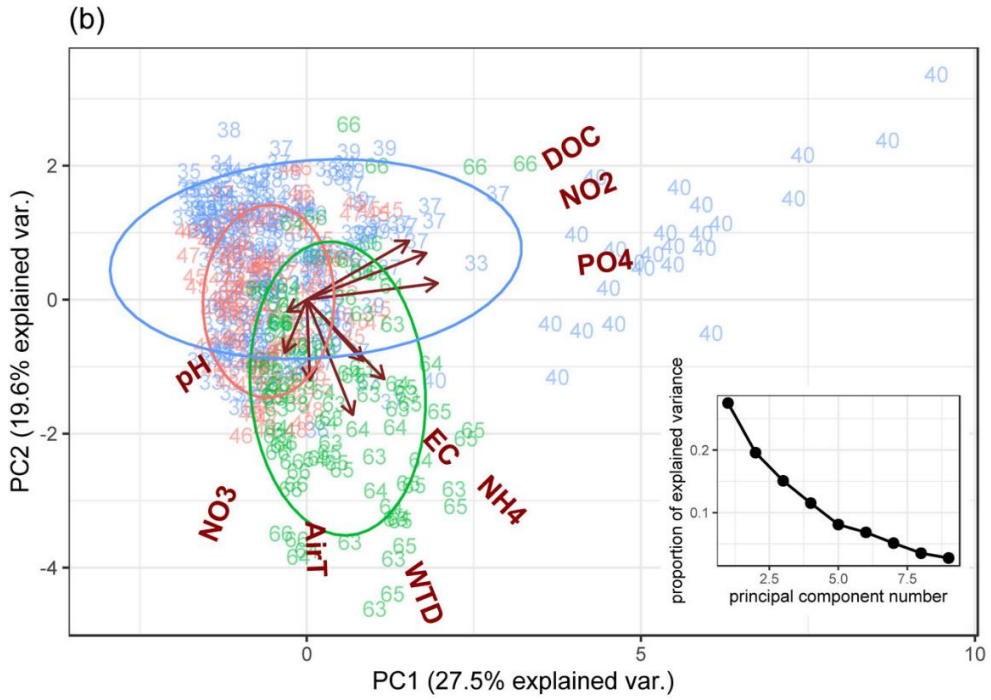


Forsinain seasonal variability

- August 2018 NO_3-N spike
- Greater difference between sites for NH_4-N
- DOC, pH and PO_4-P seasonal variability
- FOAB – significantly higher Electrical conductivity (EC) than any other site ($p < 0.01$)







groups
IB
AB
R

Principal Component Analysis

- (a) Flanders Moss (raised bog)
- (b) Forsinain (blanket bog)
- Electrical conductivity (EC), NH_4-N and WTD – associated with forestry
- DOC, NO_2-N, PO_4-P – associated with restoration
- Consistent outliers – nests 16, 17 (a) and 40 (b)

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Results Summary

- **Electrical conductivity (EC), NH_4-N and WTD – main legacy effects from afforestation**
- DOC, PO_4-P main restoration effects

Flanders Moss

- PO4-P still significantly higher ~10 years after restoration than the intact bog
- Nest 16, 17 where greater forest biomass in furrows a significant source of organic C and PO_4-P
- E4:E6 ratio suggests a greater recovery in DOM quality in the raised bog

Forsinain

- DOC still significantly higher ~17 years after restoration than the intact bog
- Nest 40 where greater forest biomass in furrow after mulching a significant source of organic C and PO_4-P

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Discussion

- High electrical conductivity (EC) in the afforested bog at Forsinain thought to be due to sea salt deposition due to maritime proximity
- Elevated PO_4-P – most likely source is forest biomass although some may have been coming from the peat at the earliest site to be restored at Flanders Moss where all useable timber and brash was removed
- Raised bog – significantly greater DOC than blanket bog thought to be from microbial-plant interactions in upper peat layer and climatic differences
- DOM composition from E4:E6 and $SUVA_{254}$ measurements had changed with afforestation and subsequent restoration

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Conclusions

- The water table had recovered to almost the same levels as intact bog at both raised bog and blanket bog sites through restoration
- Few significant differences in pore-water chemistry between intact bog ~10 years after restoration in the raised bog and ~17 in the blanket bog
- PO_4-P and DOC two main variables that differed significantly
- DOC concentrations were significantly higher in the raised bog than the blanket bog
- Leaving brash in furrows and drains can be a significant source of organic C and PO_4-P
- Complete recovery is likely to be a multidecadal process

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