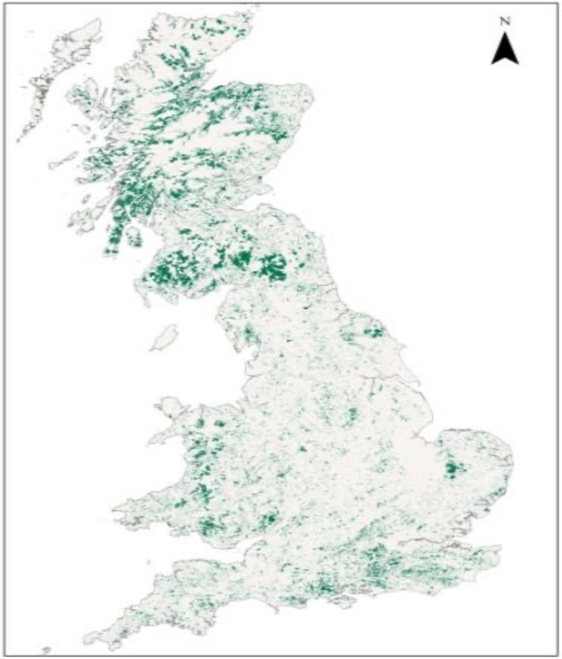
Forest Research

What is the current carbon storage and future carbon sequestration potential for forest soils in the UK?

Elena Vanguelova

Forest Research, UK

GB forests & woodlands



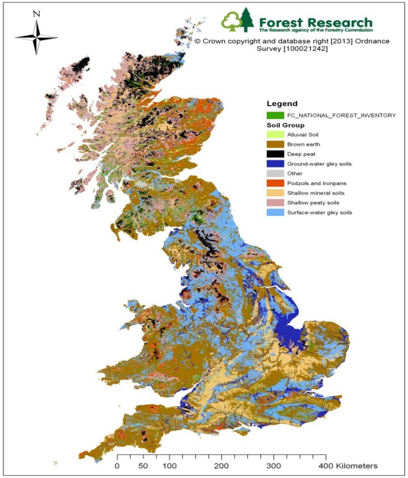
- 3.1 million hectares (13% of land)
- 0.8 Mha public forest estate
- 1.6 Mha conifer
- 1.5 Mha broadleaves

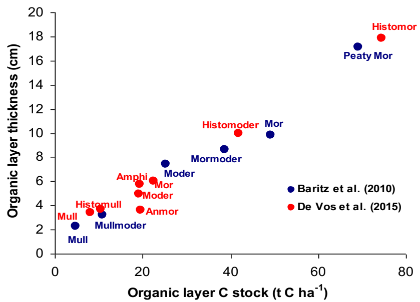
- Important ecosystem services
- Soil & water protection
- Biodiversity
- Cultural & recreational
- 8.4 Mt/a softwood, 0.4 Mt/a hardwood
- **C stock and C sequestration**

- Woodland creation - *England - 10 to 12% by 2060; Scotland 17% to 25% of land area by 2050; Wales - 10% to 13.5% land cover by 2030.*

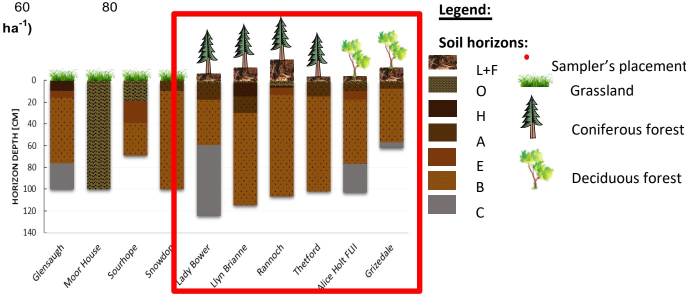
UK soils

- <u>High spatial variation in soils and forest fragmentation</u>
- Plantation forestry historically mainly on poor and highly organic upland soils
- Native and broadleaved woodland in lowlands and more productive soils
- Drainage and ploughing at establishment//Fertilisation at the poor soils
- Forest soils differ from agricultural soils (higher acidity, better soil structure, larger spatial variability, less disturbed, <u>well developed organic layers</u>



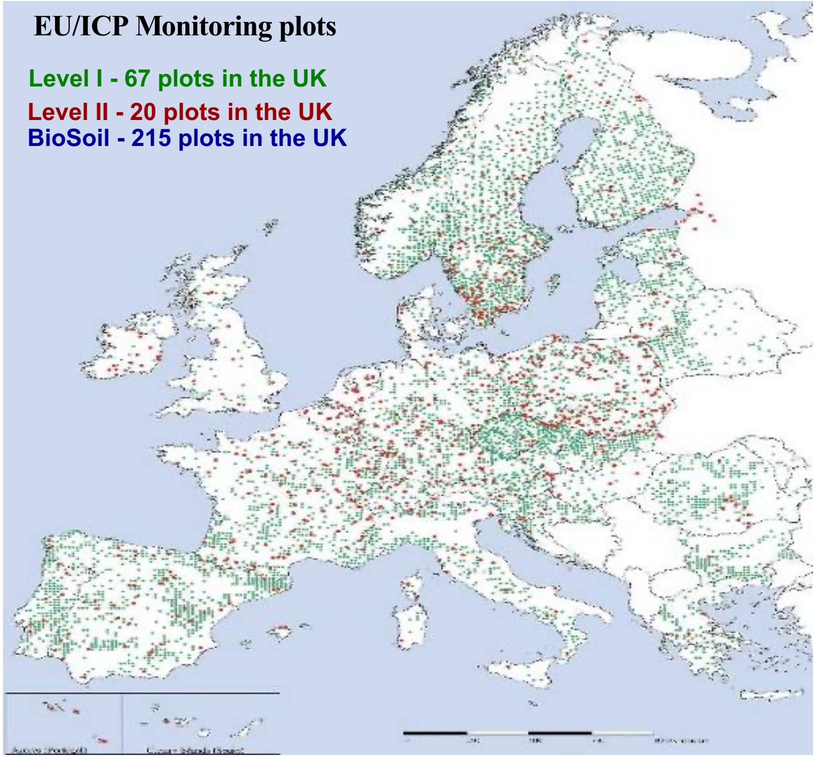


Vanguelova et al., 2016.



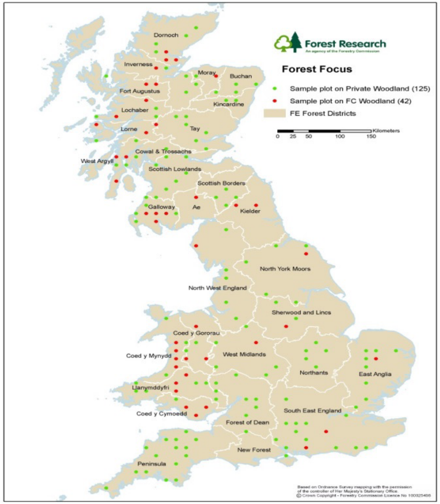
Soils datasets

Use of extensive and intensive forest monitoring networks



BioSoil – soil and deadwood carbon stocks

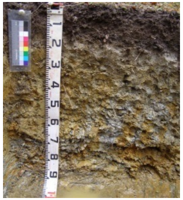
UK BioSoil plot locations - 215 plots



Soil analysis down to 80 cm
Soil Carbon (%)
Soil Bulk density
Soil C stocks
Soil C pools
(labile, stable and inert)

Podzol

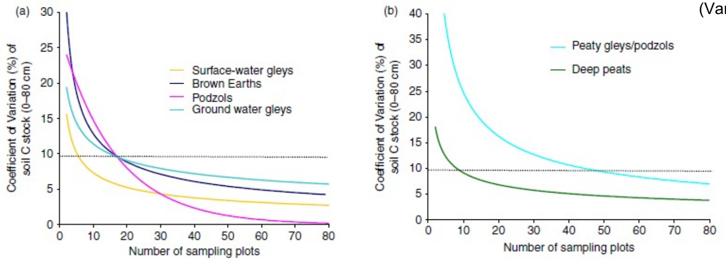
Gleysol

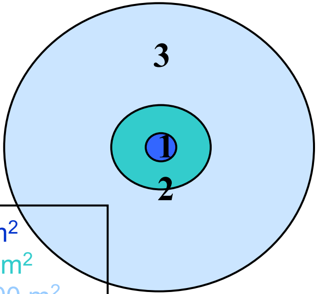


Histosol

Sensitive analysis for soil C stocks for each main soil type

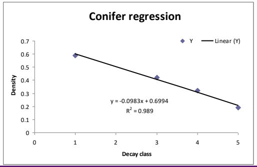
(Vanguelova et al., *2013*)

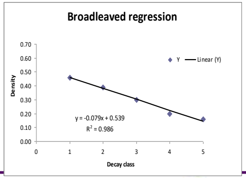


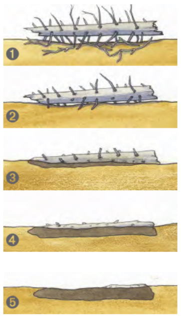


Plot 1 -30 m^2
Plot 2 -400 m^2
Plot 3 – 2000 m^2

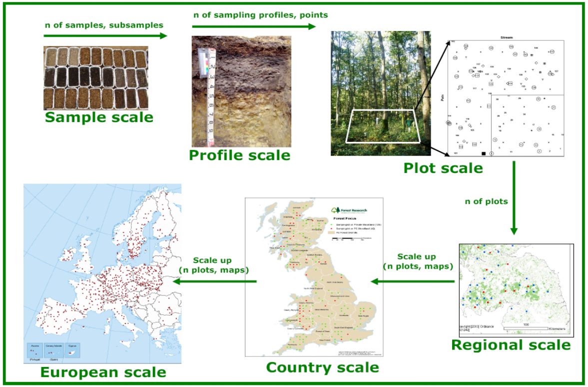
- **Type of deadwood**
- coarse woody debris, D>10 cm
- fine woody debris, D>5cm<10cm
- stumps
- **Length and diameter** (in plot of 400 m2)
- **Decay classes – 1 to 5**







Soil – sampling and scales



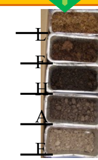

Sampling

Organic layers density (25 x 25 cm quadrat, 3 per plot)



Soil pits (3 per plot)

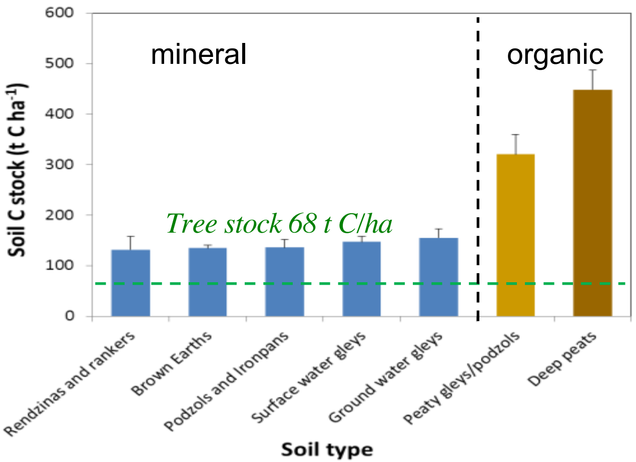

Soil augering (10-30 per plot)

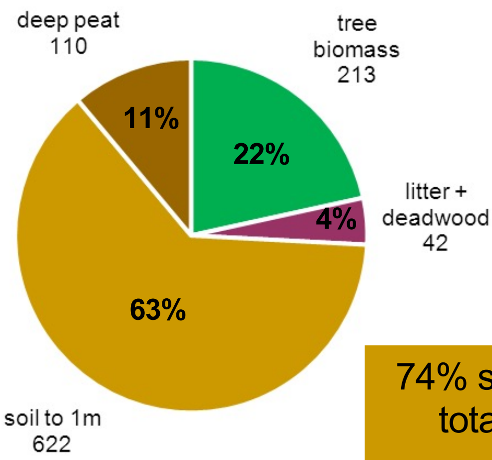

Vanguelova et al., 2016. *Environ. Monit. and Asses.*

UK forest carbon storage

Estimates from the National Forest Inventory (2010-14) & BioSoil survey (2005-10)

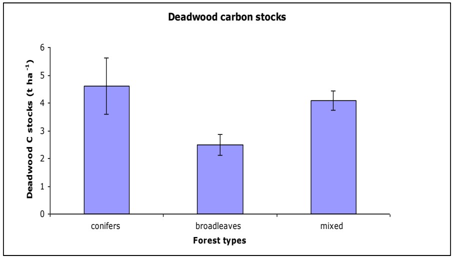


(Vanguelova et al., Soil Use & Man., 2013)



74% soils total

total UK C stock 'in forest' = 987 Mt C



Deadwood carbon in
-conifers (4.6 t C ha^{-1}),
-mixed plots (4.1 t C ha^{-1}) and
-broadleaves plots (2.5 t C ha^{-1})

(Vanguelova et al.,in prep)

C stocks distribution across the UK

Total soil carbon stocks (Mt) per soil type, forest type and country

Country	England		Wales		Scotland		
Forest type	Coniferous	Broadleaves	Coniferous	Broadleaves	Coniferous	Broadleaves	Great Britain total
Soil type							
(b) 0–100 cm							
Rankers and rendzinas	4.1	13.3	0.8	0.4	1.7	0.2	21
Brown earths	22.0	41.5	12.0	10.5	21.7	11.2	119
Podzols and Ironpans	8.5	6.1	6.7	0.1	25.7	7.6	55
Surface-water gleys	12.4	28.4	1.5	3.1	18.2	5.2	69
Groundwater gleys	1.9	4.7	0.1	0.4	0.0	0.0	7
Peaty gleys/podzols	19.9	2.9	8.2	1.5	200.4	13.3	246
Deep peats	12.9	4.3	6.4	0.3	78.2	2.2	104
Total C stock per forest type	81.7	101.2	35.8	16.2	345.9	39.7	
Total C stock per country	183		52		386		621

England
30% in brown earths
25% gley soils

Wales
40% brown earths
20% peaty soils

Scotland
55% peaty soils
20% deep peats

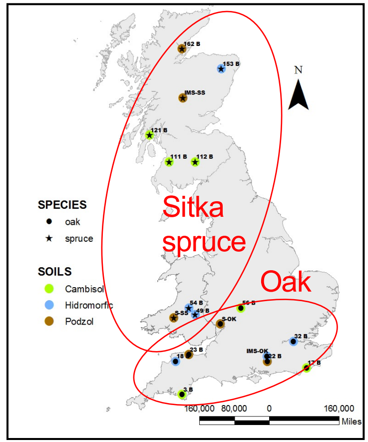
GB
40% peaty soils
20% brown earths
20% deep peats
15% gley soils

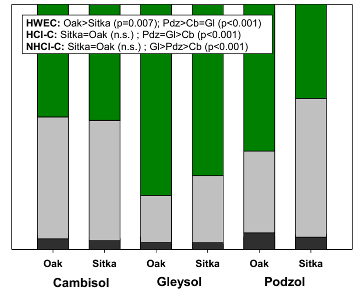
(Vanguelova et al., *2013 Soil Use & Man.*)

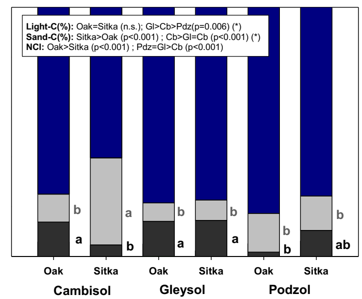
Stability of SOC in Typical Forestry Ecosystems in United Kingdom

Theoretical C Pools	Chemical Extractions (*Humification*)	Physical Fractions (*Physical Complexation*)
LABILE/ACTIVE (months-years)	Hot Water Extractable Carbon (HWEC)	Non-physically protected: FLF
SLOW (decades)	Acid Hydrolisis (HCl)	Physically protected: Aggregated (IALF) or sand minerals (CSD+ FS)
PASSIVE-STABLE (100-1000s)	Residual C	Physical protection: Silt+clay minerals (CST + SC)

Olk & Gregorich. 2006. Meaningful pools in determining SOC and N dynamis. SSSAJ.







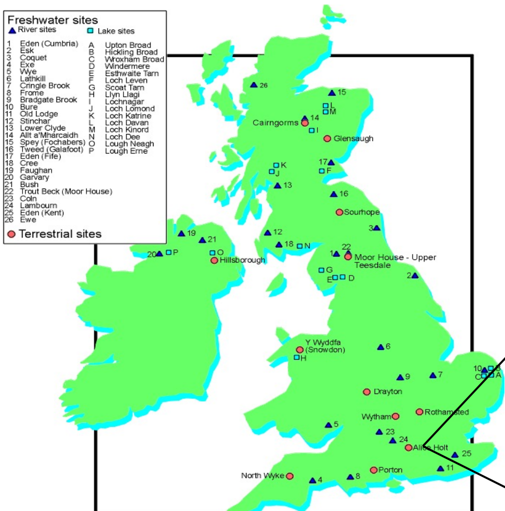
- ➢ Significant differences in most C fractions among forests, both in terms of ***soil types*** (**stable C pools: gley soils and podzols**) and ***tree species*** (labile C pools in topsoils).

- ➢ **Physically inert carbon associated with clay fraction - 70 % in Gley soils**

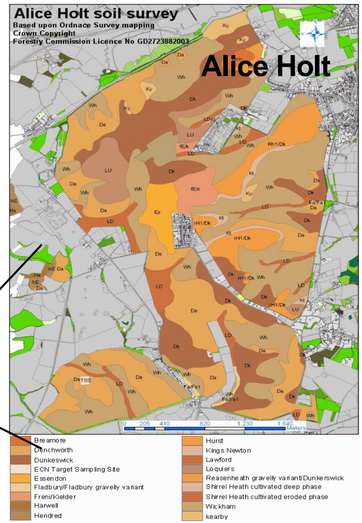
(Villada, PhD thesis, 2013, UoR)

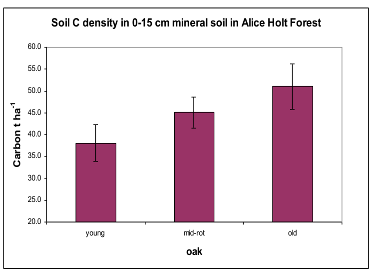
Forest chronosequence – Oaks on gley soils

Repeated soil survey (every 5 years) for 20 years

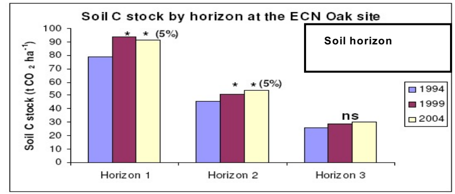


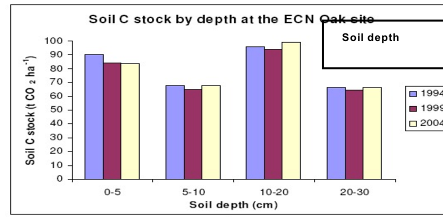
180 Chronosequence - Oak – surface gley soils





Pitman et al. 2014



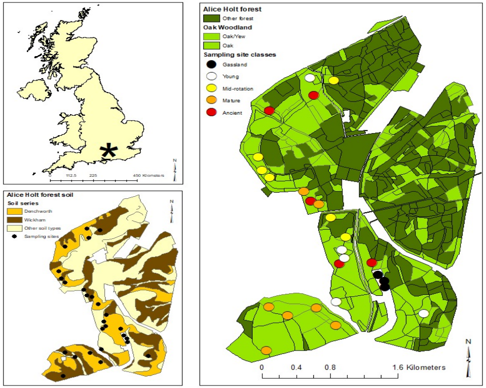


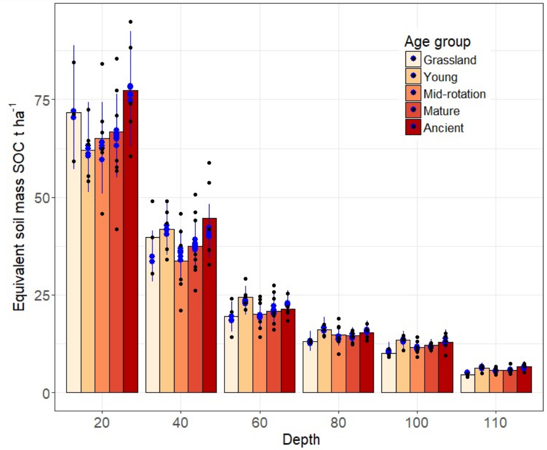
Benham, 2012

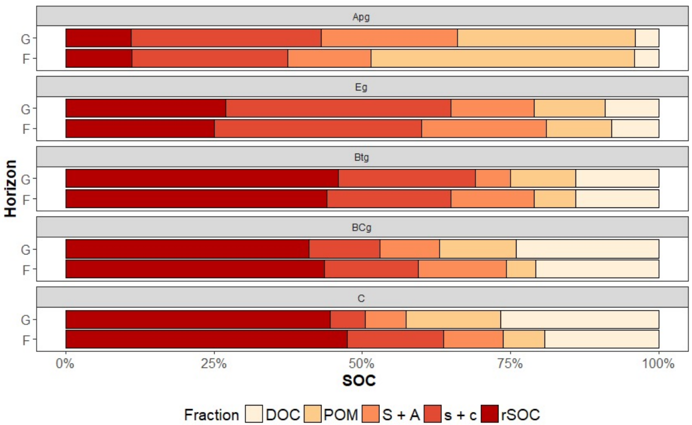
- Increase at 0.34 t C ha^{-1} y^{-1}, at topsoil mainly due to increase in horizon thickness.

- Increase at 0.1–0.2 t C ha^{-1}y^{-1} across young (~25 years), mid-rotation (~60 years) and old (120+ years) stands.

Deep carbon changes across forest chronosequences







- 50% of SOC stored in soil >20 cm depth in both forest and grassland
- Higher POM in topsoil in grassland compared to forest
- Higher resistant SOC in forest compared to grassland in deeper soils

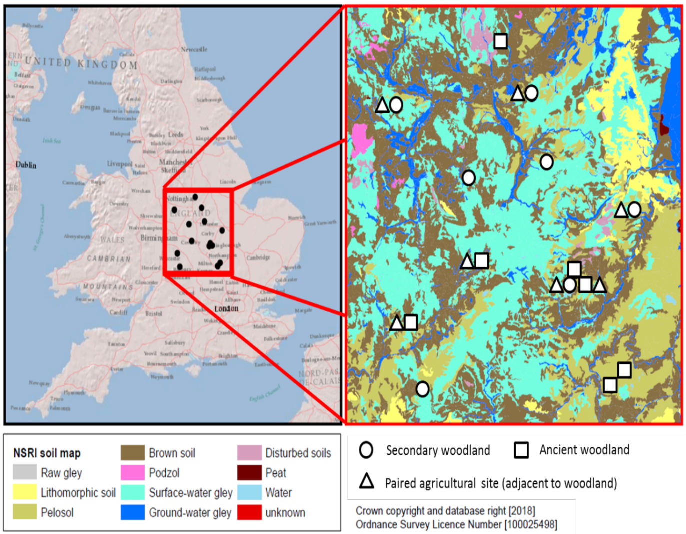
SOC physical fractionation in the **220 year old forest** stands (F) and grassland (G).
Bars present total SOC t/ha, colours - SOC fractions

Dr Rita Razauskaite
(PhD thesis)

Woodland chronosequence – mixed Oaks on gley soils

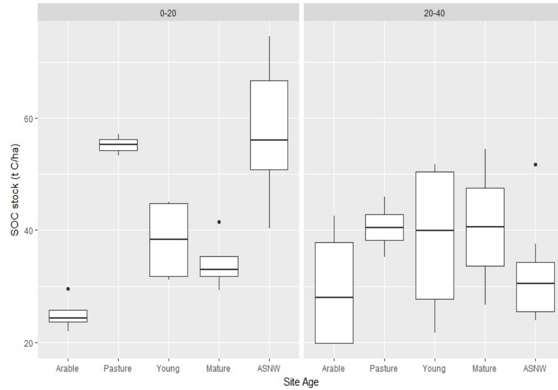
Woodland Creation and Ecological Networks project

(WrEN; www.wren-project.com)

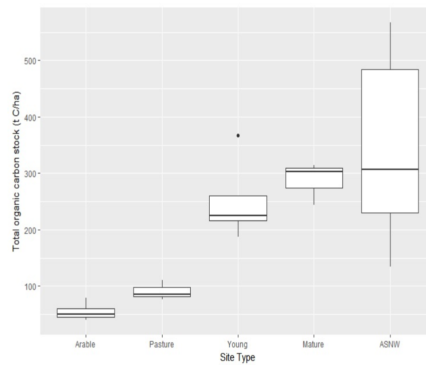


(Ashwood et al., 2019)

- ➢ Increase at 0.2-0.4 t C ha^{-1} y^{-1}, at topsoil –woodland on arable land



Soil C stock changes in 0-20 and 20-40 cm mineral soil



Soil C stock changes in organic + 0-40cm mineral soil

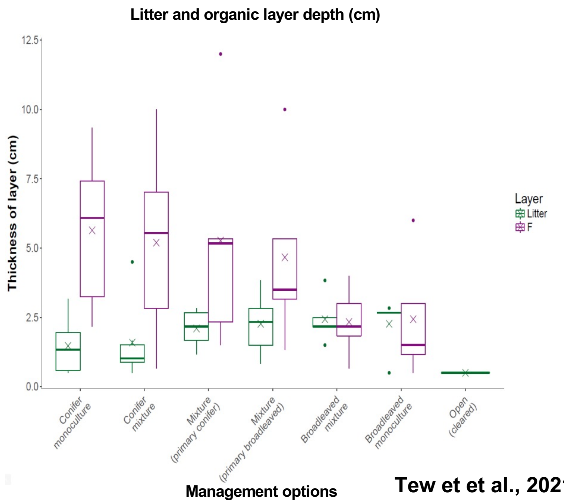
Forest Research

Forest and heathland soil C stocks comparison

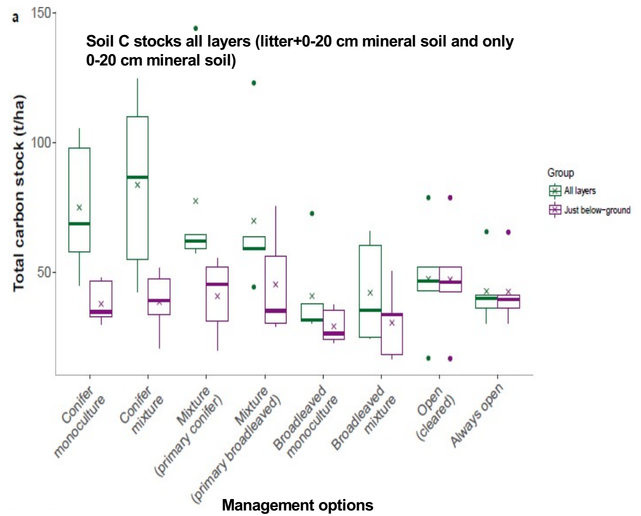
Management option	Category description	Calcareous plots	Acidic plots	Total number of plots
Conifer monoculture	One species, conifer	2	4	6
Conifer mixture	3+ species, all conifer	3	3	6
Broadleaved monoculture	One species, broadleaved	2	3	5
Broadleaved mixture	3+ species, all broadleaved	3	2	5
Mixture (primary conifer)	3+ species, combination of broadleaved and conifers, largest component is conifer	2	3	5
Mixture (primary broadleaved)	3+ species, combination of broadleaved and conifers, largest component is broadleaved	3	2	5
Open (cleared)	Sites recently cleared from forestry to revert to heathland	3	2	5
Always open	Historical heathland sites, never planted	3	2	5
Total				42

Eleanor Tew, PhD student, University of Cambridge/East Anglia FC district/FR

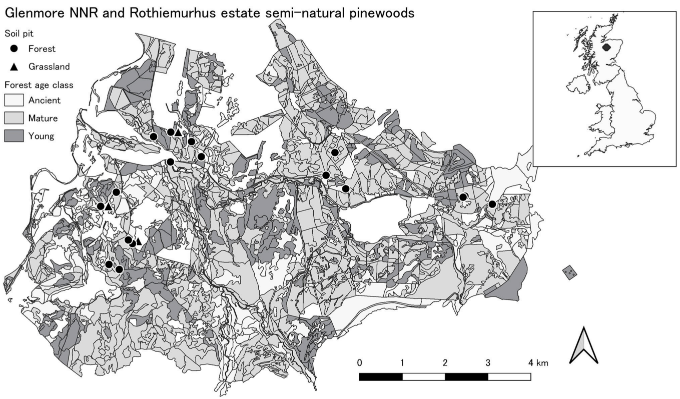
- **C accumulation in organic layer – at rate 0.5-0.9 t C/ha/y**
- **No change of mineral sandy soil over >50 years of afforestation**



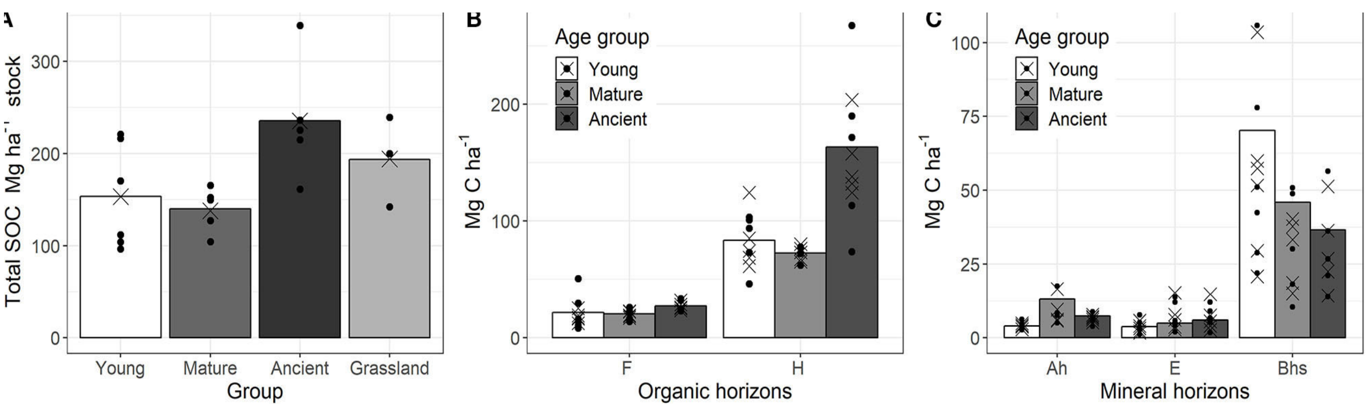
Tew et et al., 2021



Forest chronosequence – Scots pine on podzols



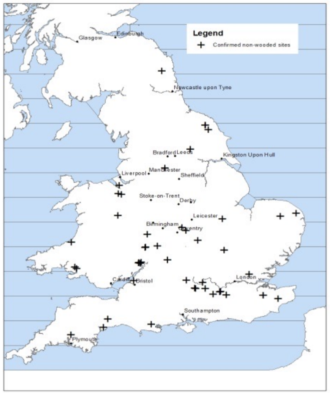
- Soil organic carbon stock changes in a >120 year-old Scots pine chronosequence and adjacent grassland sites on sandy podzolic soils.
- Significant carbon accumulation was measured in the top organic soil horizons with forest age.
- No changes were noted in the deeper mineral sandy soil horizons.



Razauskaite et al., 2020

Afforestation national scale projects

21 sites afforested since 1970's surveys in England and Wales



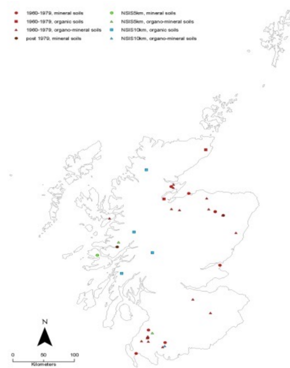
Soil type: brown earths, gley soils, podzols

Forest type: conifer, broadleaves and mixed

Land use: arable, grassland, pasture, scrub

- increasing surface organic layers under afforestation has provided the highest C stock increase under all forest types, on all soil types and from all previous land uses
- afforestation was neutral or for soil C sequestration when sandy soils are converted to conifer forestry.

40 sites afforested since 1970's surveys in Scotland



Soil type: deep peats, peaty gleys Peaty podzols, gleys, podzols

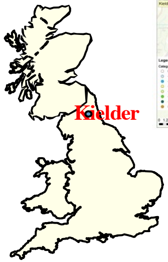
Forest type: conifer

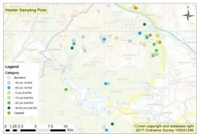
Land use: grassland, pasture, moorland

- Organic layer Increase of 0.56 t C ha^{-1} a^{-1}
- Sitka spruce 0.72 t C ha^{-1} a^{-1} larch with 0.33 t C ha^{-1} a^{-1}
- All other things being equal, it is preferable to plant on gleys (gained 17 t C ha^{-1}) rather than podzols (lost 11 t C ha^{-1})

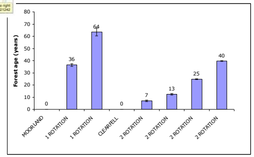
Forest chronosequence –Sitka spruce on peaty gleys

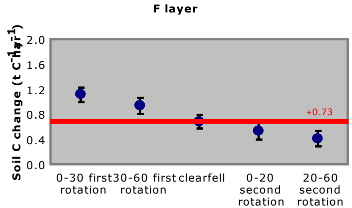
Chronosequence - Sitka spruce - peaty gley soils

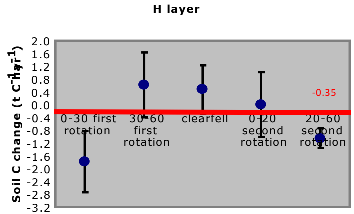


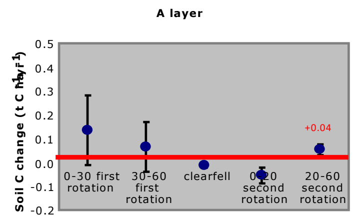


Forest stands age, ~100 years over 2 rotations

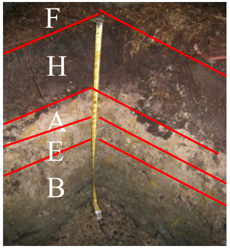


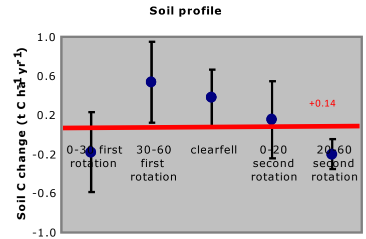






Peaty gley soils



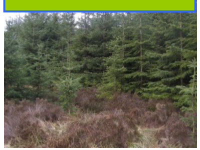


Moorland

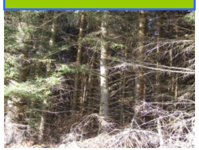
Sitka 1st rot-60 years old

Sitka cleafell

Sitka 2nd rot-15 years old



Sitka 2nd rot -25 years old



Sitka 2nd rot- 40 years old

- C accumulation in organic layers – 0.5-0.7 t C ha/y
- C lost in peat horizon due to soil disturbance was compensated by C accumulation in the upper organic F horizon.
- Over two rotations of conifer afforestation, the total C stock of the organo-mineral soils was unchanged

Some conclusions

- Forests planted on mineral clay soils and under broadleaf tree species generally resulting in increased soil C content at a rate of 0.1-0.4 t C/ha/y.
- Mineral soil high in clay content could accumulate more stable carbon. So future targeting such soils for woodland creation will increase the long term soil carbon sequestration.
- Deeper and more spatial rooted tree species will aid carbon sequestration with soil depth.
- Conifer species will increase C in their organic layer at rate 0.33-0.9 t C/ha/y depending on species and rotation.
- Forest planted on previously arable land can result in the higher C sequestration in the soils compared to forest planted on grassland.
- Afforestation on organo-mineral or organic soils may result in substantial loss of soil C due to soil disturbance during forest planting. However, this can be compensated by increase in organic layers in the long term.
- Forest management practices can change these forest soil carbon storage and dynamics.

FR
Andy Moffat
Tom Nisbet
Sue Benham
Frank Ashwood
Ed Eaton
James Morison
FR Laboratory
Technical support Unit
Tania Sanders

PhD students
Antia Villada
Rita Razauskaite
Eleanor Tew