Ecosystem Nutrition II Dipperz 2015

Long-term and large-scale macronutrient modelling in terrestrial ecosystems

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ONGOING WORK

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NERC Macronutrient Cycles Programme Consortium Grant
www.ltls.org.uk

LTLS CNP

Analysis and simulation of the Long-Term / Large-Scale interactions of C, N and P in UK land, freshwater and atmosphere

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J Quinton *Lancaster U*
ME Stuart *BGS*
AP Whitmore *Roth Res*
RC Helliwell *JHI**
NL Rose *UCL*
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* Funded by the Scottish Government

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LTLS questions & approach

- Over the last 200 years, what have been the temp… responses of soil C, N and P pools in different UK cat… …ient enrichment?
- What have been th… …d P transfers from land to th… …estuaries?
- How … …water biodiversity responded to increa… …stem productivity engendered by nutrient enrich… …t at different locations?

…or, how did we get to where we are today?

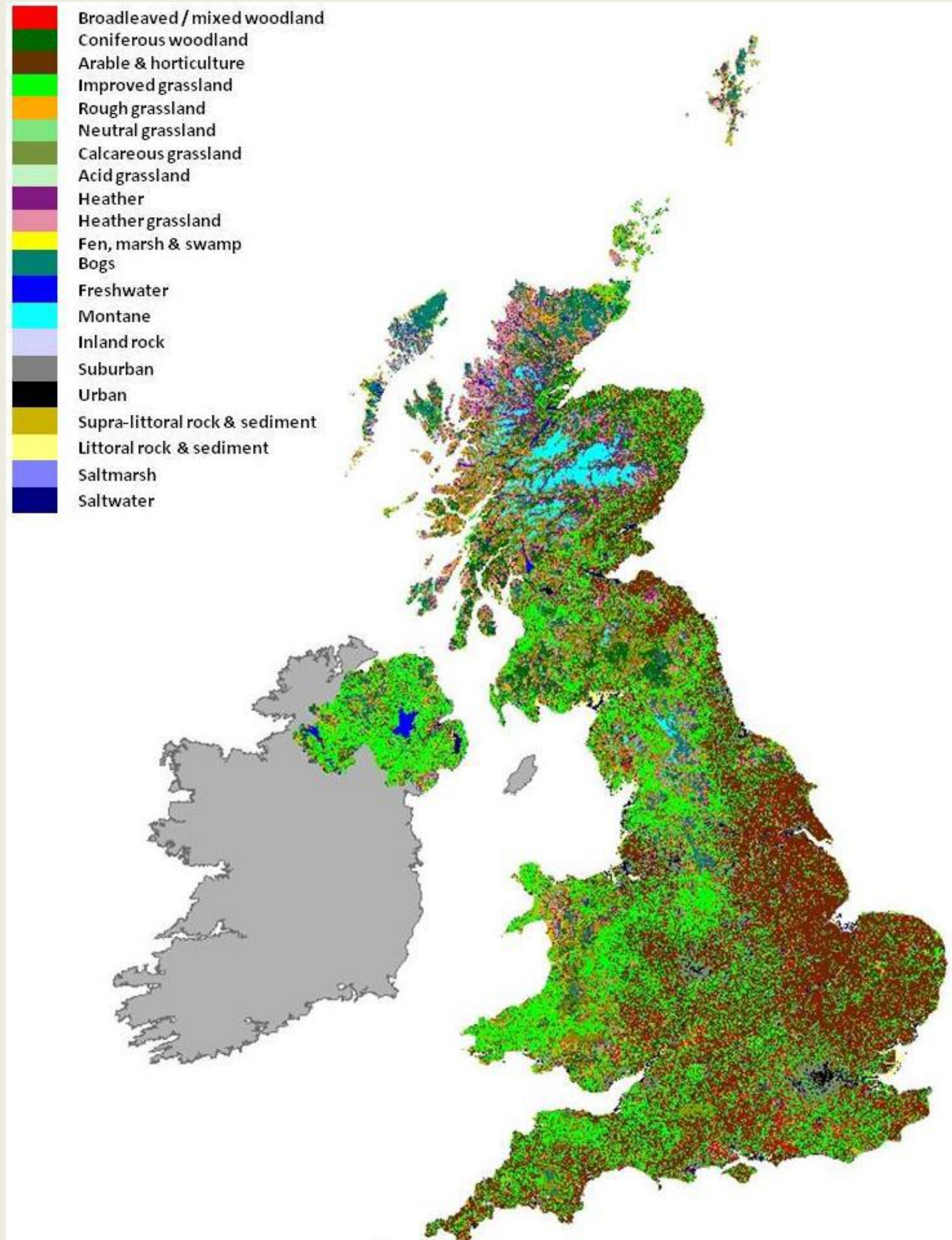
<u>Answered by:</u>

integrated modelling analysis,

aimed at accounting for observable present element pools and fluxes in different UK catchments in terms of their nutrient enrichment histories

Followed by: scenario-based forecasting with Stakeholder participation

The United Kingdom



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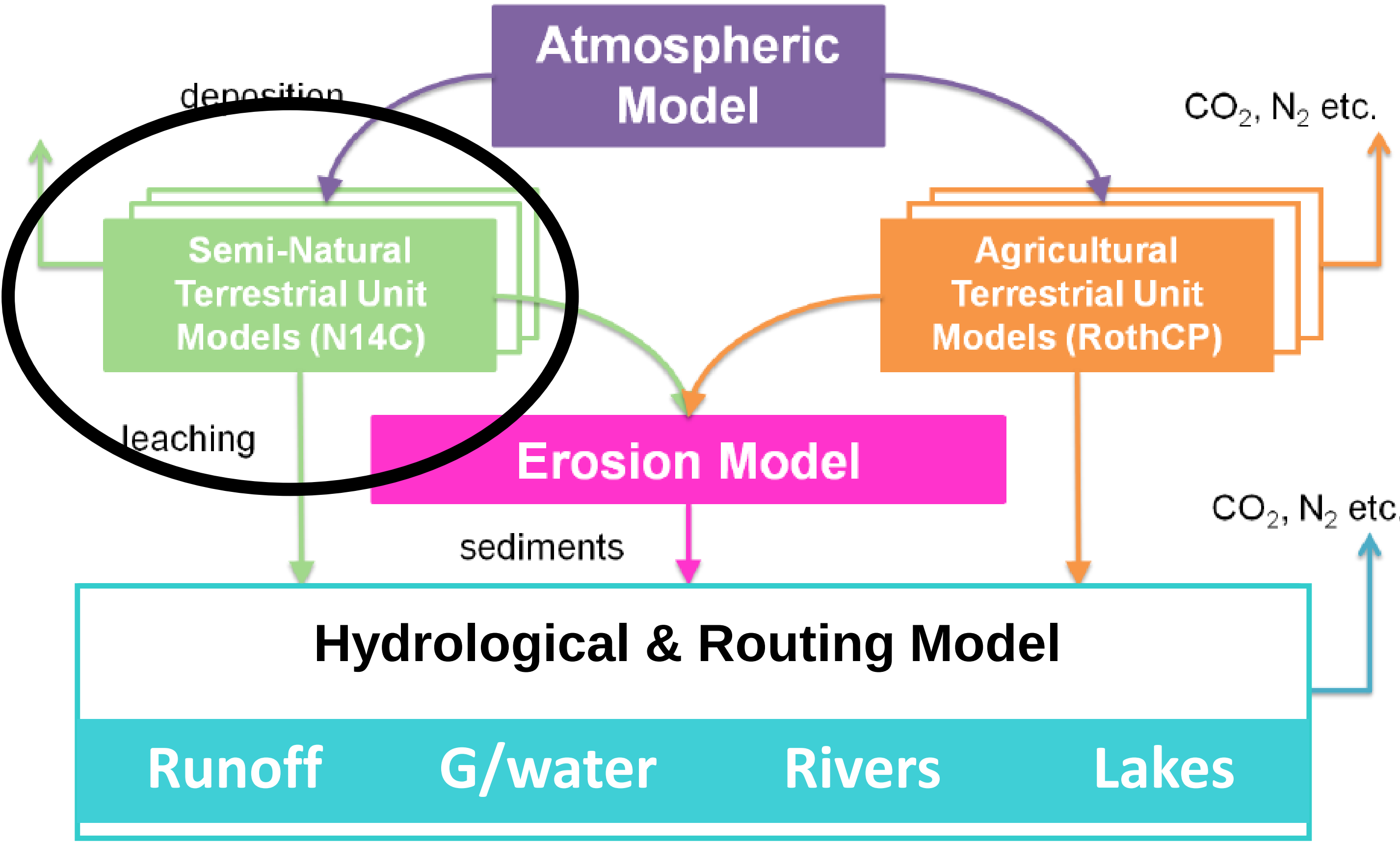
LTLS activities



+ Biodiversity modelling based on biogeochemistry

<u>+ Measurements</u>

	soil denitrification	***soil survey (^{14}C)***
	river transport (^{14}C)	***lakes***
	fuel experiments	***bracken survey***
	NPP	

What we need and what we have

For semi-natural terrestrial ecosystems in the UK:

NEED	Seasonal / annual (1800-2000) soil C, N, P pools net primary productivity (NPP) inorganic N and P leaching fluxes DOC, DON, DOP leaching fluxes (erosion)

by 5 x 5 km grid cell, by land use type

HAVE	Land cover maps 2007, ~1930, ~1700 Recent climate, past anomalies Soil and geological maps Atmospheric deposition 1800-present Palaeo-ecology

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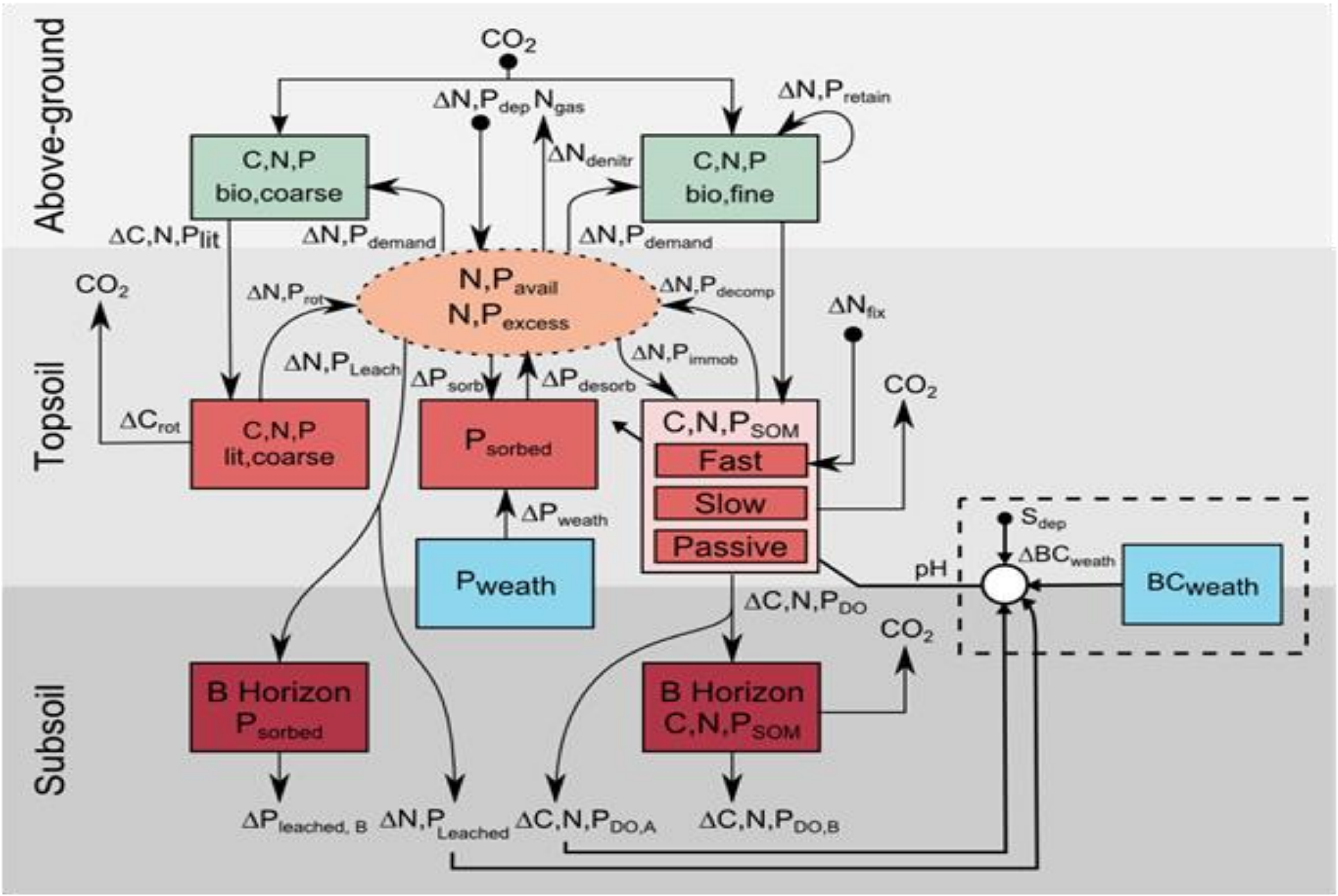
N14CP



Above-ground
Topsoil
Subsoil
CO_2
$\Delta N,P_{dep}$
N_{gas}
$\Delta N,P_{retain}$
C,N,P bio,coarse
C,N,P bio,fine
ΔN_{denitr}
$\Delta C,N,P_{lit}$
$\Delta N,P_{demand}$
$\Delta N,P_{demand}$
N,P_{avail}
N,P_{excess}
$\Delta N,P_{rot}$
$\Delta N,P_{decomp}$
ΔN_{fix}
CO_2
$\Delta N,P_{Leach}$
$\Delta N,P_{immob}$
ΔP_{sorb}
ΔP_{desorb}
CO_2
ΔC_{rot}
C,N,P lit,coarse
P_{sorbed}
C,N,P_{SOM}
Fast
Slow
Passive
ΔP_{weath}
S_{dep}
ΔBC_{weath}
pH
P_{weath}
BC_{weath}
$\Delta C,N,P_{DO}$
CO_2
B Horizon P_{sorbed}
B Horizon C,N,P_{SOM}
$\Delta P_{leached,B}$
$\Delta N,P_{Leached}$
$\Delta C,N,P_{DO,A}$
$\Delta C,N,P_{DO,B}$

Features of the model

Links the C, N and P cycles

Pools and fluxes

Seasonal timestep

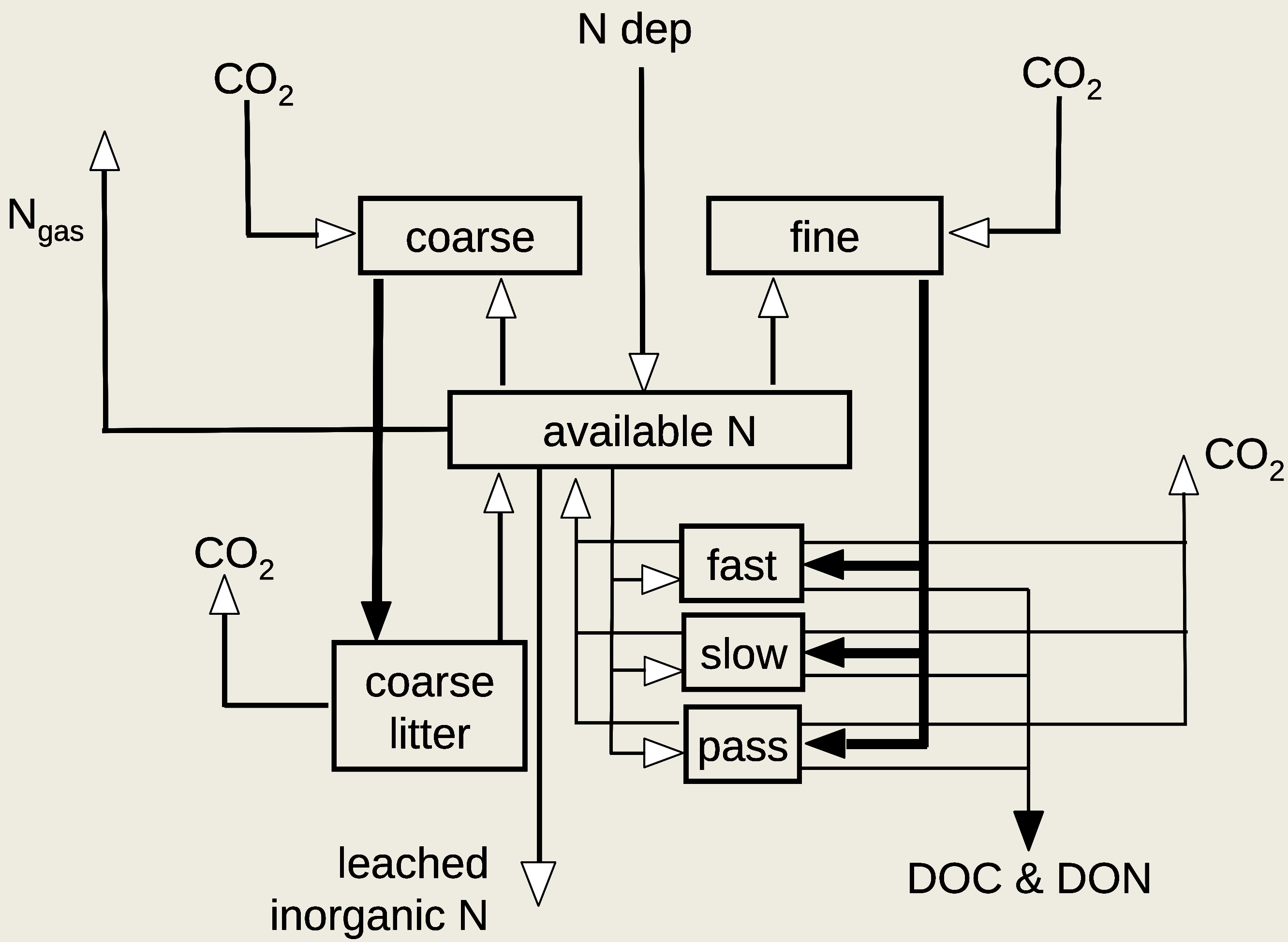
Microbes not explicitly modelled

Simultaneous simulation of many variables

Runs over the Holocene (12000 yr)

Fitted from field data (at plot scale)

N14C topsoil



PLANTS

NITROGEN

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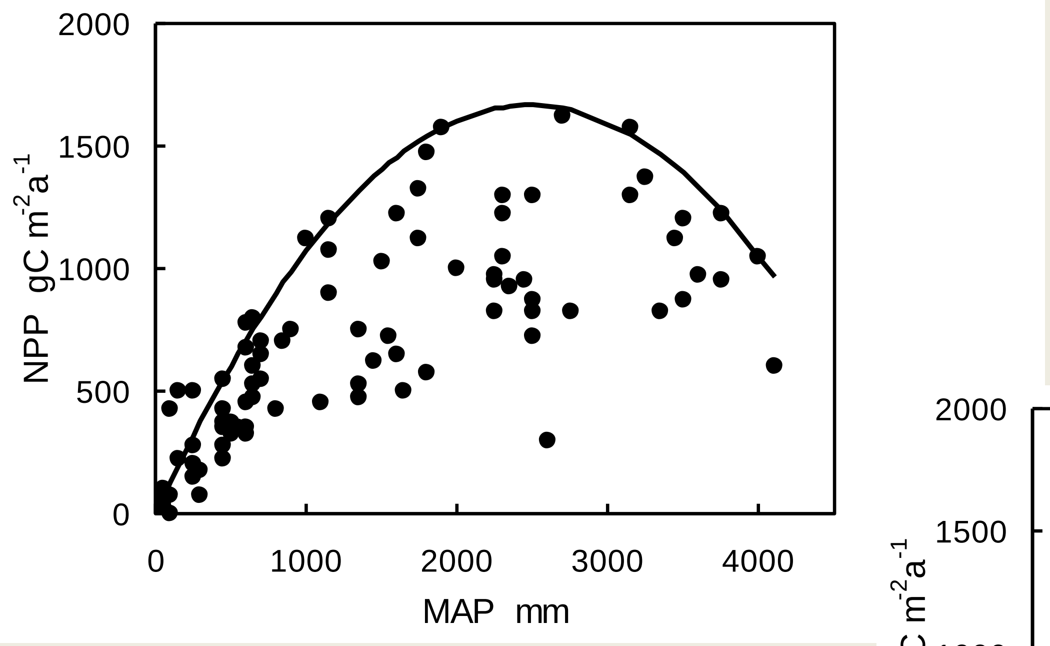
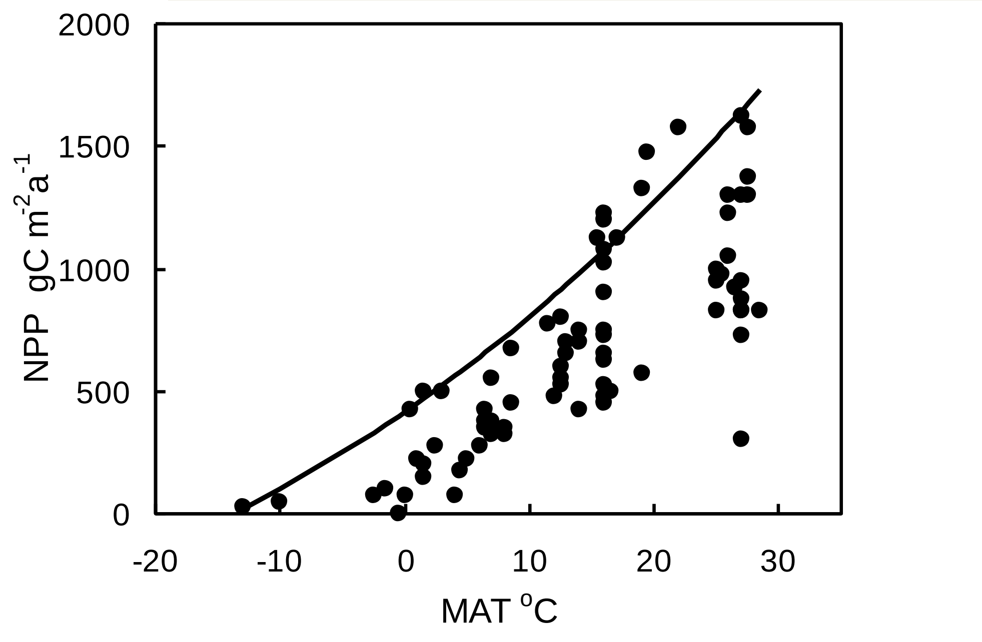
PLANTS: MAP & MAT LIMIT NPP

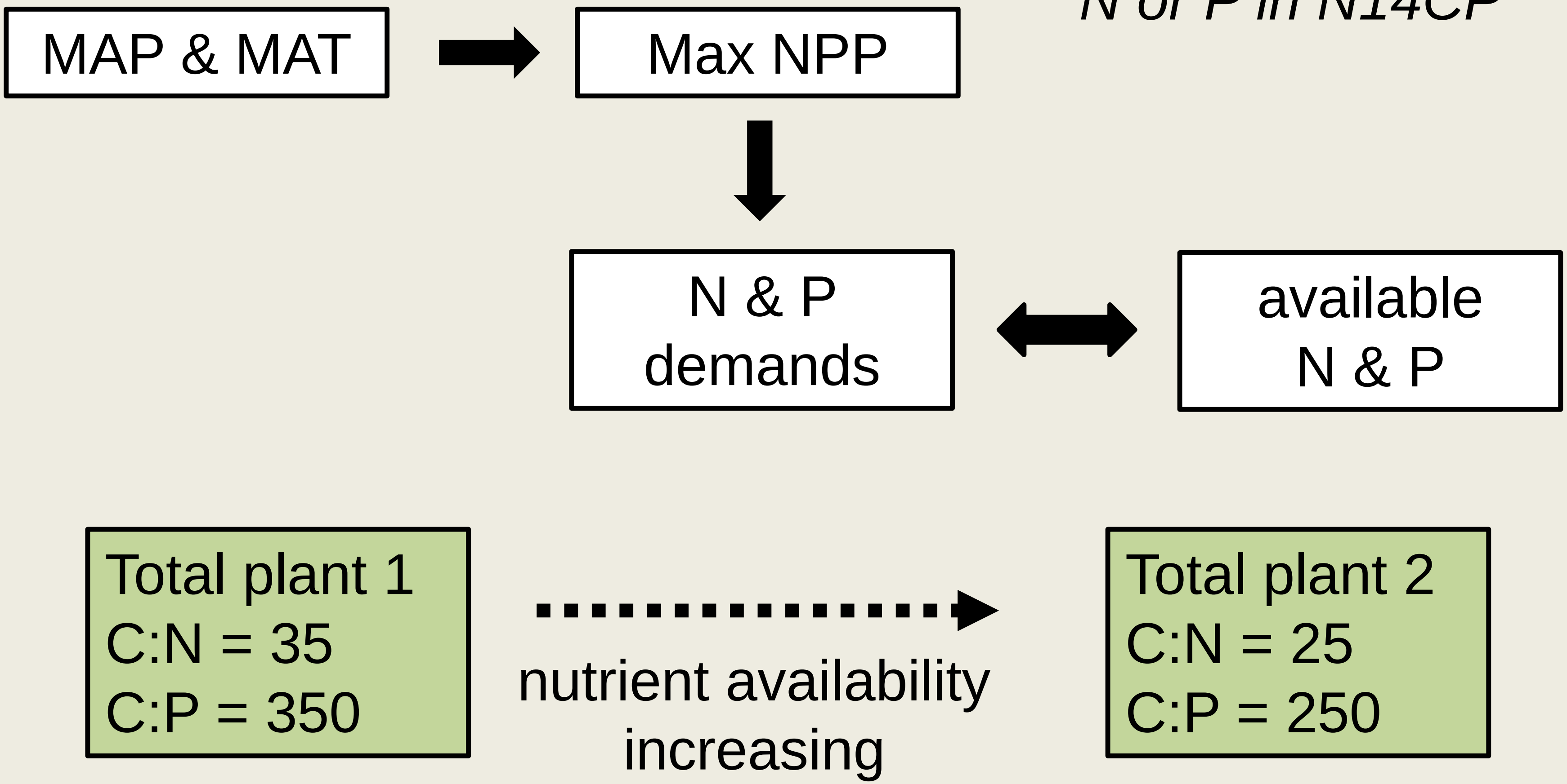




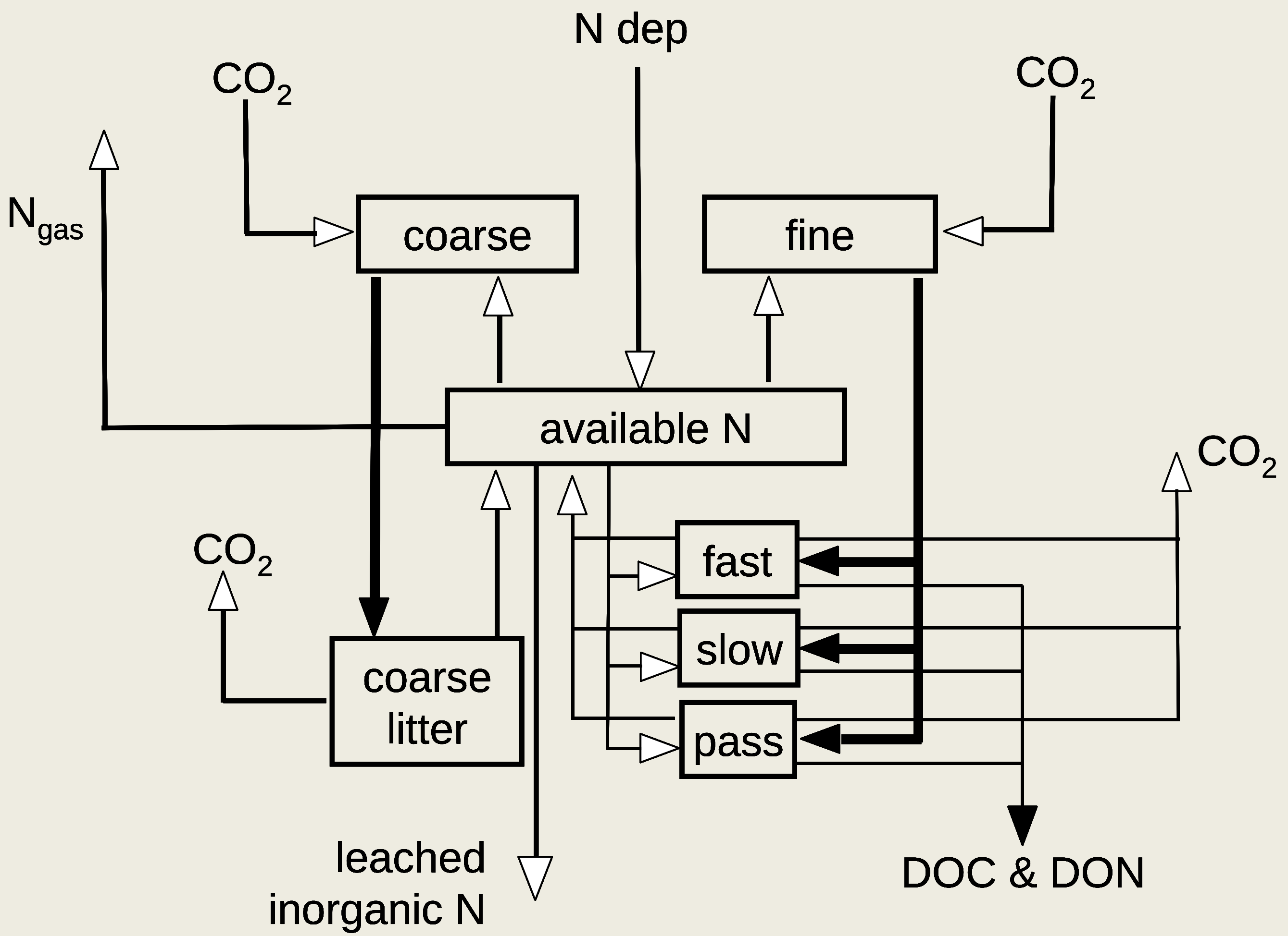
data compiled by Chapin et al. (2002)

PLANTS: NUTRIENTS LIMIT NPP

Only N limits in N14C
N or P in N14CP



N14C topsoil



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Comparing ^{14}C contents of topsoils (~15 cm) over time

	forest			non-forest			
	n	^{14}C	SD	n	^{14}C	SD	p
1947-1962	6	94.7	1.1	6	91.5	1.7	>0.05
1970-1978	28	111.3	1.2	6	106.1	3.4	>0.05
1990-1998	27	111.5	0.9	21	104.8	2.2	<0.02
2000-2004	43	110.2	0.8	26	100.8	1.3	<0.001
2005-2008	22	107.4	1.3	98	100.7	0.8	<0.001

Forest soils are richer in bomb carbon

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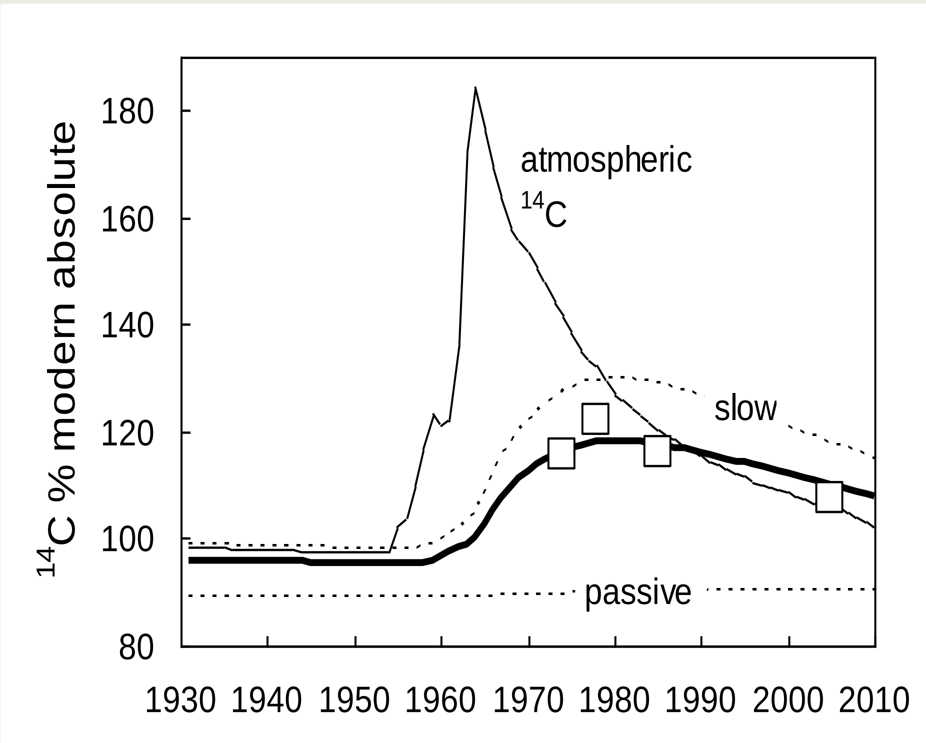
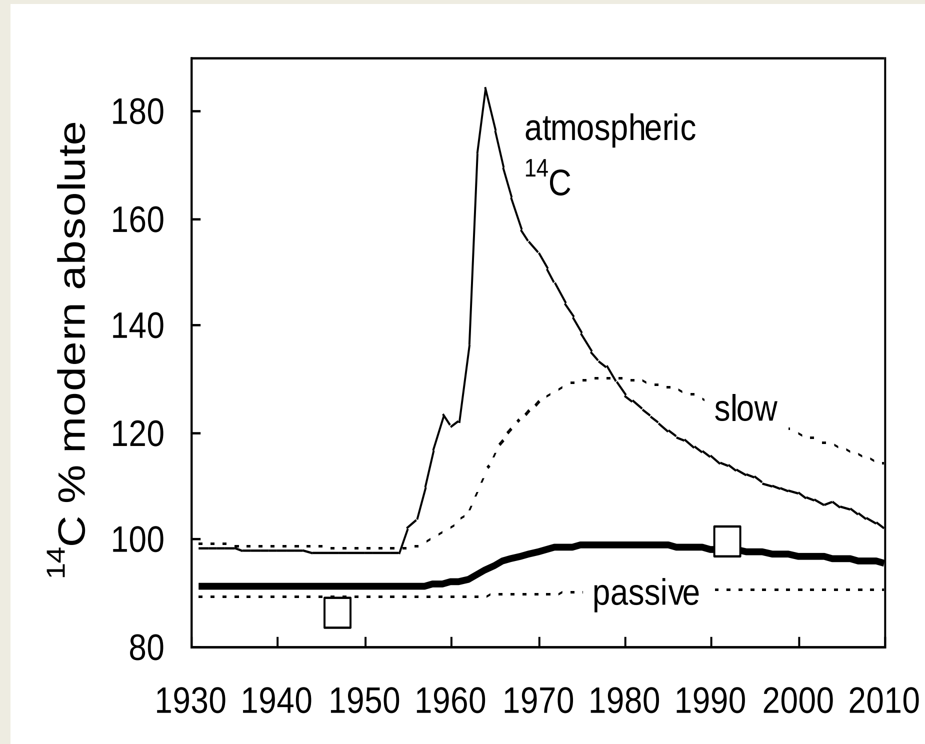
Steady-state soils – finding the correct slow / passive ratio

forest soil 5.97 kgC m^{-2}



slow fraction 0.71

non-forest soil 4.02 kgC m^{-2}



slow fraction 0.23

N14C & N14CP do not assume steady-state, but the same ideas apply.

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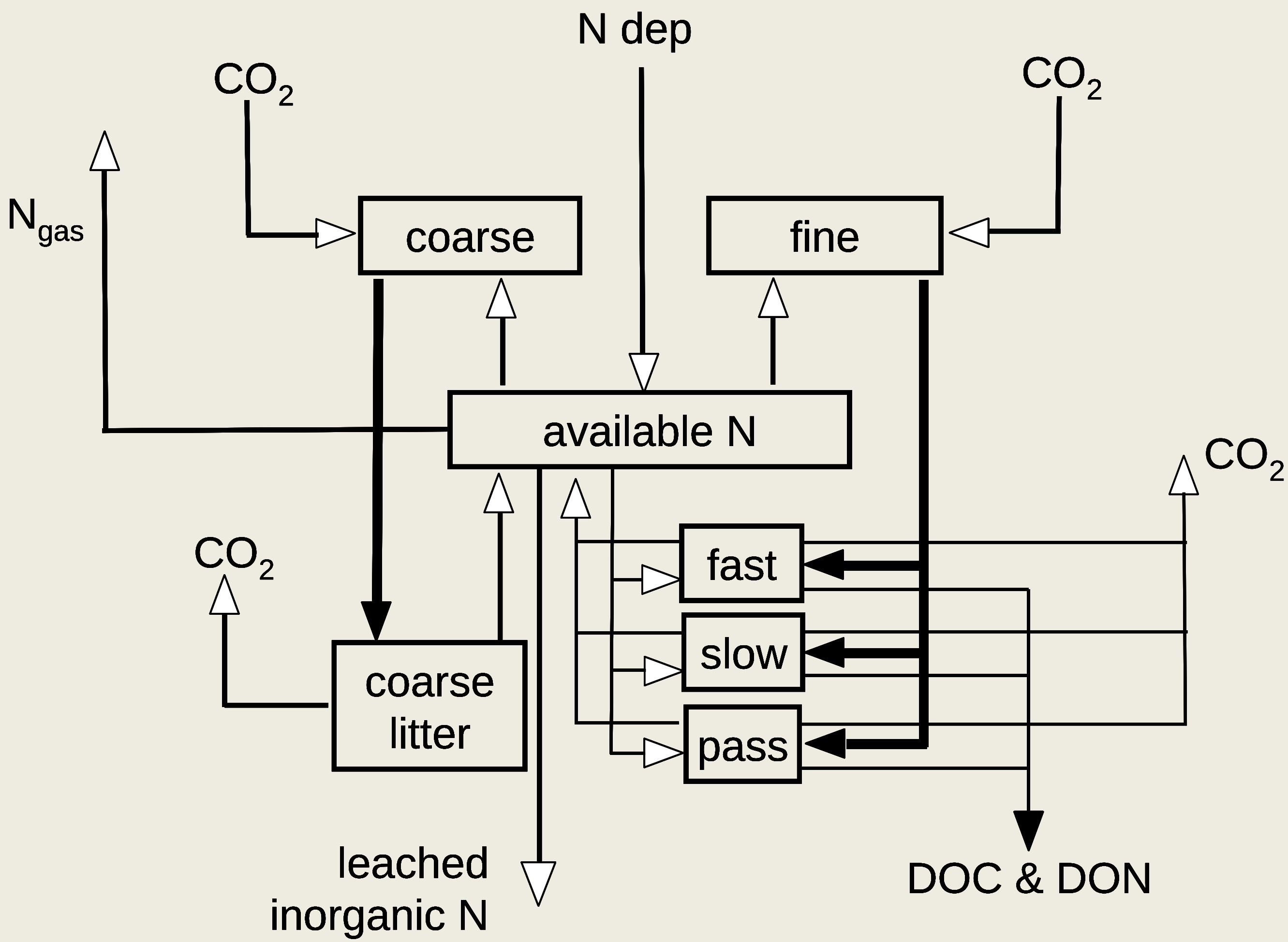
N14C topsoil



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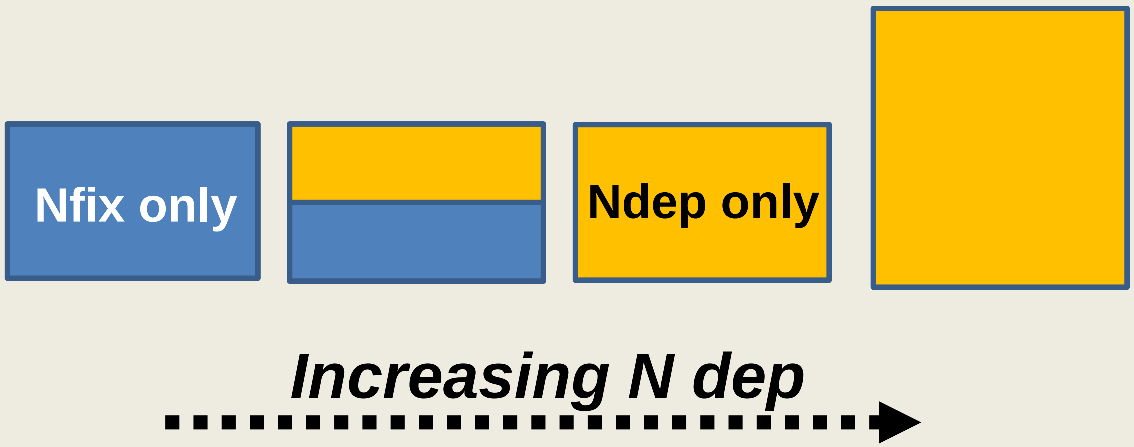
Nitrogen inputs

Pre-1800 N fixation only
constant in N14C
depends upon P in N14CP

Post-1800 N fixation + N deposition
down-regulation of N fixation



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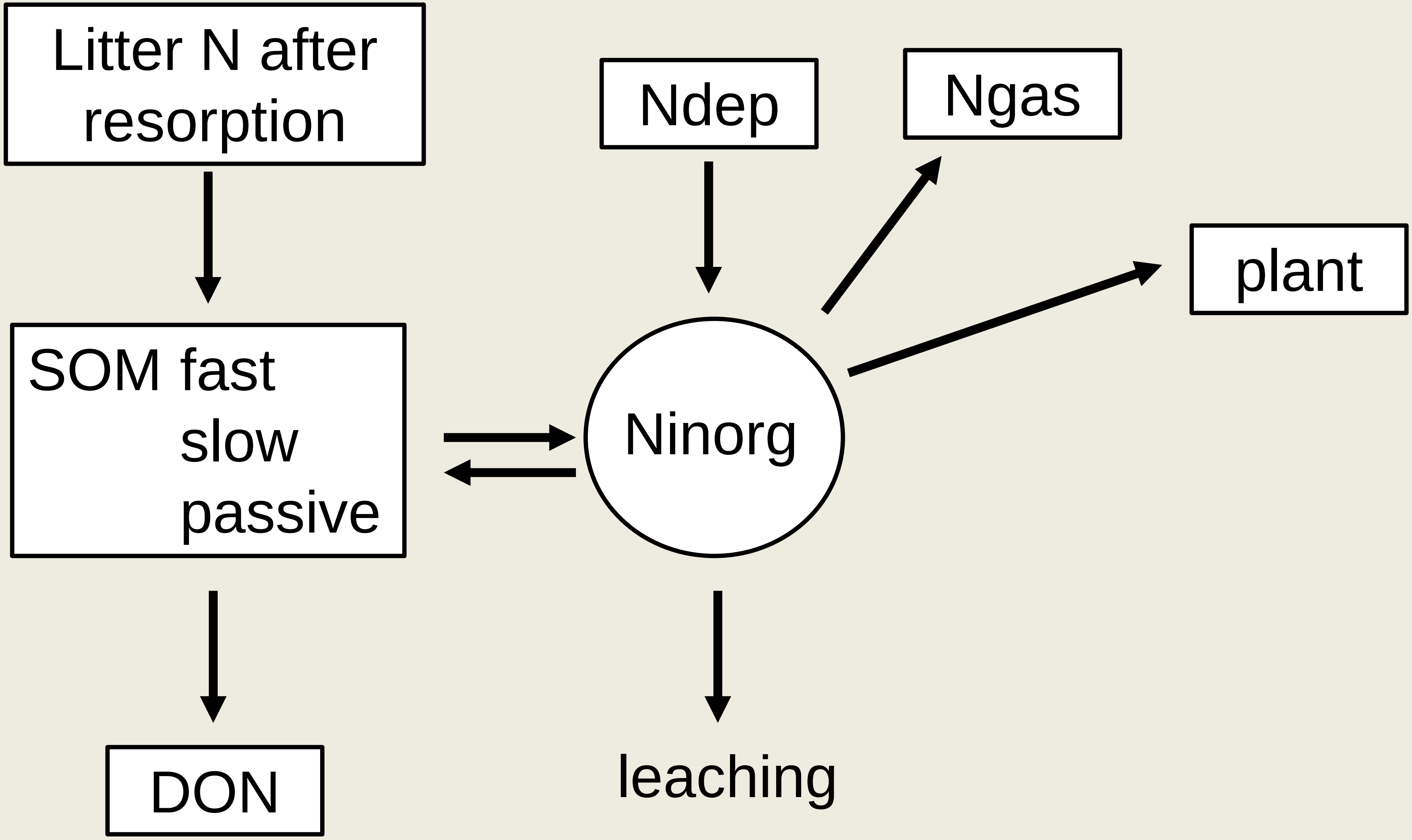
Nitrogen processes



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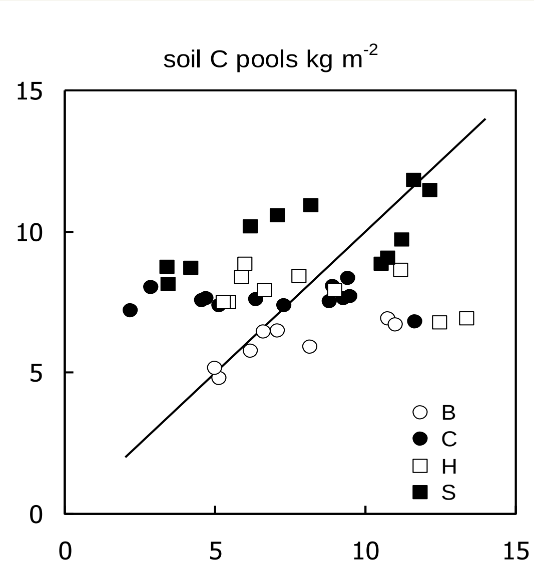
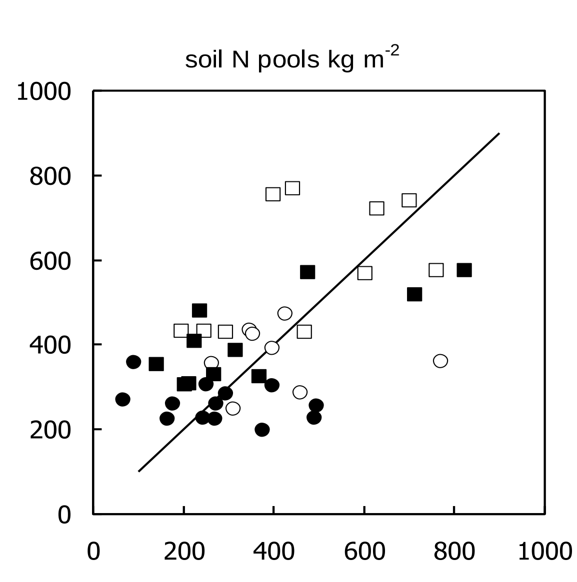
Fitting N14C to 42 sites

Universal parameter set





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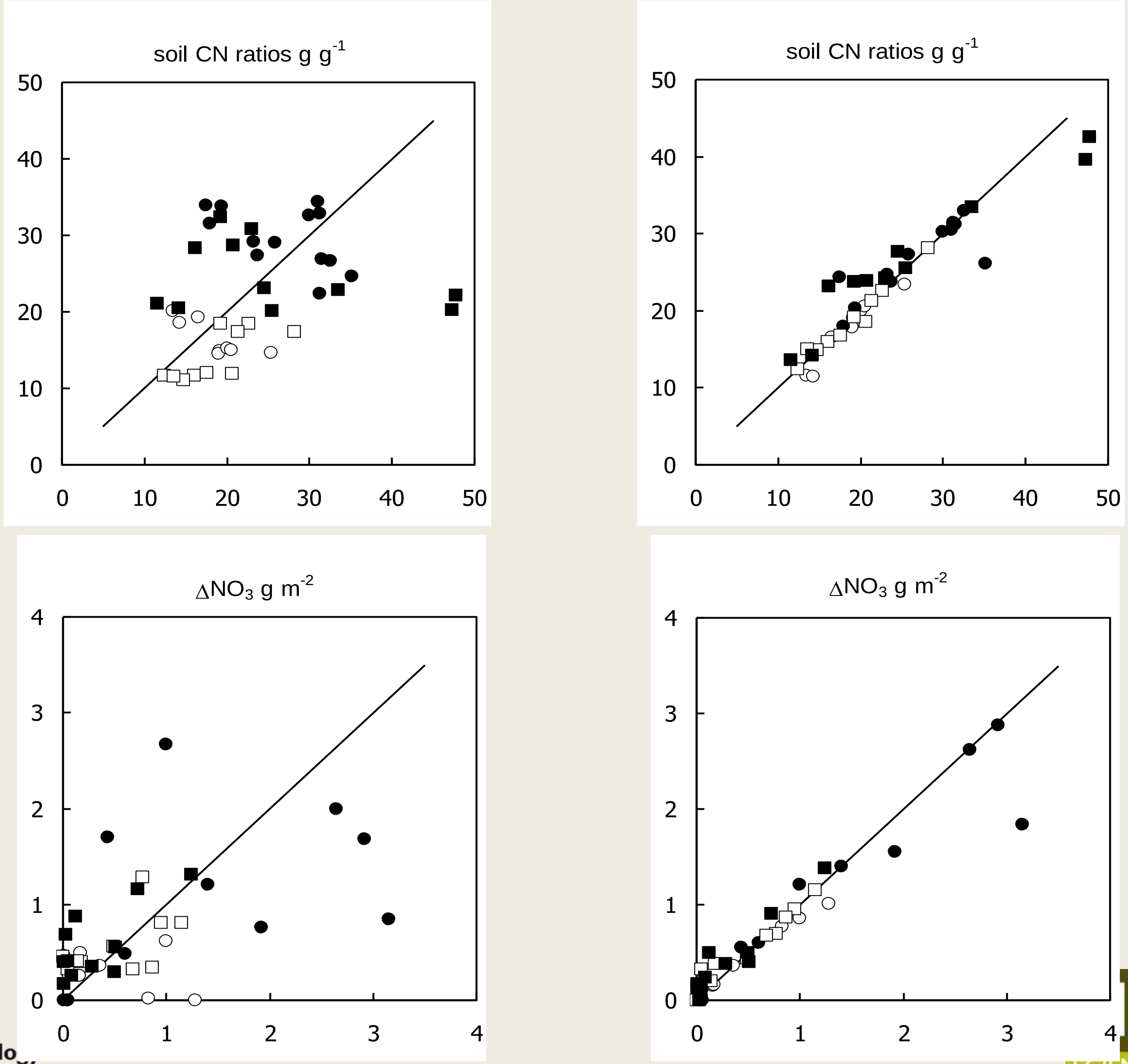
Fitting N14C to 42 sites



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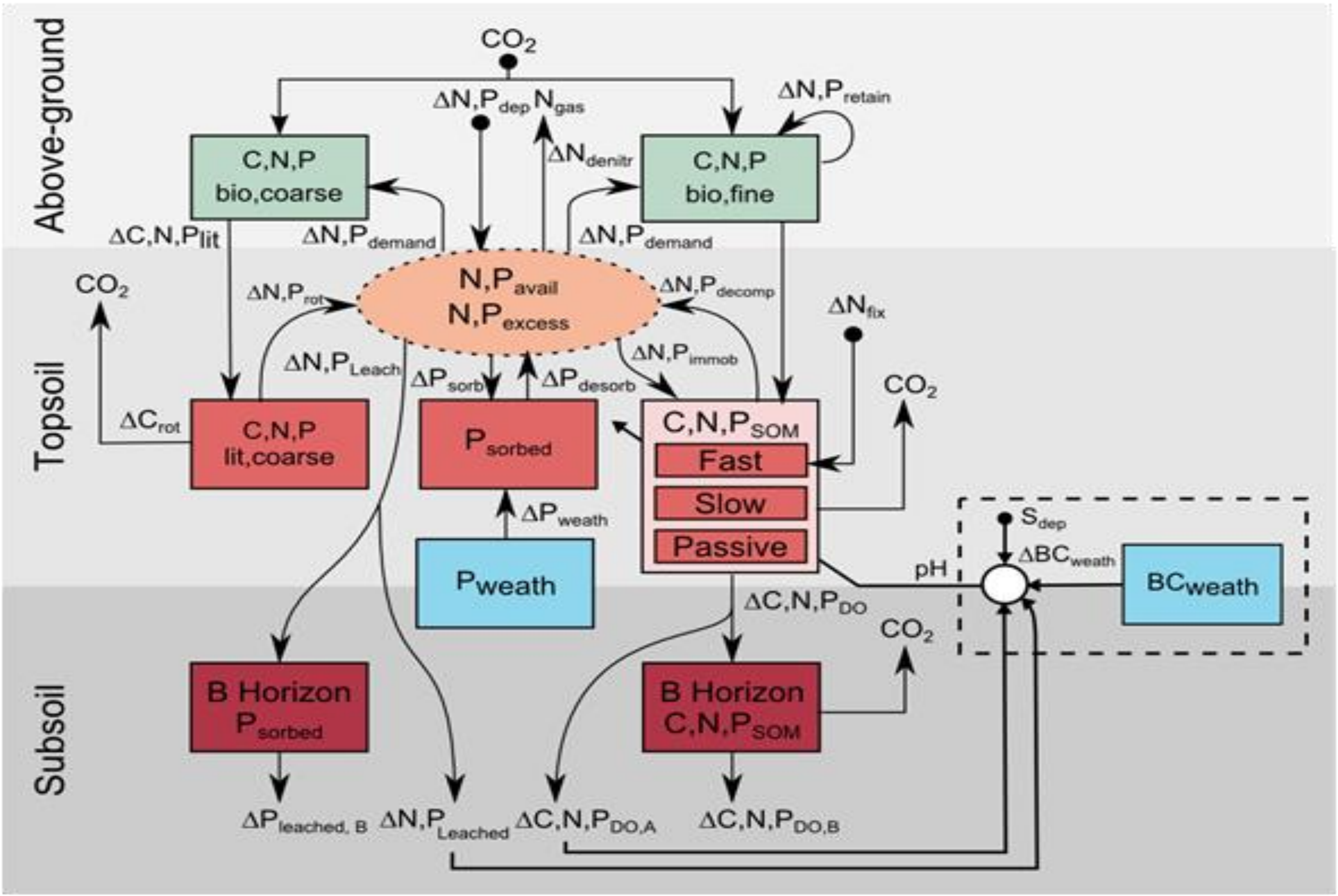
N14CP



Above-ground
Topsoil
Subsoil
CO2
ΔN,Pdep Ngas
ΔN,Pretain
C,N,P
bio,coarse
ΔNdenitr
C,N,P
bio,fine
ΔC,N,Plit
ΔN,Pdemand
ΔN,Pdemand
CO2
ΔN,Prot
N,Pavail
N,Pexcess
ΔN,Pdecomp
ΔNfix
ΔN,PLeach
ΔPsorb
ΔPdesorb
ΔN,Pimmob
CO2
ΔCrot
C,N,P
lit,coarse
Psorbed
C,N,PSOM
Fast
Slow
Passive
ΔPweath
Pweath
Sdep
ΔBCweath
pH
BCweath
ΔC,N,PDO
CO2
B Horizon
Psorbed
B Horizon
C,N,PSOM
ΔPleached, B
ΔN,PLeached
ΔC,N,PDO,A
ΔC,N,PDO,B

N14CP - key points about P

- Acquisition of P
  1. weathering into soil
  2. (net) deposition to ombrotrophic peat

- Soil organic matter can immobilise & release P

- P can be cleaved from SOM

- Inorganic P is sorbed by soil solids in topsoil and subsoil

- N fixation depends on P

- Lost mainly as DOP

Starting pool
First-order dissolution

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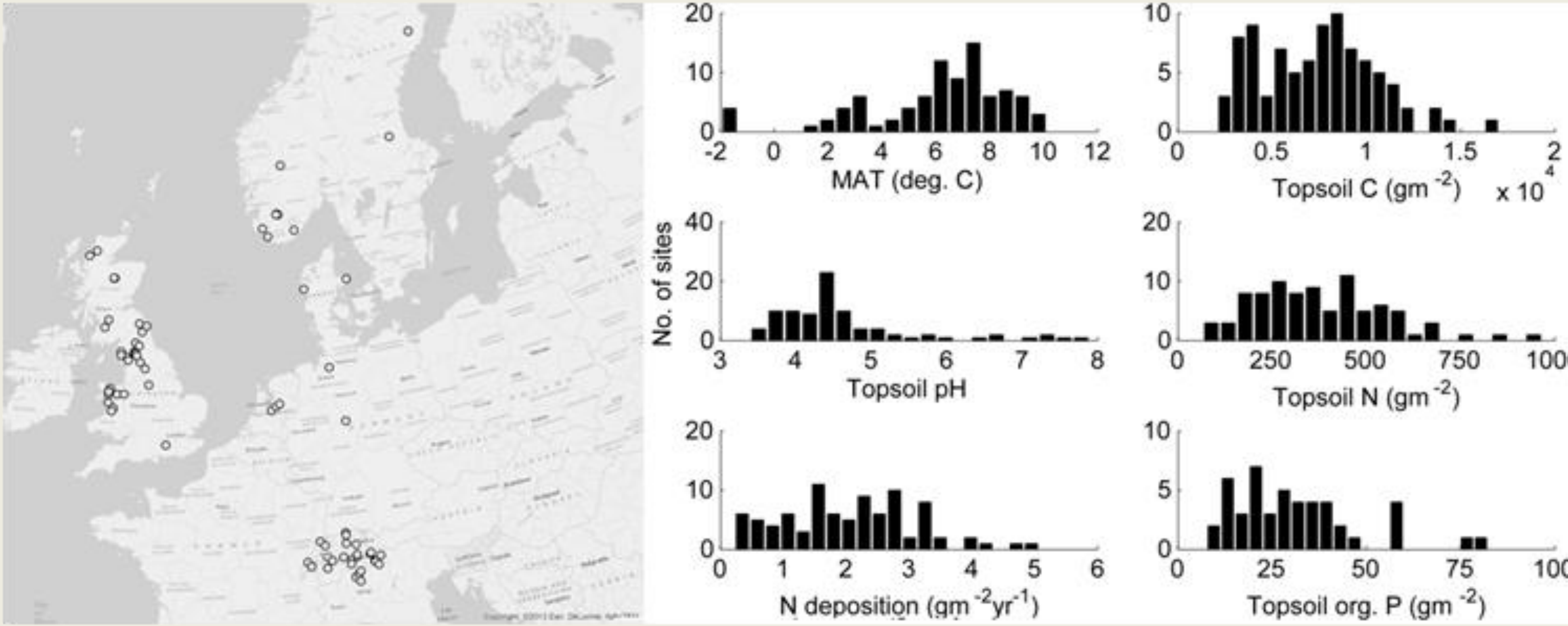
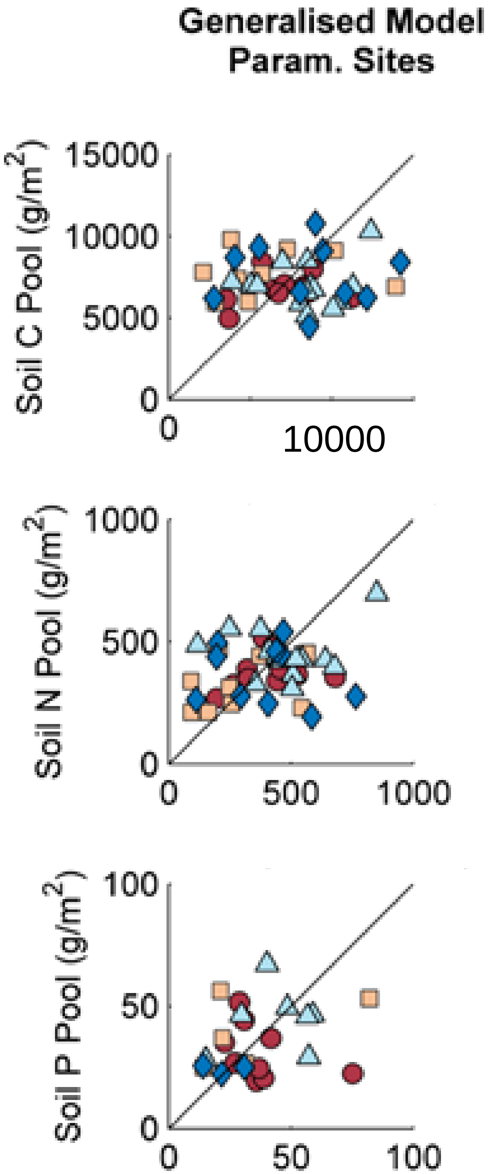
Fitting N14CP: plot data

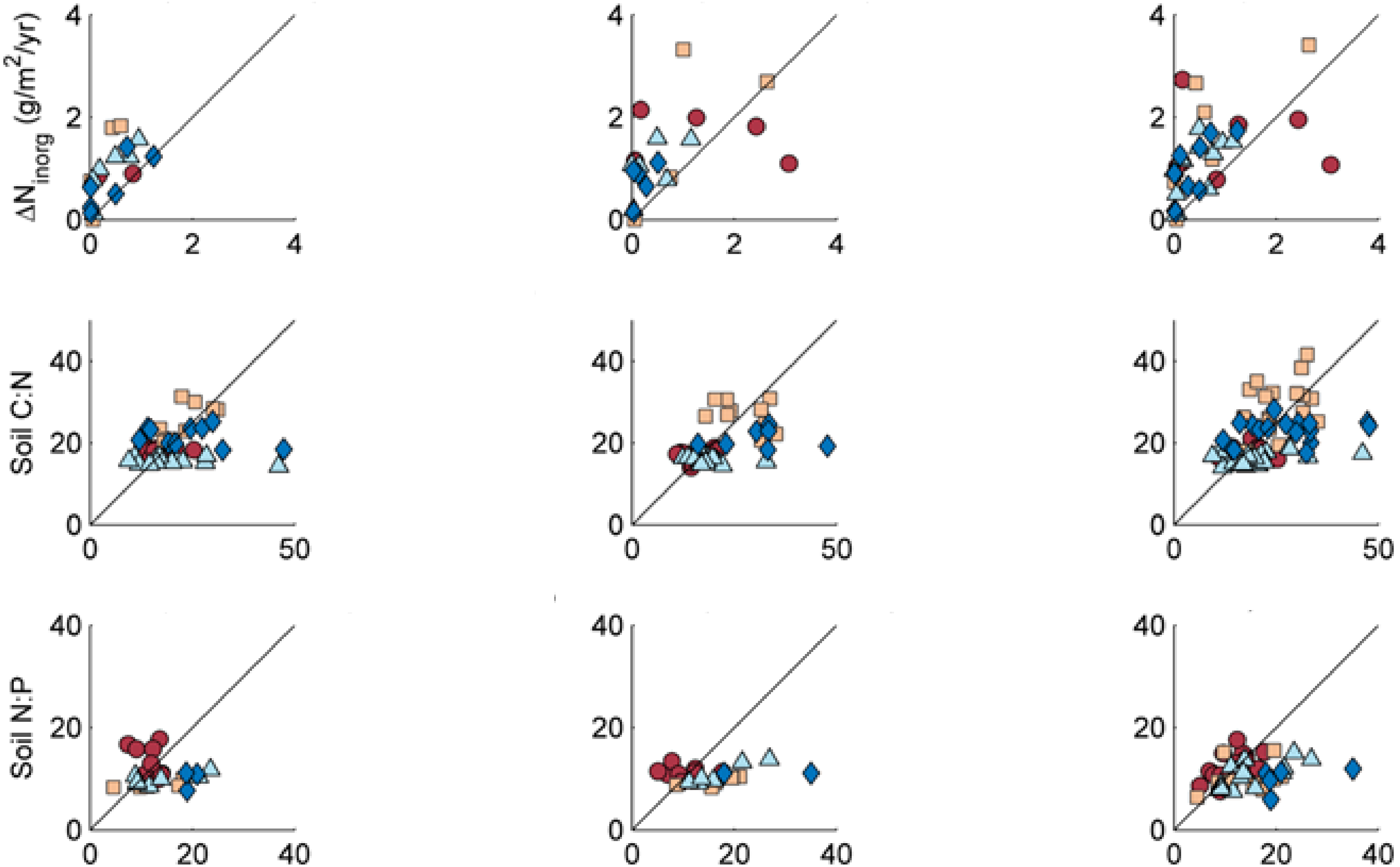


14C data for other sites!

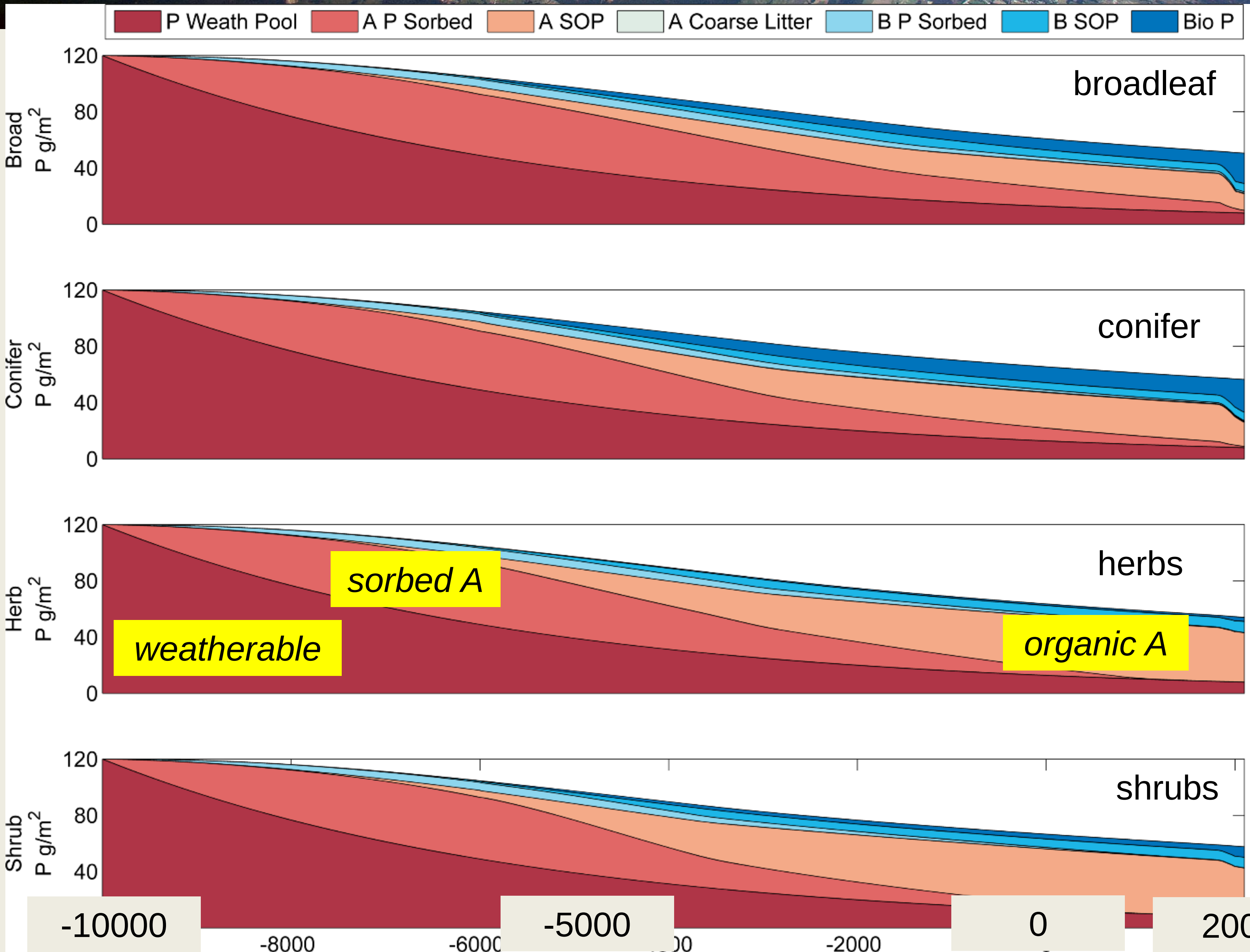
N14CP fitting results: soil C N and P pools



N14CP fitting results: iN leaching, CN, soil NP



Soil P pools over the Holocene



Limitations of the model

Average behaviour is OK

Inter-site variability poorly captured with available drivers

Possible improvements:

measure of (starting) P pool
insights into parameter variation

Running N14CP

- MAP, MAT by site, with historical anomalies
- N & S deposition history by site
- Vegetation history: broadleaf / conifer / herbs / shrubs / peat
- Weathering: information, assumptions or calibration
- ***Soil formation starts at 10,000 BC***

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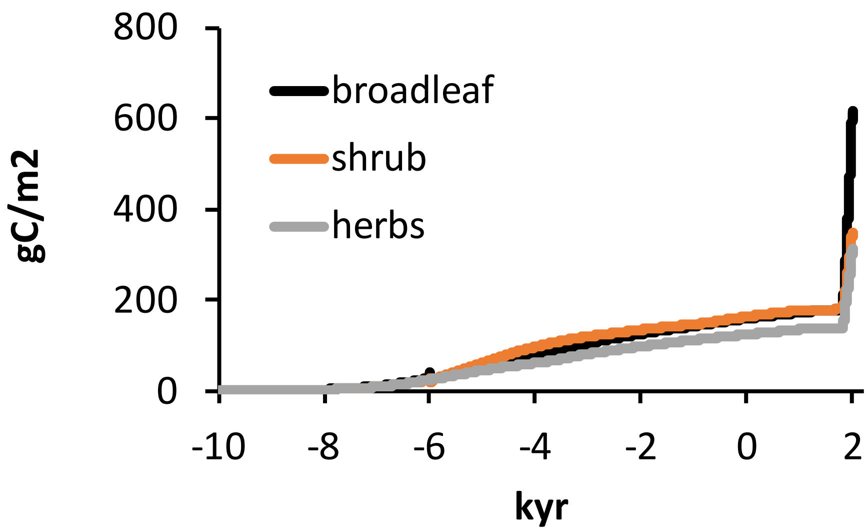
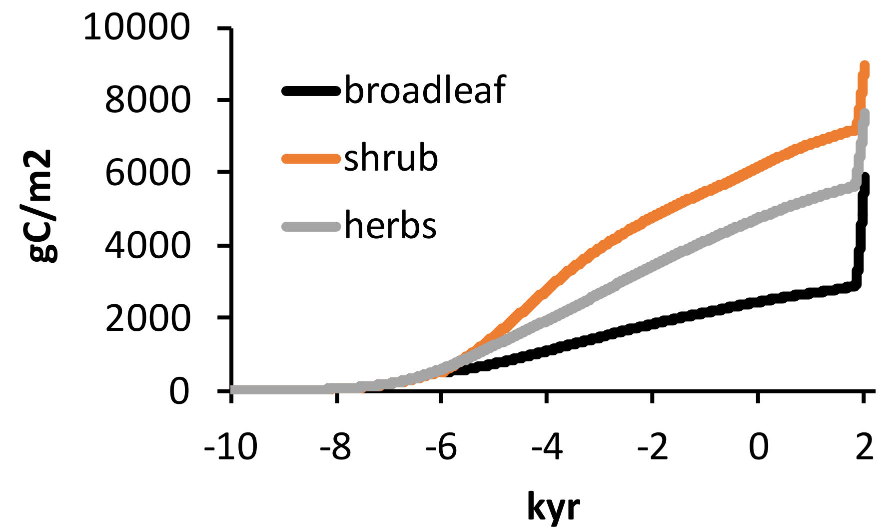
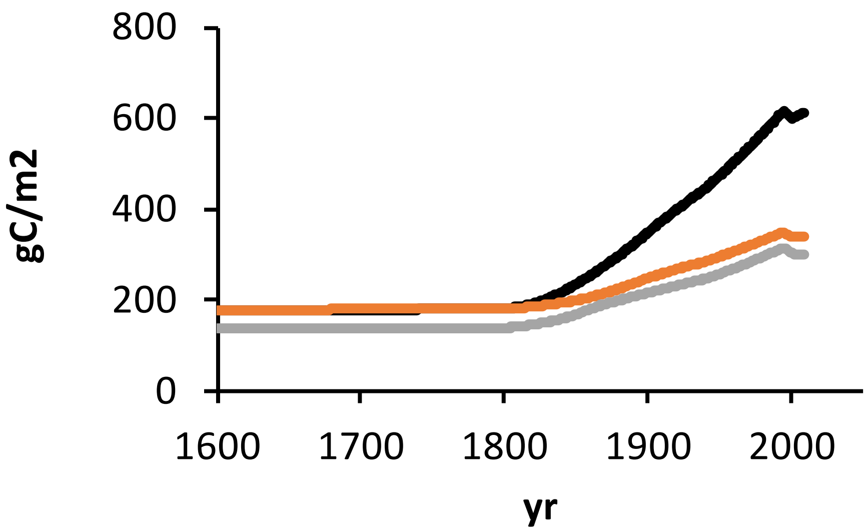
Semi-natural ecosystems / median climate and N deposition

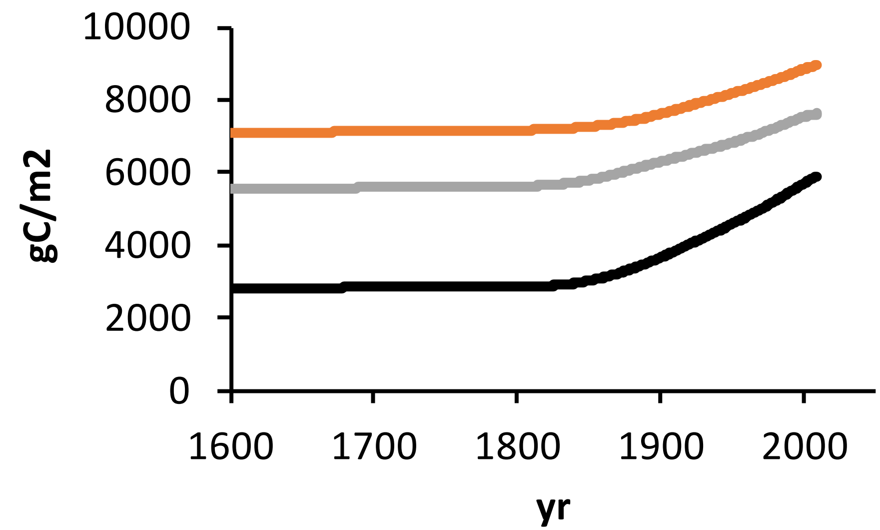




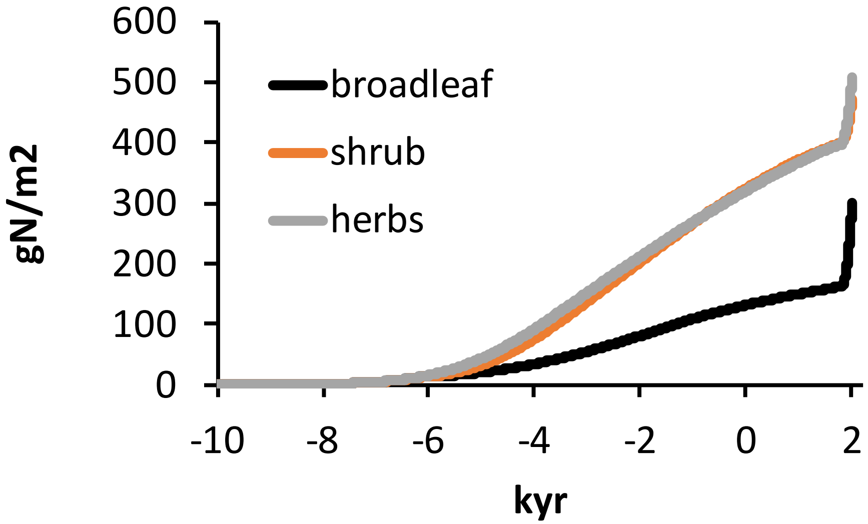
Net Primary Productivity

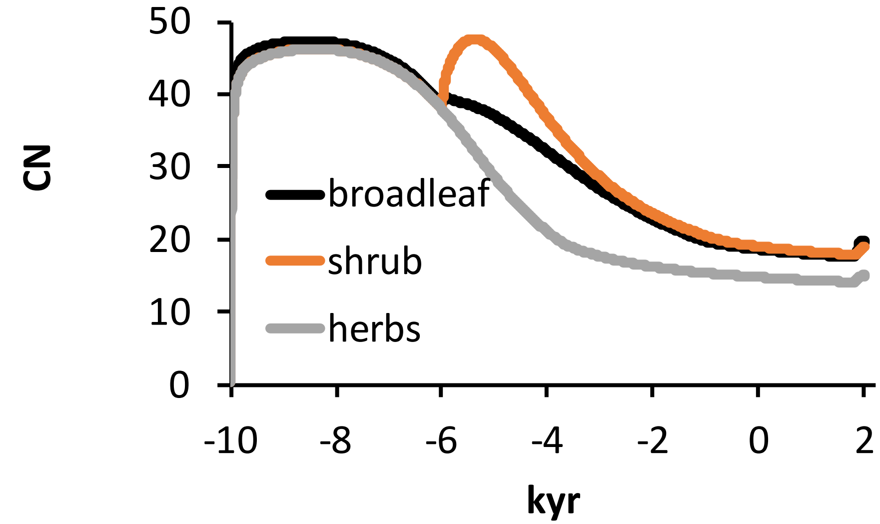
Soil organic C





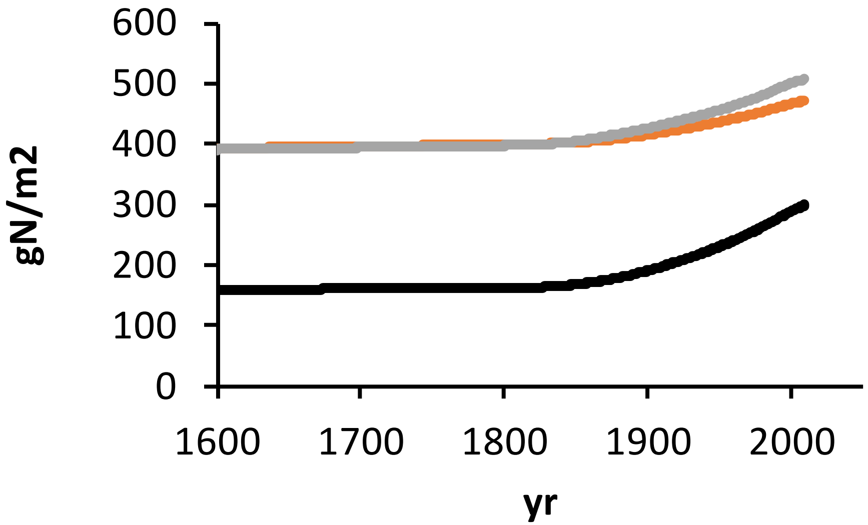
Semi-natural ecosystems / median climate and N deposition

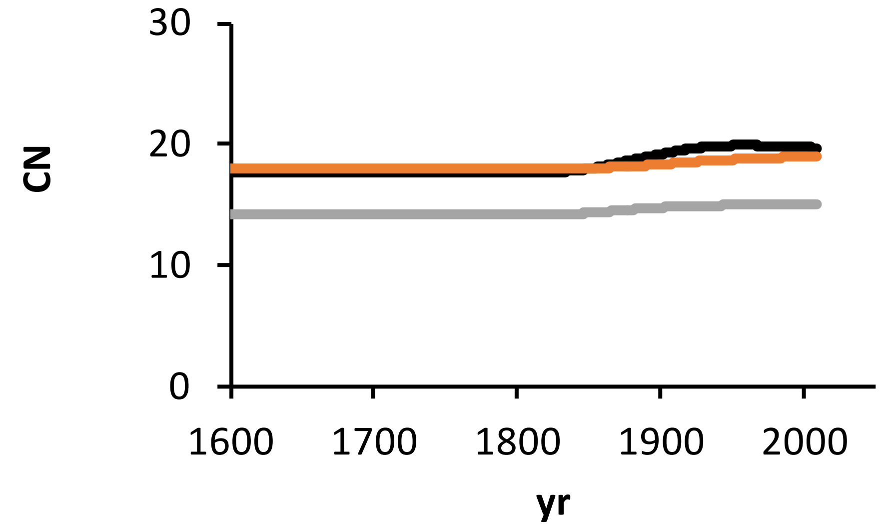




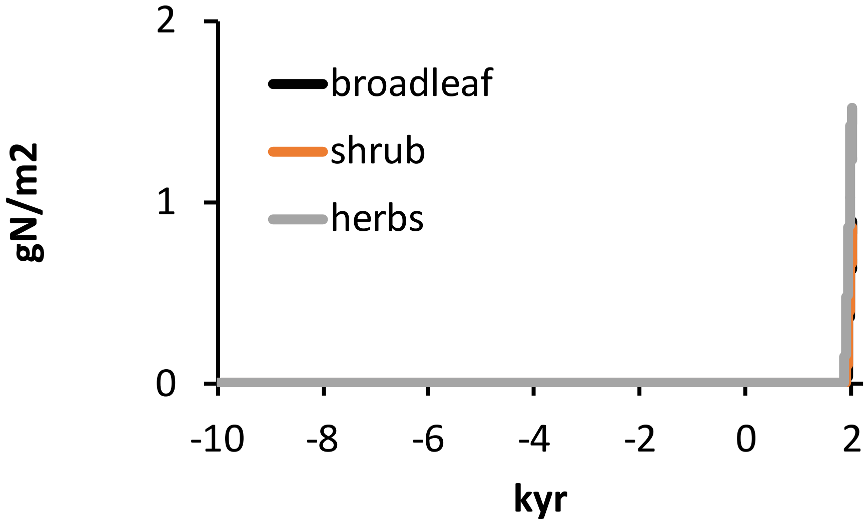
Soil organic N

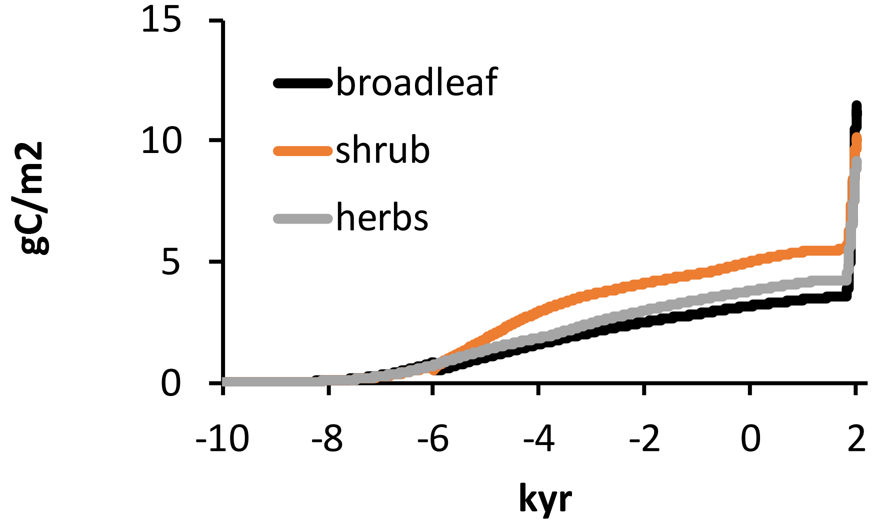
Soil CN ratio



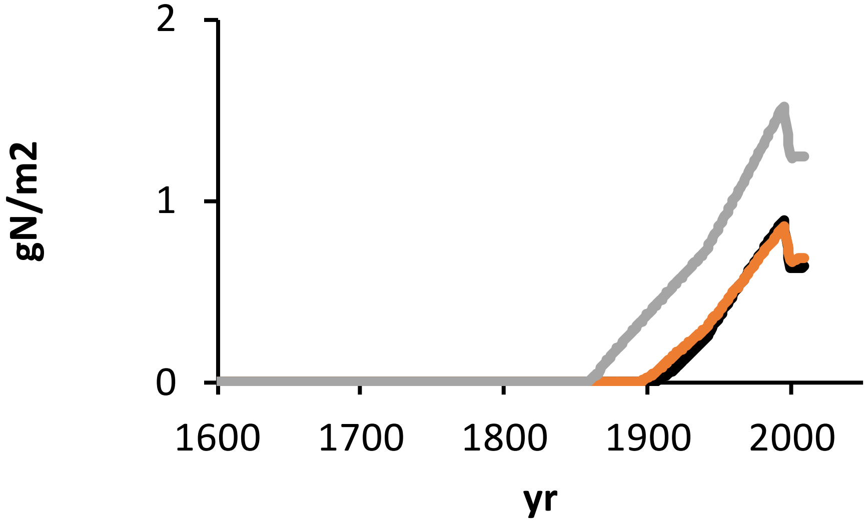


Semi-natural ecosystems / median climate and N deposition

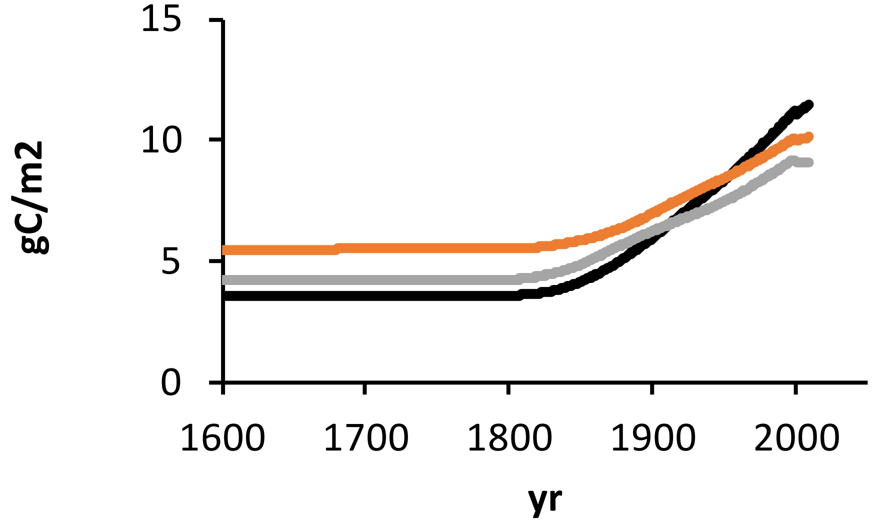




Inorganic N leaching

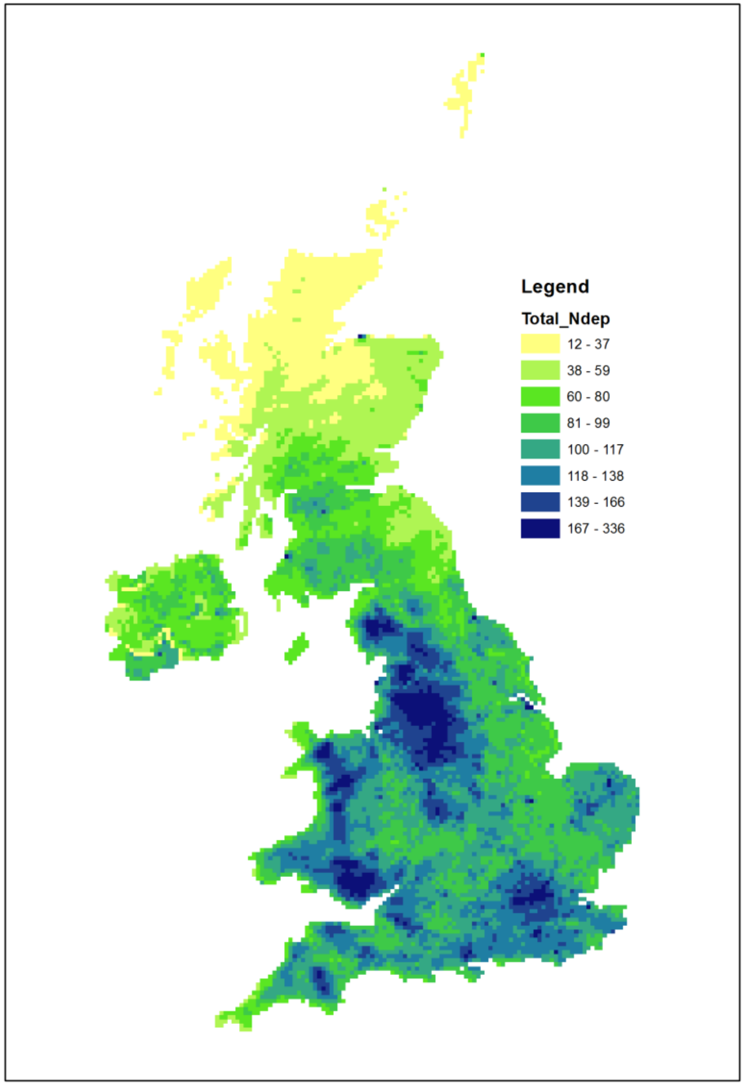


DOC leaching

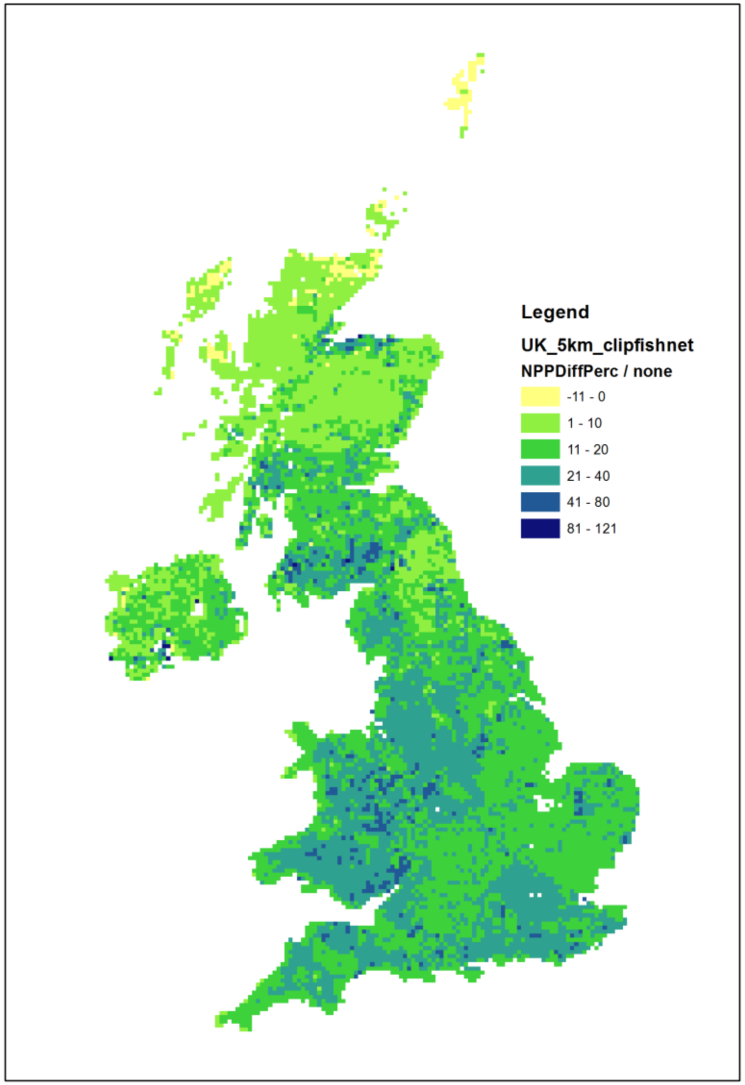


Net Primary Productivity & N deposition

Cumulative Ndep (g/m2) 1900-2000



Simulated % increase in NPP 1900-2000



Next steps

Combine N14CP outputs for the whole UK (10,000 grid cells) with agricultural and erosion model outputs

Inputs to rivers, lakes, groundwater →

Run process models for waters

Complete spatial simulation 1800-2000

Test against observations

Run scenarios to 2100

Relate biogeochemistry to biodiversity – terrestrial, lakes

Learn lessons –
Think about how to do this better

Acknowledgements

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B Rihm (METEOTEST, Switzerland)
C Bryant (NERC Radiocarbon Facility)
AF Harrison (CEH)
R Tipping

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Questions

Is this modelling too simple?

What are the scales of spatial variability?

What other factors could be included (with data)?

Is the use of a single limiting factor for NPP justified?

Is spin up to steady state OK?

How sensitive is current soil to its history?

Parameters & variables

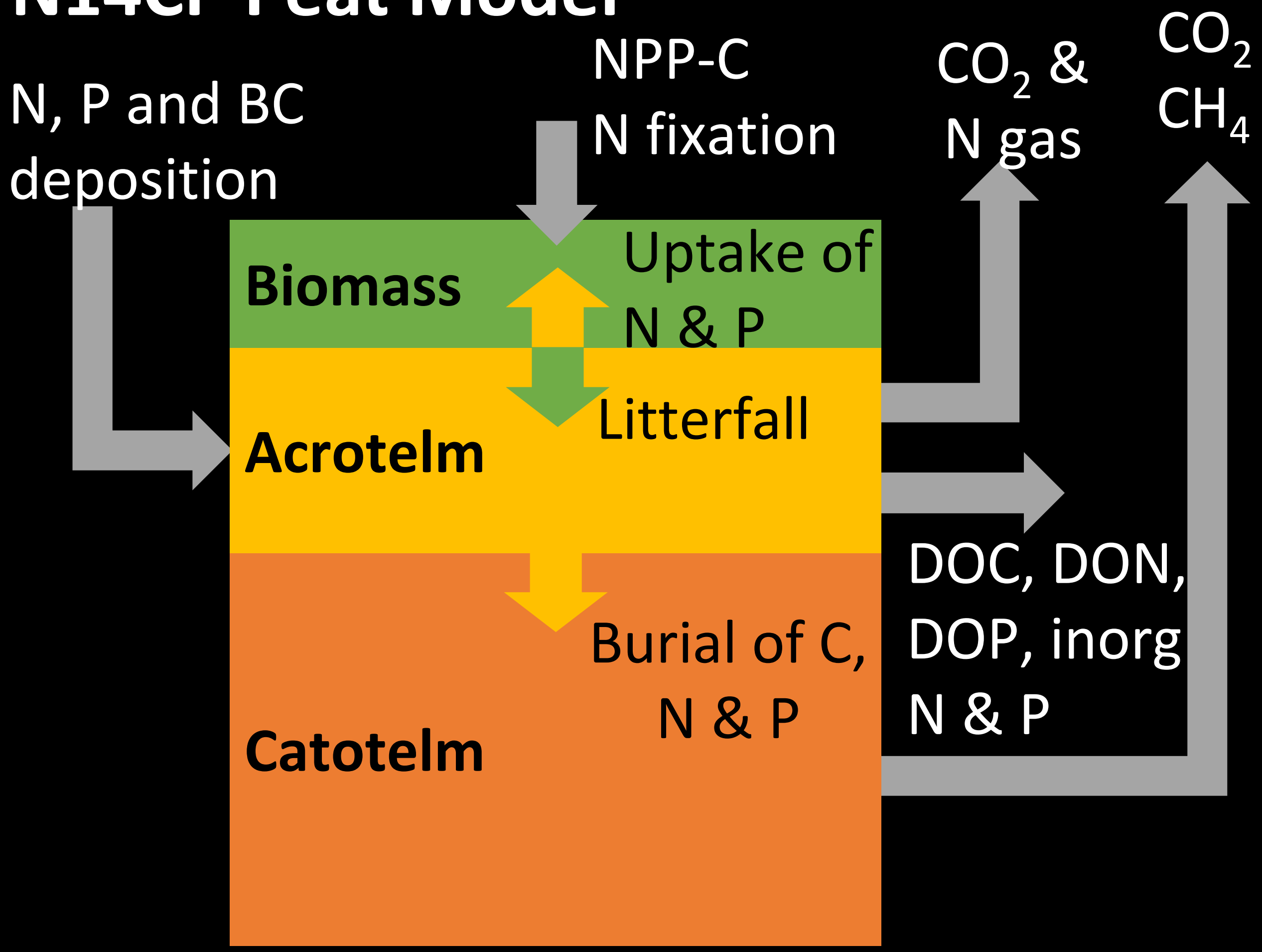
k_{immobN} broadleaf, conifer, herbs, shrubs	4
f_{fast} trees, non-trees	2
$f_{passive}$ trees, non-trees	2
k_{denitr} f_{DOC} $\Delta N_{immob2,max}$ $f_{gr,1}$ $f_{gr,2}$	5

13

C pool / N pool / C:N / Ninorg leach ***42 sites***

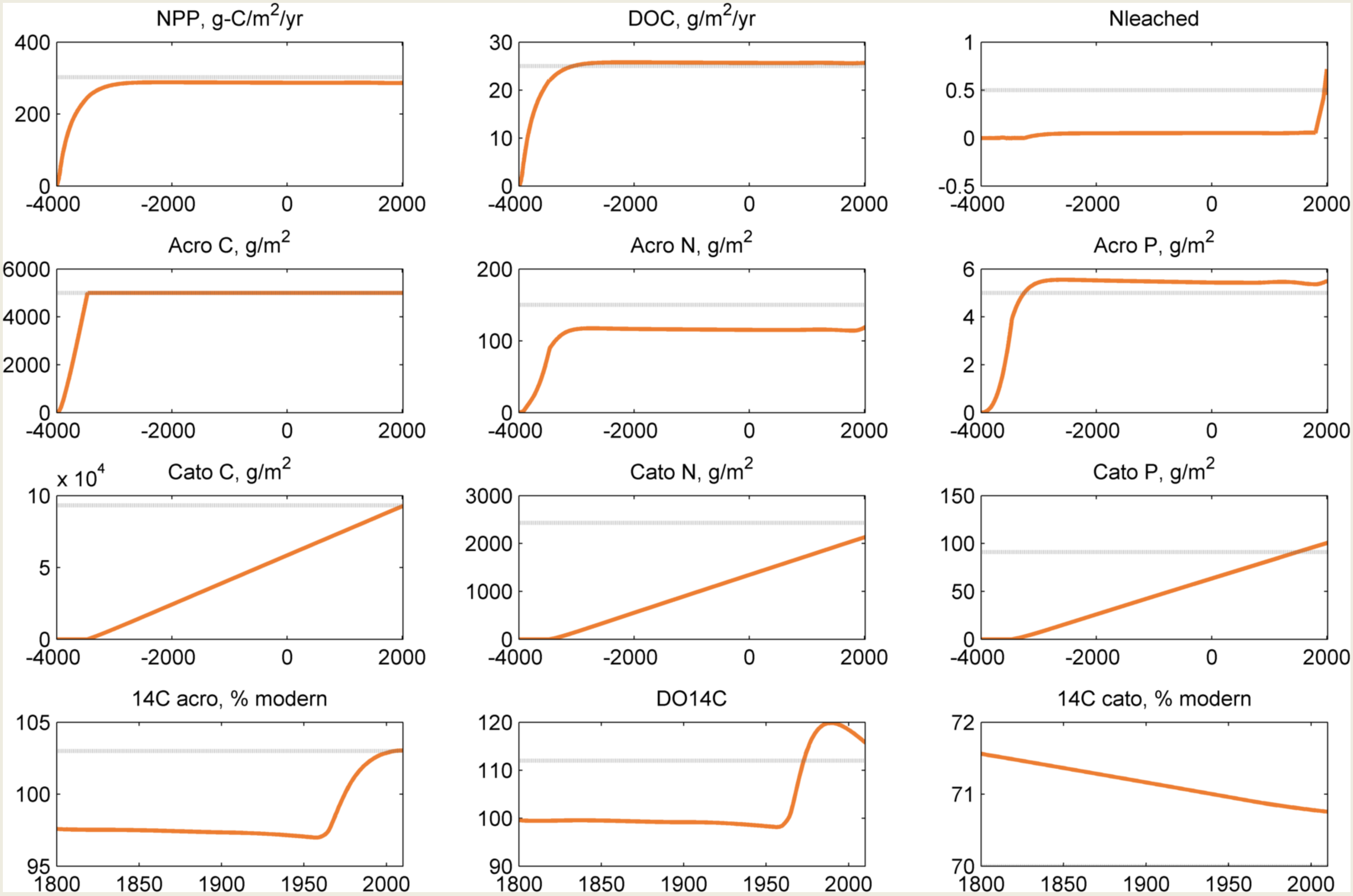
DOC leach / DON leach / denitrification / NPP ***average***

N14CP Peat Model

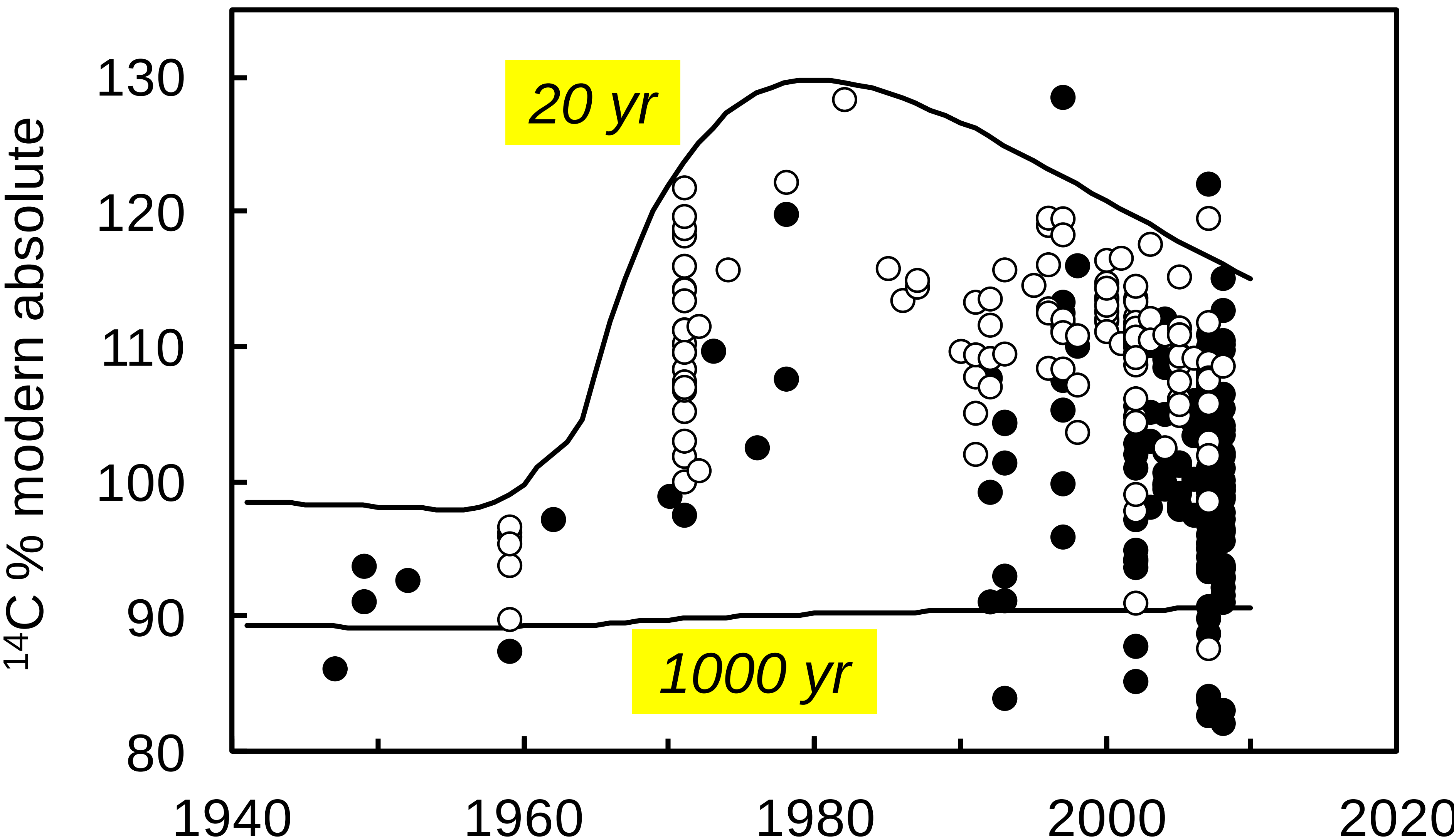


- Burial of C N and P occurs once the acrotelm reaches a certain size.
- These nutrients then become disconnected hydrologically, and undergo very slow decomposition.

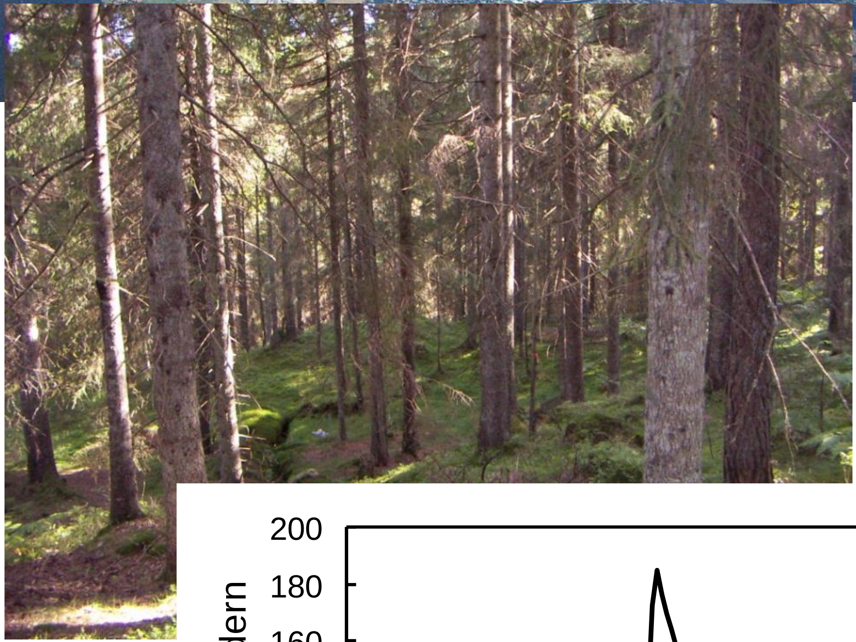
BLANKET PEAT (acro*telm*, cato*telm*)



250 topsoil ^{14}C values open = forest / closed = non-forest



Spruce forests, Sweden

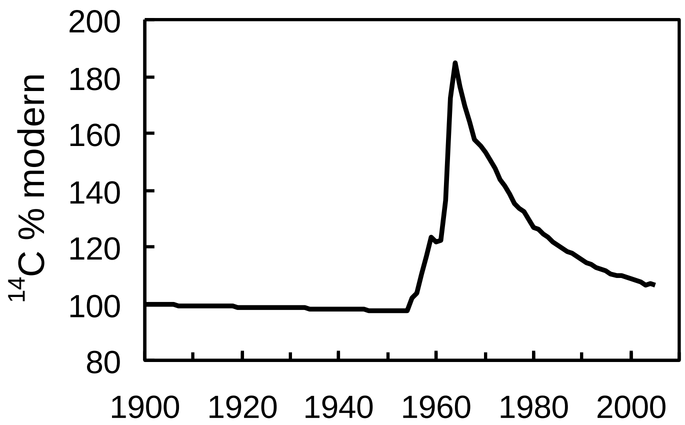


O-horizon

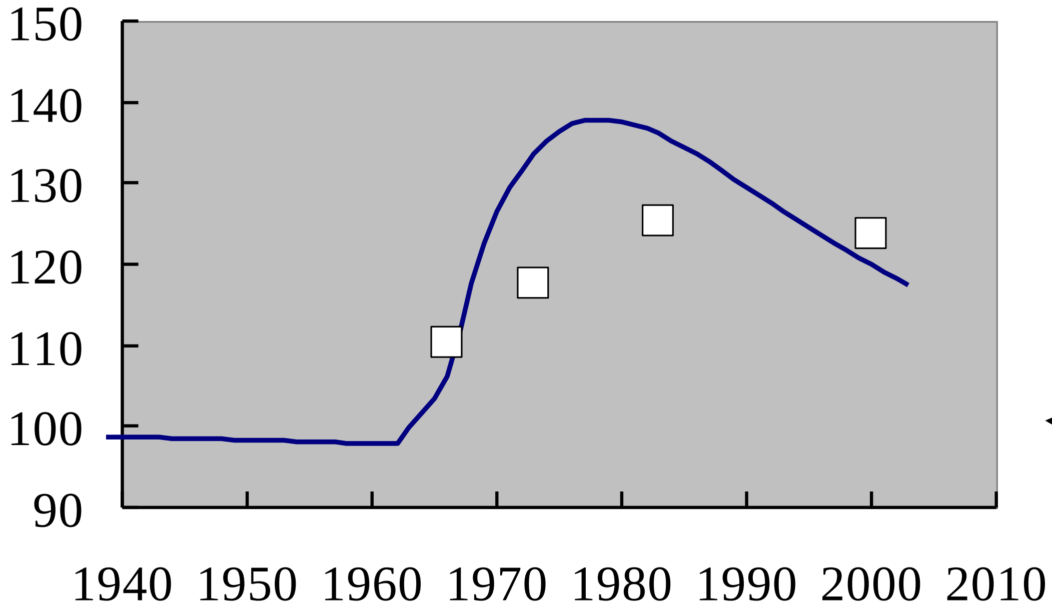
C pool ~ 2000 gC m^{-2}

Litter input ~ **200** gC m^{-2} a^{-1}

Steady-state MRT = **10** years



^{14}C data (M Fröberg, C Bryant)



5-year delay of ^{14}C in tree

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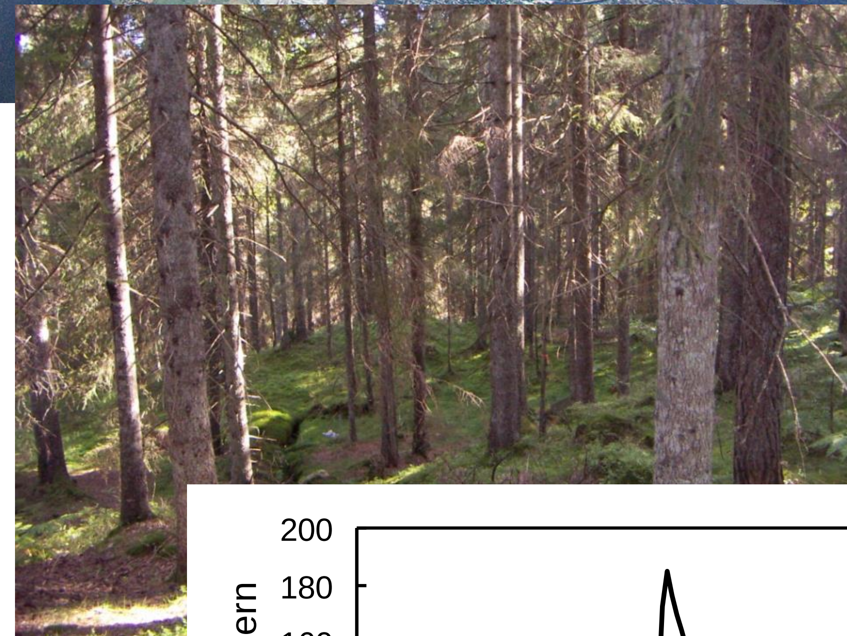
Spruce forests, Sweden

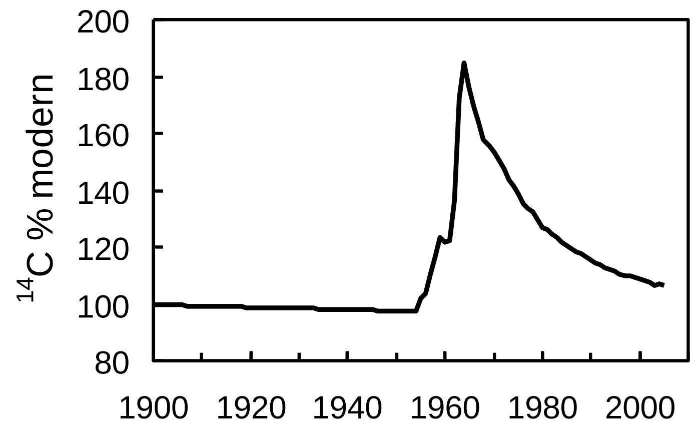
<u>O-horizon</u>

C pool ~ 2000 gC m^{-2}

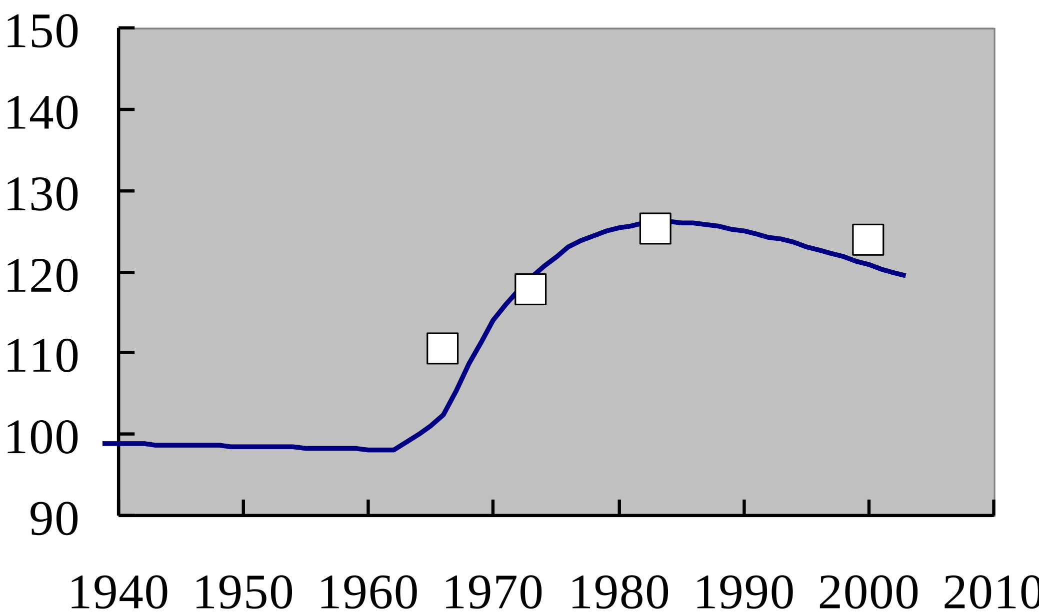
Litter input ~ **100** gC m^{-2} a^{-1}

Steady-state MRT = **20** years





^{14}C data (M Fröberg, C Bryant)



5-year delay of ^{14}C in tree

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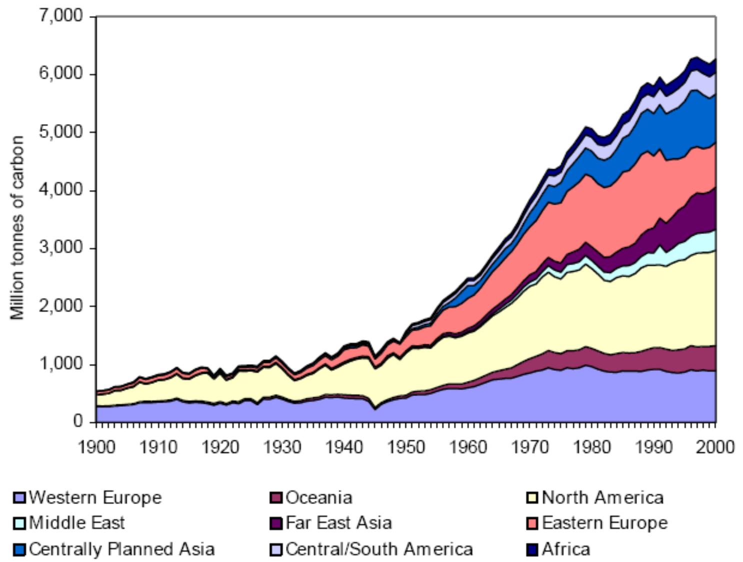
LTLS focus period 1800-2000

Chart 5A.1 Global emissions from fossil fuel combustion from 1990 to 2000



Source: Marland, G., T.A. Boden, and R. J. Andres, Global, Regional, and National CO_2 Emissions

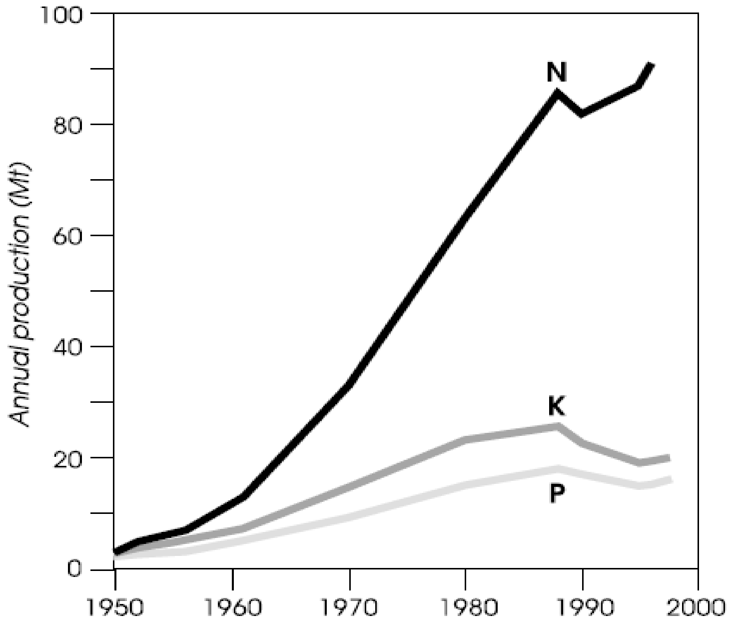


Figure 3. Global Production of Inorganic Fertilizers, 1950-2000.

"…human beings are now carrying out a large scale geophysical experiment…"

Revelle & Suess, 1956

"…the UK's long-term, spatially-distributed, biogeochemical experiment in nutrient enrichment…"

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