Assessing the implications of atmospheric deposition and harvest-residue removal on nitrogen budgets in Irish forests

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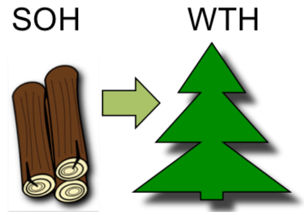
Photograph: Randy E Barnett

Continued inputs of nitrogen (N) from atmospheric deposition can alter N cycling in forests with important ecological effects

1. Changes to net primary productivity & C sequestration
2. Changes to plant species diversity
3. Altered tree nutrition and vitality
4. Nitrate leaching leading to soil acidification and mobilisation of metals

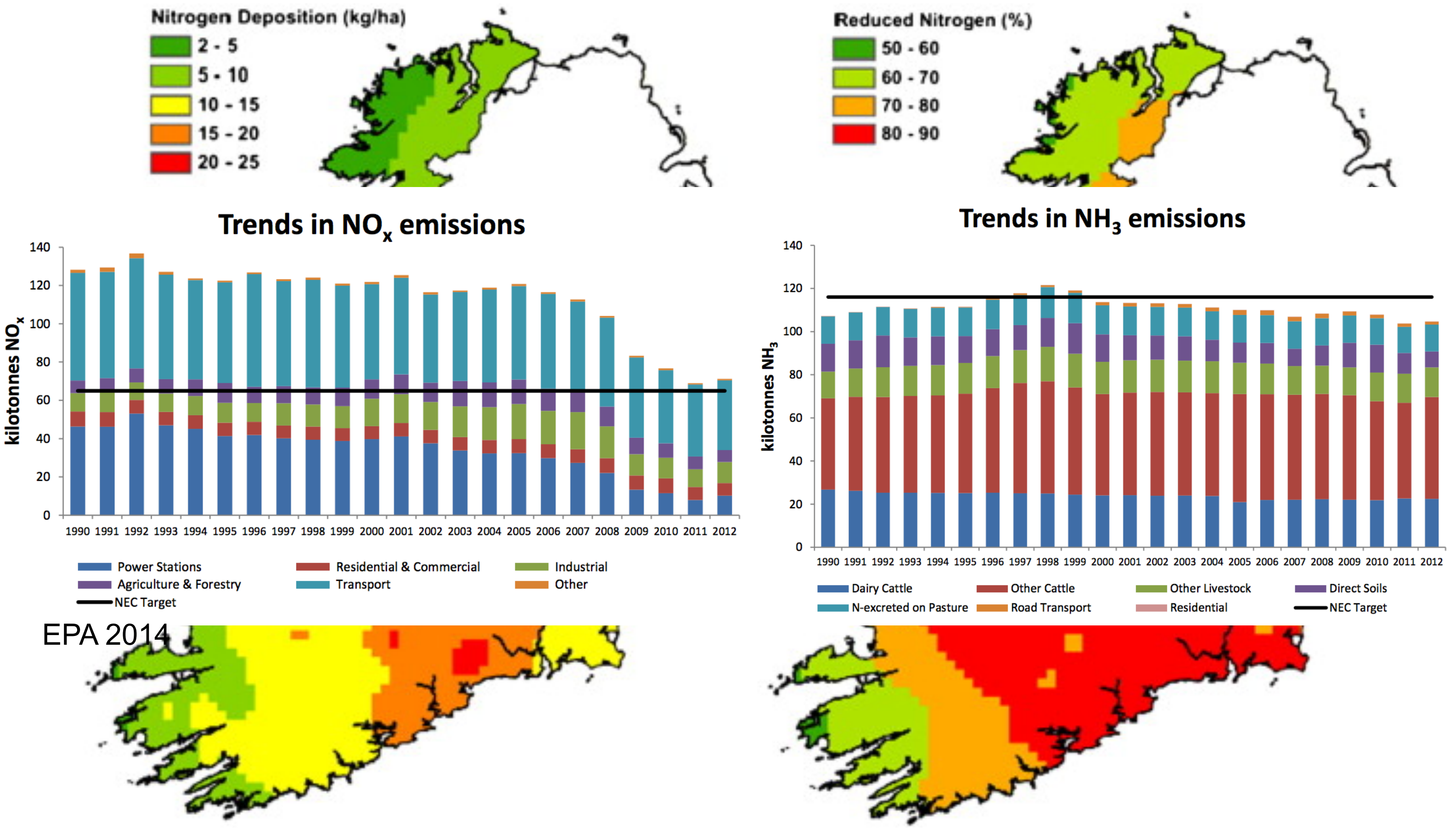
Photograph: http://natforex.ie/

Over the long-term, the N status of forest ecosystems depends on the balance between input and output fluxes



$$\Delta N_{ecosystem} = N_{deposition} + N_{fixation} - N_{harvest} - N_{leach} - N_{denit}$$

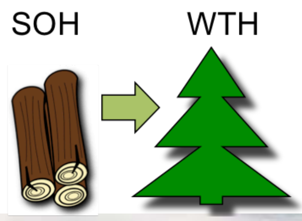
Nitrogen deposition in Ireland is dominated by domestic emissions of ammonia



Henry & Aherne, 2014 **Nitrogen deposition and exceedance of critical loads for nutrient nitrogen in Irish grasslands** Science of The Total Environment, Vol: 470–471, 216 – 223

In addition to atmospheric deposition, management strongly influences N cycling in Irish forests

1. Primary plantation forests located on shallow mineral or organic soils
2. Intensively managed: plantations comprise fast growing conifer species with short rotations
3. Afforestation is recent – majority are first rotation forests – converted from acidic grassland, moorland or peat.
4. Removal of harvest residues for bio-energy



Study objectives:

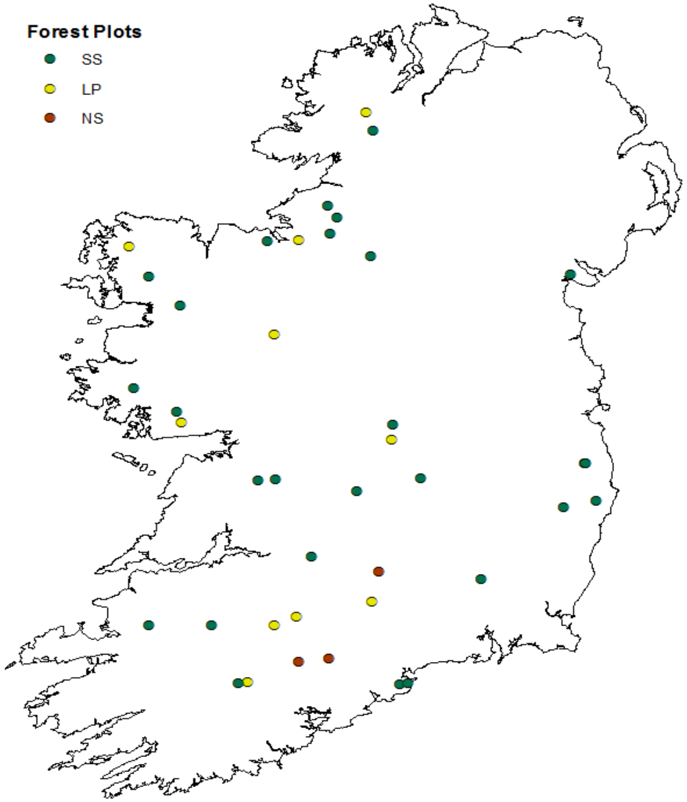
1. To assess the impact of atmospheric N deposition and harvest scenarios on N budgets in Irish forests

$$\Delta N_{ecosystem} = N_{deposition} + N_{fixation} - N_{harvest} - N_{leach} - N_{denit}$$

2. To determine the critical load of nutrient N to prevent N leaching and associated soil acidification

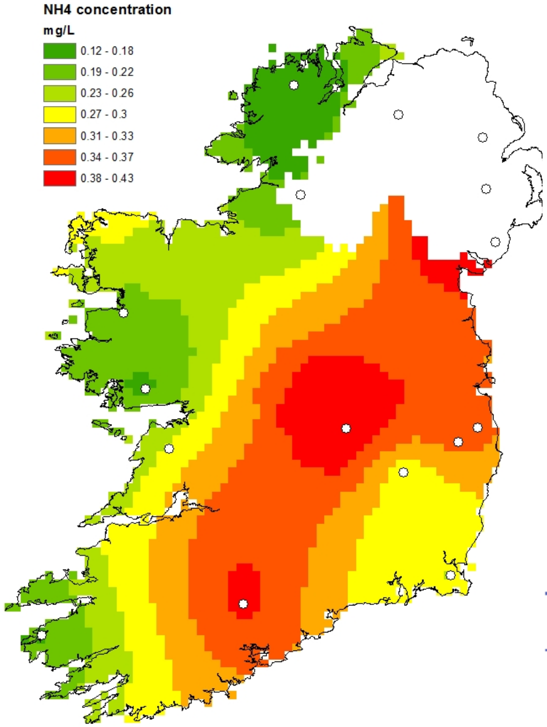
$$Cl_{nut}(N) = N_{harvest} + N_{immob} + N_{denit} + N_{fixation} + N_{leach}$$

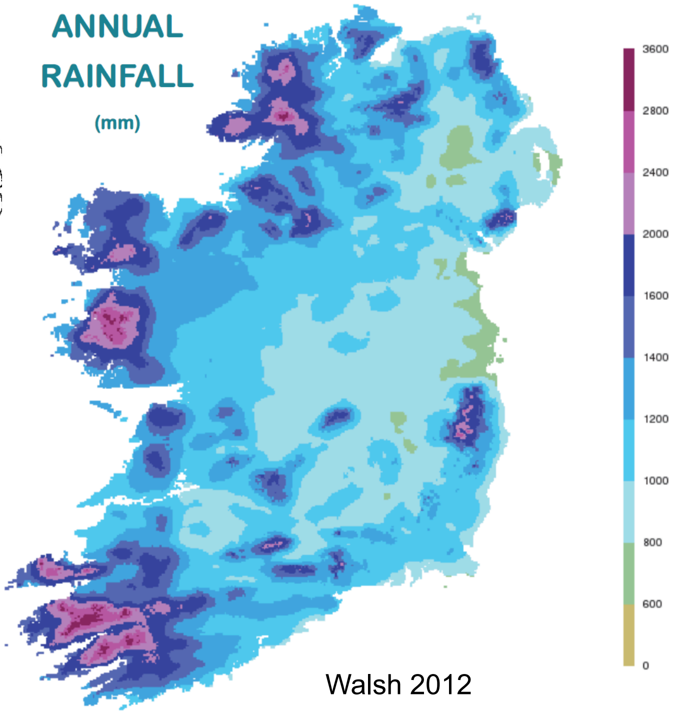
Approach: Site specific budgets @ 40 forest ICP-Forest plots



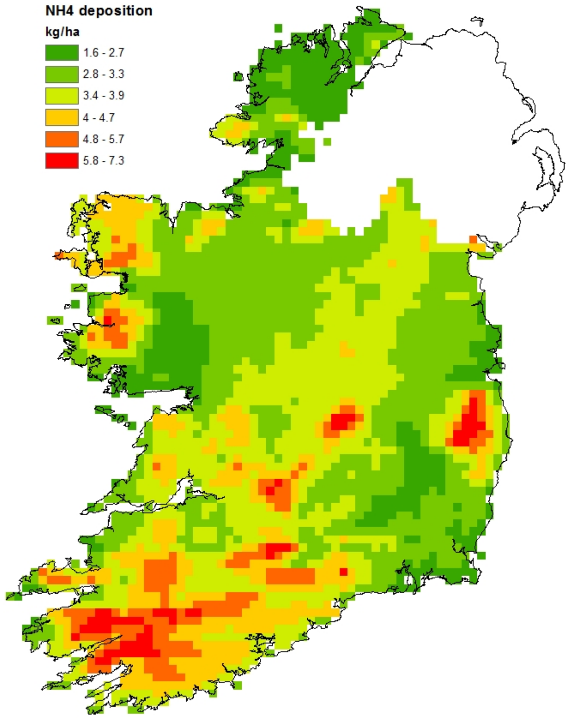
$$\Delta N_{ecosystem} = N_{deposition} + N_{fixation} - N_{harvest} - N_{leach} - N_{denit}$$

$NO_3^- + NH_4^+ + NO_x + NH_3$





Walsh 2012



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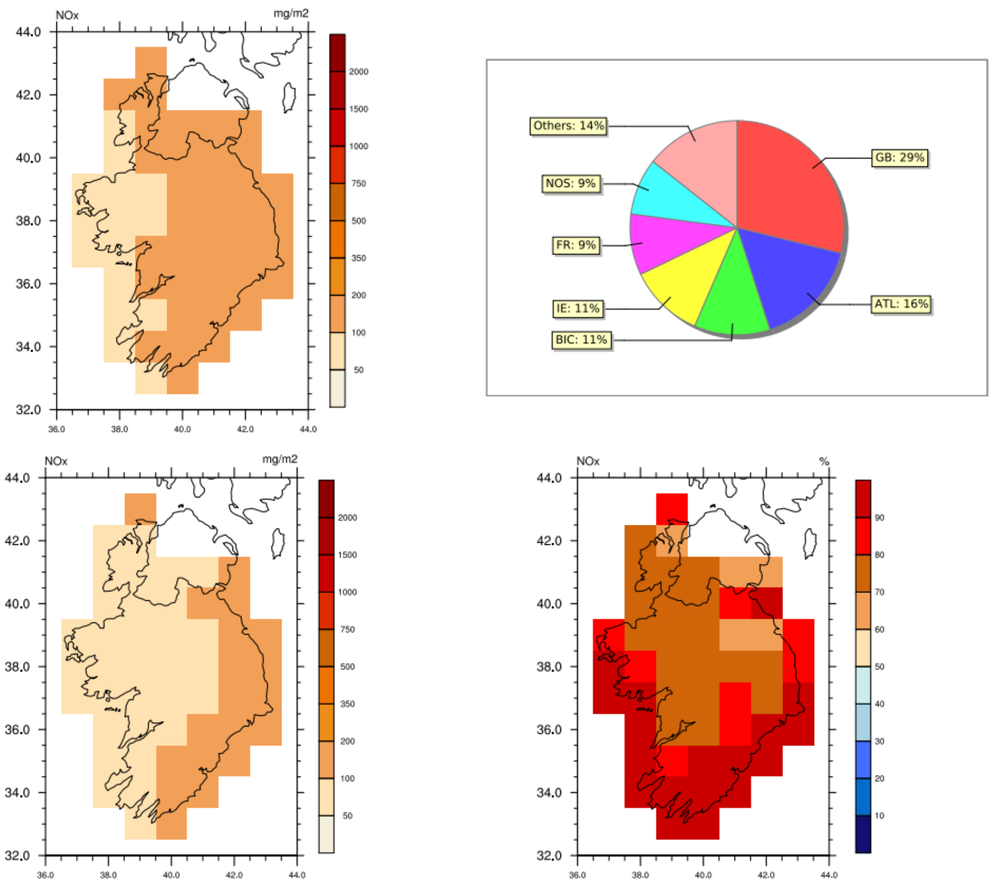

EMEP/MSC-W (Gauss et al. 2012)
Transboundary air pollution by main pollutants (S, N, O3) and PM in 2010

Figure 9: Top left: Deposition of oxidised nitrogen in Ireland. Unit: mg(N)/m^2. Top right: The six main contributors to oxidised nitrogen deposition in Ireland. Unit: %. Bottom left: Oxidised nitrogen deposition from transboundary sources. Unit: mg(N)/m^2. Bottom right: Fraction of transboundary contribution to total deposition. Unit: %.

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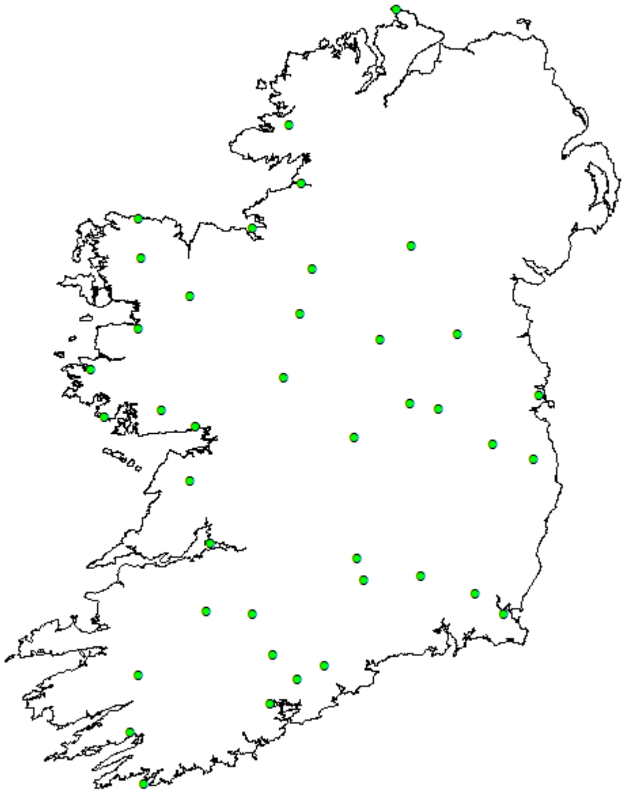

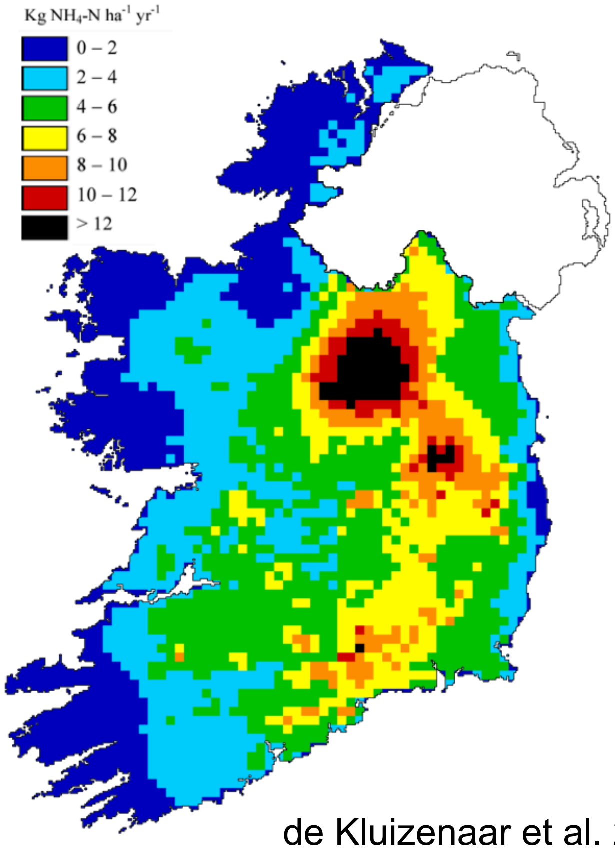

de Kluizenaar et al. 2000

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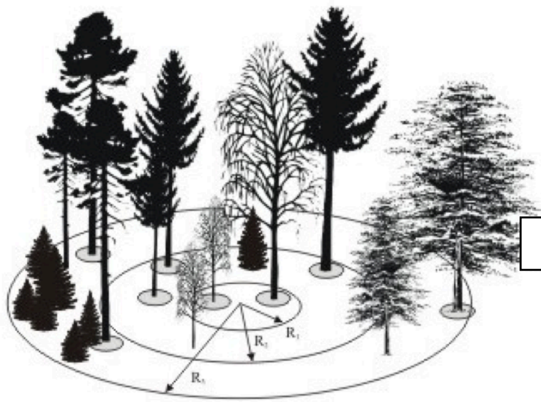


1. BioSoil survey

2. Growfor: Irish dynamic yield models for forest management

Component	Eqt No	Source	Equation
Stemwood	1	Irish yield model	biomass = volume ha^{-1}·stemwood basic density
Stembark	2	This study	ln(biomass) = 0.126574·dbh − 0.1065634
Live branch	3	This study	ln(biomass) = 0.1126·dbh − 0.3405
Dead Branch	4	This study	biomass = 1.2771·dbh − 12.378
Needle	5	This study	$\log_{10}$(needle) = 2.73955·$\log_{10}$(dbh) − 2.78585

3. Allometric equations

4. Element concentrations

		mg/g					
Species	Component	C	N	P	K	Ca	Mg
SS	Branch	508	3.91	0.40	1.75	2.39	0.46
	Needles	524	11.93	0.98	4.72	3.23	0.68
	Stem wood	509	1.21	0.04	0.33	0.49	0.08

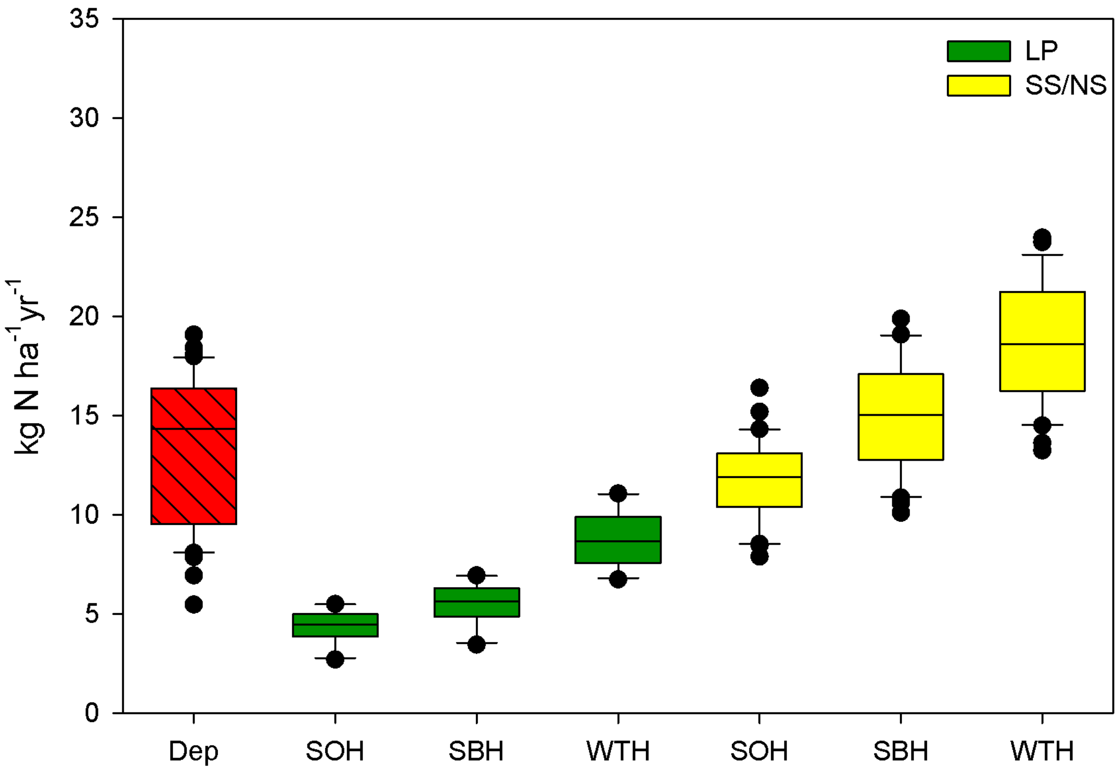
$$\Delta N_{ecosystem} = N_{deposition} + N_{fixation} - N_{harvest} - N_{leach} - N_{denit}$$

1. The N fixing term ($N_{fixation}$) was omitted – no N-fixing plants or mosses
2. Leaching losses – set to a minimum (1 kg N ha^{-1} yr^{-1})
3. Denitrification rates (kg N ha^{-1} yr^{-1}) based on literature values:
   - ~ 0.5 @ podzol Wales (Emmett et al. 1995)
   - 0.8 (10 months) @ peaty gley England (Zerva & Mencuccini 2005)
   - 0.03 to 1.31 @ 7 sites in Europe (Pilegaard et al. 2006)

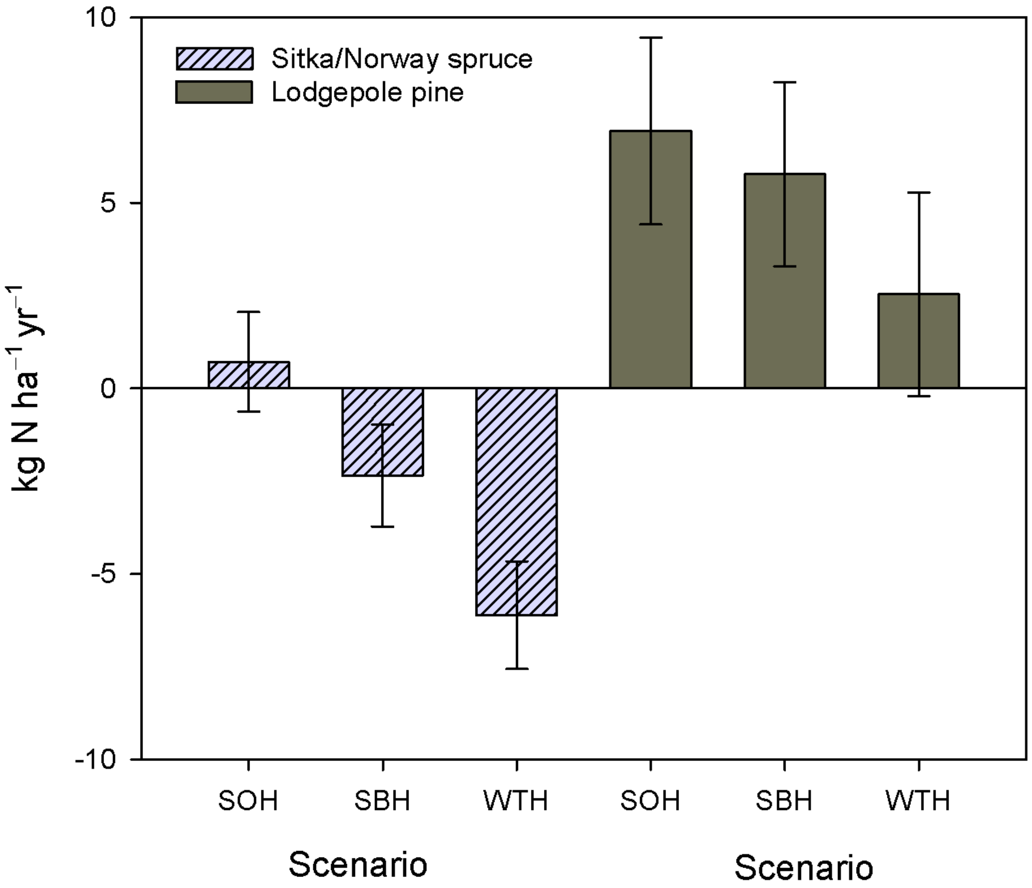
Well-drained mineral	0.5
Poorly drained mineral (gley)	1.0
Peat	0.0


Photograph: http://natforex.ie/

1. N deposition was greater than N removal in pine but equal to or less than N removal in spruce



2. Budgets were negative for spruce when harvesting residues were removed



N removal in spruce was larger than that reported elsewhere in Europe and North America

ref	species	country	kg N ha^{-1} yr^{-1} stem only	whole tree	note
This study	*Picea sitchensis*	Ireland	12	19	
	Pinus contorta	Ireland	4.4	8.7	
Stevens 1995	*Picea sitchensis*	UK	2.4-3.8	7.1-9.0	
Miller et al. 1993	*Picea abies*	Scotland	2.8	7.2	
	Picea sitchensis	Scotland	3.0	7.4	
Akselsson et al. 2007	*Picea abies*	Sweden	1.2-2.8	3.0-6.5	
Zetterberg et al. 2013	*Picea abies*	Sweden	0.7-1.8	3.5-5.9	From: Björkroth & Rosén 1977
	Pinus sylvestris	Sweden	1.1	1.6	
Palviainen & Finer 2012	*Pinus*	Finland	2.3	5.2	
	Picea	Finland	2.7	9.6	
	Betula	Finland	4.4	8.3	
Ranger et al.1995	Pseudotsuga	France	5.8	9.8	60 year rotation
Fichter et al. 1998	*Fagus*	France	3.3		
	Picea abies	France	4.7		
Paré et al. 2002	Balsam fir	Canada	1.2	3.9	medium stand density
	Black spruce	Canada	0.6	1.8	
	Jack pine	Canada	1.1	2.0	
	Paper birch	Canada	1.6	4.4	
	Trembling aspen	Canada	2.1	4.7	
Federer et al. 2001	Hardwoods	USA		2.0-3.2	120 year rotation

The large N removal in harvesting for spruce was due to the high rate of biomass removal and stemwood N concentrations

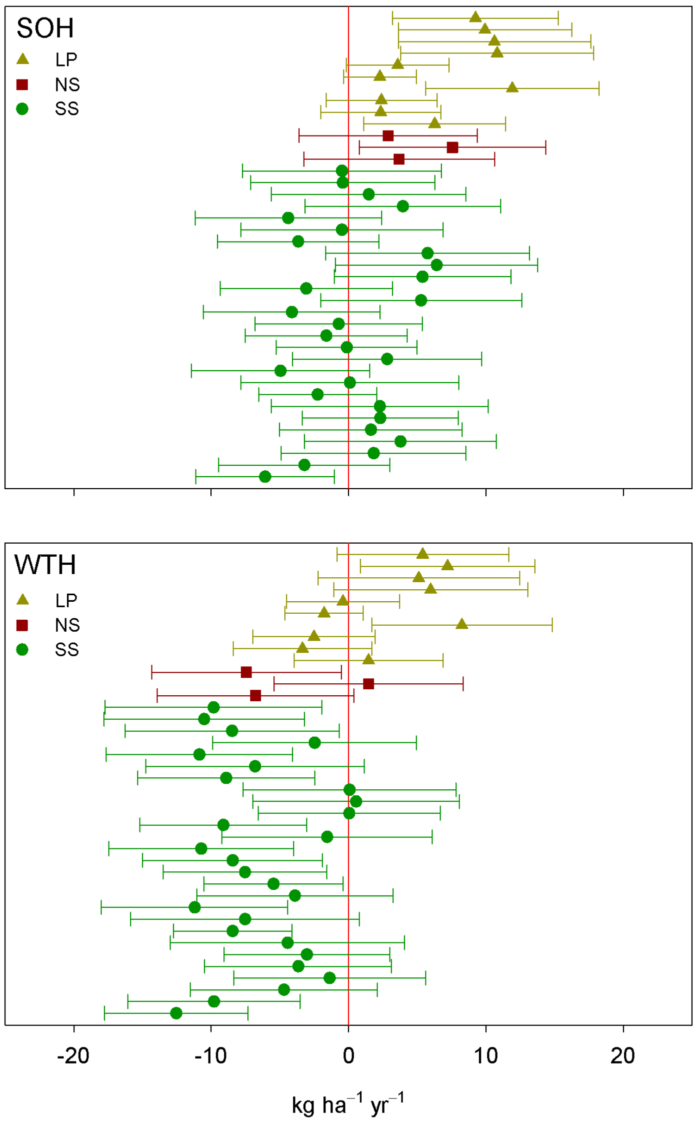
species	source	Location	mg g^{-1}	range	# sites
Picea sitchensis	this study	Ireland	1.2	(0.9 - 1.7)	5
	Tobin et al. 2008	Ireland	2.4	(2.3 - 2.6)	2
	Carey & O'Brian 1979	Ireland	1.6	-	1
	Carey 1980	Ireland	0.7	-	1
	Freer-Smith & Kennedy 2003	UK	0.5	(0.3 - 1.2)	24
	Miller 1993	Scotland	0.3	-	1
Picea abies	Jacobsen et al. 2002	Europe	0.8	(0.3 - 2.1)	29
	Lucas et al. 2014	Sweden	1.0	(0.5 - 1.8)	6

ref	species	tonnes ha^{-1} yr^{-1} stem only	whole tree	note
this study	*Picea sitchensis*	8.3	9.5	
	Pinus contorta	4.7	5.2	
Stevens 1995	*Picea sitchensis*	4.6 - 5.3	5.9 - 6.4	
Zetterberg et al. 2013	*Picea abies*	2.1	2.8	
	Pinus sylvestris	1.6	2.0	
Palviainen & Finer 2012	*Pinus*	2.5	2.8	
	Picea	2.5	3.3	
	Betula	2.8	3.1	
Miller et al. 1993	*Picea abies*	4.0	4.5	
	Picea sitchensis	4.7	5.3	
Ranger et al.1995	*Pseudotsuga*	5.9	6.6	60 year rotation

3. How much N deposition before ecosystem damage? - critical loads

$$CL_{nut}(N) = N_{harvest} + N_{immob} + N_{denit} + N_{fixation} + N_{leach}$$

1. Acceptable leaching losses ~ 2 kg N ha^{-1} yr^{-1}
   - Based on a concentration of 0.2 mg L^{-1} (Spranger et al. 2004)
2. Immobilisation ~ 2kg N ha^{-1} yr^{-1}
   - Values used for Sitka spruce: 1 - 3 kg N ha^{-1} yr^{-1} (Hornung et al. 1995; Emmett & Reynolds 1996)
3. Critical loads - results
   - for spruce: 16, 19 and 23 kg N ha^{-1} yr^{-1}
   - for pine: 9, 10 and 13 kg N ha^{-1} yr^{-1}
4. Excedance of critical load
   - pine: stem-only @ 7 sites (~5 kg N ha^{-1} yr^{-1}) , whole-tree @ 5 sites (~3 kg N ha^{-1} yr^{-1})
   - for spruce: stem–only @ 8 sites (1.7 kg N ha^{-1} yr^{-1}), whole-tree - none



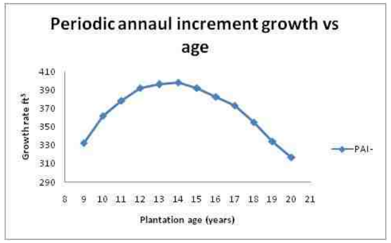
4. There was considerable uncertainty around fluxes at individual sites

Due to uncertainty associated with:

- allometric equations
- N concentrations in biomass
- uncertainty around deposition - interpolation, dry deposition velocity factor (NH_3)

Other uncertainties –

- removal of material in thinnings
- leaching losses post harvesting
- N immobilisation factor
- Temporal variation over the period of the rotation
- Soil sink strength for N deposition – presence of peat



What can we conclude?

1. Nitrogen budgets are balanced under current stem-only harvest scenario for spruce – N deposition balanced by large removal
2. Potential for negative budgets under whole-tree harvest scenario
3. Critical loads high and rarely exceeded
    - N deposition important for uptake?
4. Considerable uncertainty around budget and critical load calculations
    - simple mass balance approach
    - assumed leaching available for uptake or immobilisation

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Thank You


Questions?