Forest Research

How experiments that investigated growing Sitka spruce in mixture changed British forestry – and what happened afterwards.

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1. Introduction

A brief overview of forestry expansion in Britain.

Forest cover in Britain:
per cent changes over time

Period	Country		
	England	**Scotland**	**Wales**
1700s	8	4	-
1905	**5.2**	**4.5**	**4.2**
1924	5.1	5.6	5.0
1947	5.8	6.6	6.2
1965	6.8	8.4	9.7
1980	7.3	11.8	11.6
1997	8.4	16.4	13.8
2014	**10.0**	**18.2**	**14.8**

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Changes in species composition

Species	Area (ha) and percent (%)	
	1947	2000
Pinus sylvestris	**147.3** (20)	**219.4** (10)
Larix spp.	**78.5** (11)	**130.2** (6)
Picea sitchensis	**67.6** **(9)**	**683.7** **(30)**
Pseudotsuga menziesii	**15.3** (2)	**45.2** (2)
Other conifers	**73.6**	**301.1**
Quercus spp	174.6 (24)	206.2 (9)
Betula spp	27.2 (4)	76.6 (7)
Fraxinus excelsior	34.3 (5)	110.2 (5)
Other broadleaves	105.5	400.0

Adapted from: Mason, WL (2007) I*bis*, **149** (Suppl. 2), 41–52, Table 2

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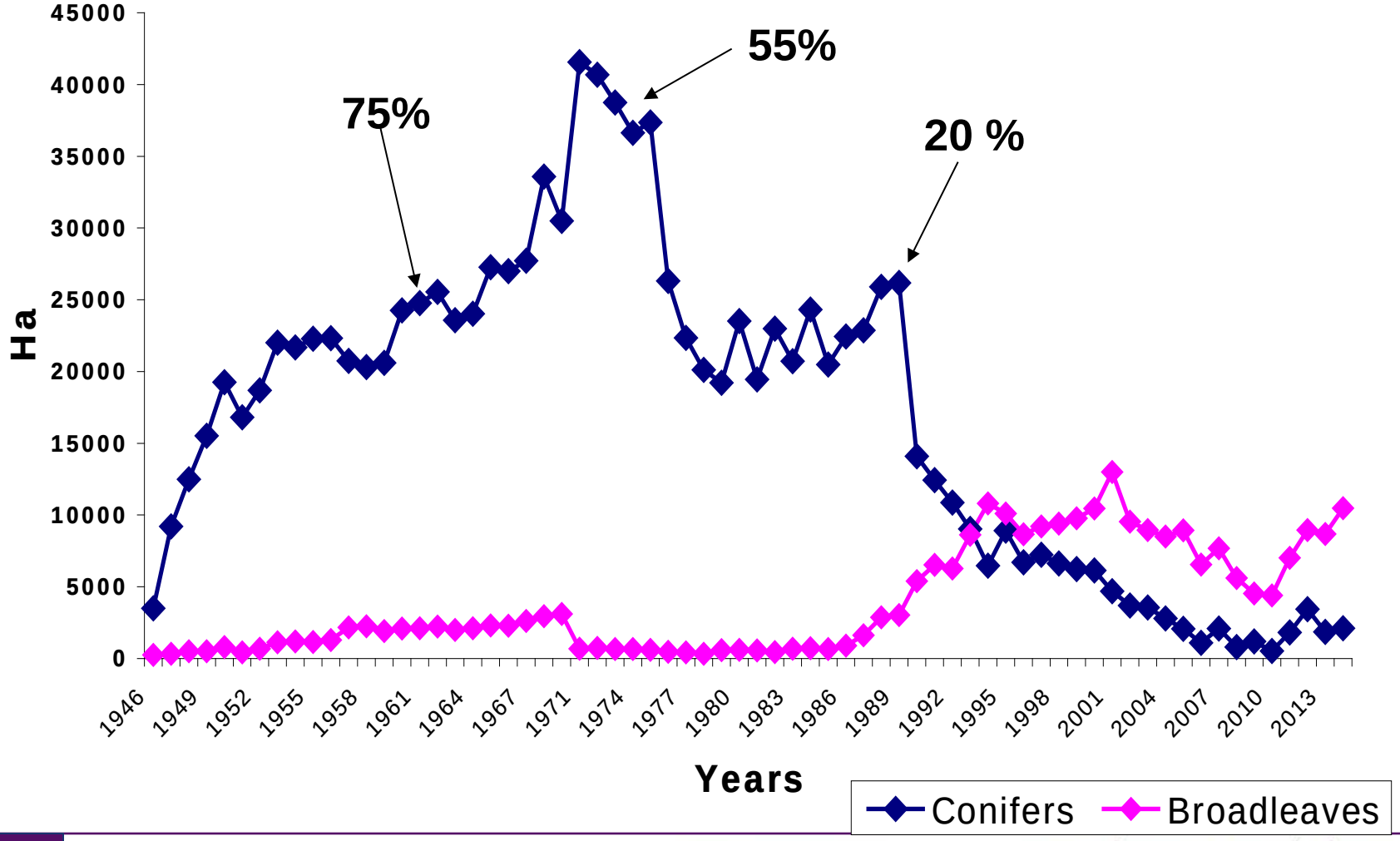
Annual rate of new planting in Great Britain: 1946-2014



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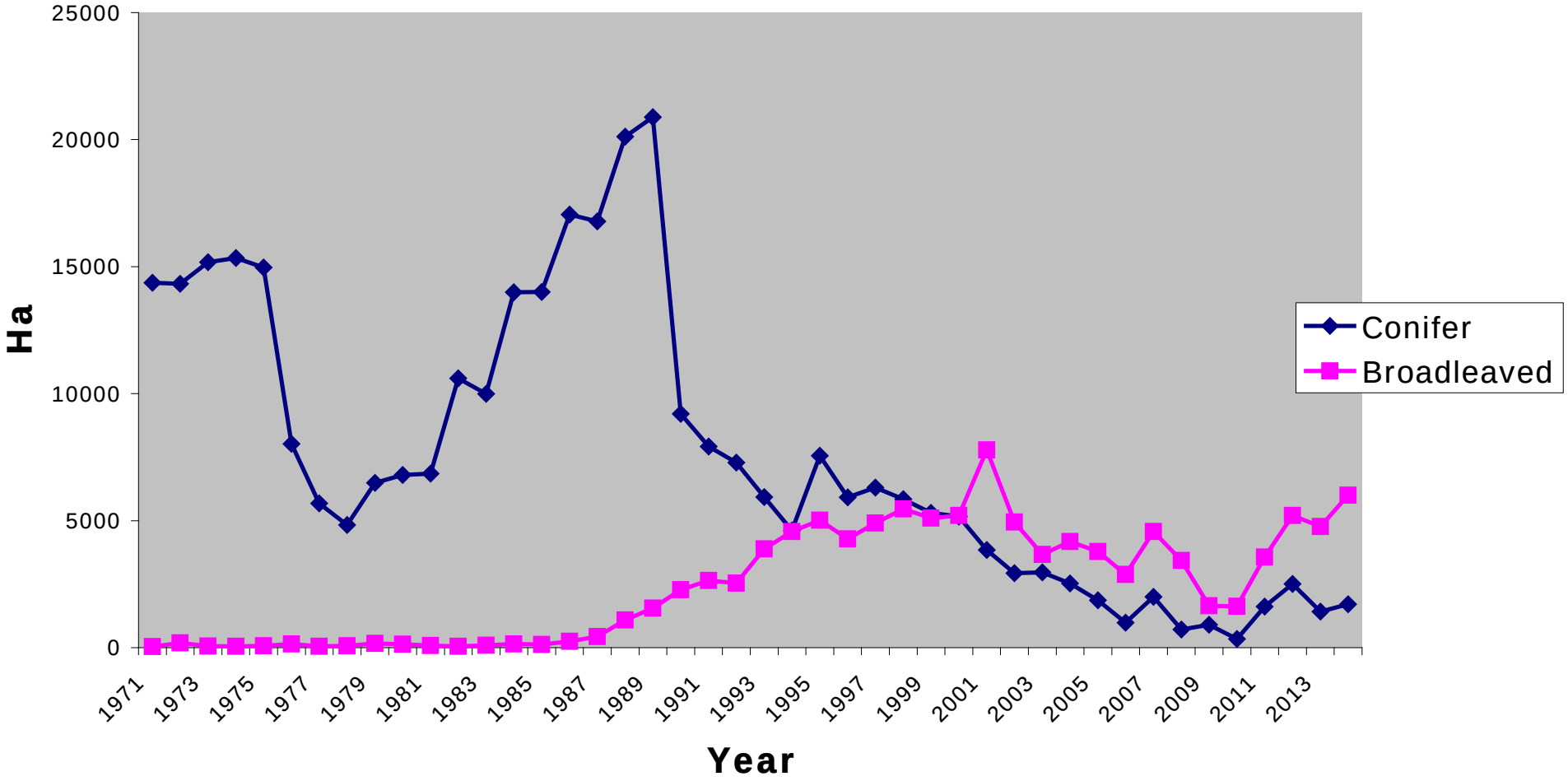
Private new planting in Scotland: 1971-2014



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Phases of conifer new planting

1. 1950-1979 - Steady rate of planting peaking in the early 1970s;
2. 1979 onwards - Progressive switch to private sector;
3. 1979-1990 - Rapid increase in private sector planting;
4. 1990 to present - Steep and continuing decline in amount of new conifer planting

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2. How did spruce mixtures enable the expansion of the 1980s?

New planting site in the 1970s

Two planting models in 1970s

1. **Intensive**: Pure Sitka spruce (*Picea sitchensis*) (*SS*) or similar species with 1-3 (N)PK applications before canopy closure.

   Anticipated productivity **12-20 m^3 ha^{-1} yr^{-1}**;

2. **Extensive**: Pure lodgepole pine (*Pinus contorta*) (*LP*) or similar with 1 P(K) application before canopy closure.

   Anticipated productivity **4-8 m^3 ha^{-1} yr^{-1}**;

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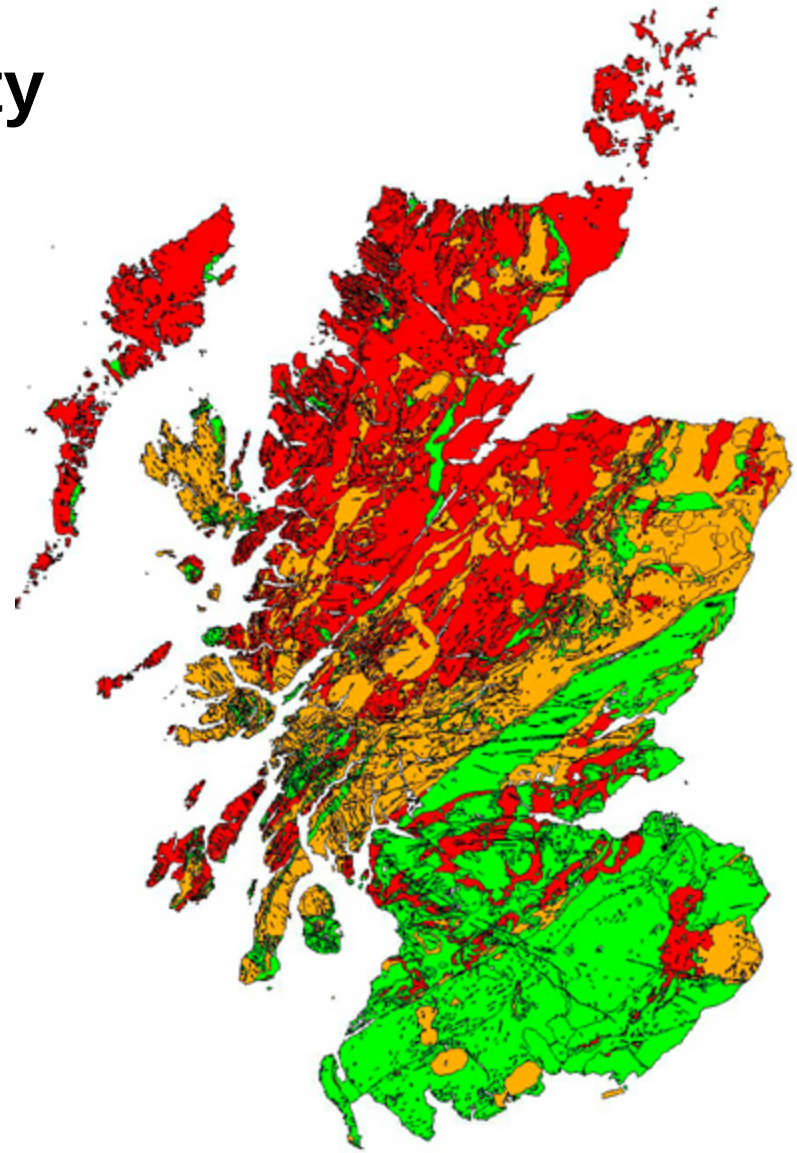
Scotland's Geology

Potential nitrogen availability

High – Little need for N application for good Sitka spruce growth

Medium – Possibly one N application required to establish pure Sitka spruce

Low – Several N applications could be required to establish pure Sitka spruce



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Enter the mixtures!

Can higher yielding forests be established on low fertility sites without intensive (and expensive) fertiliser inputs?

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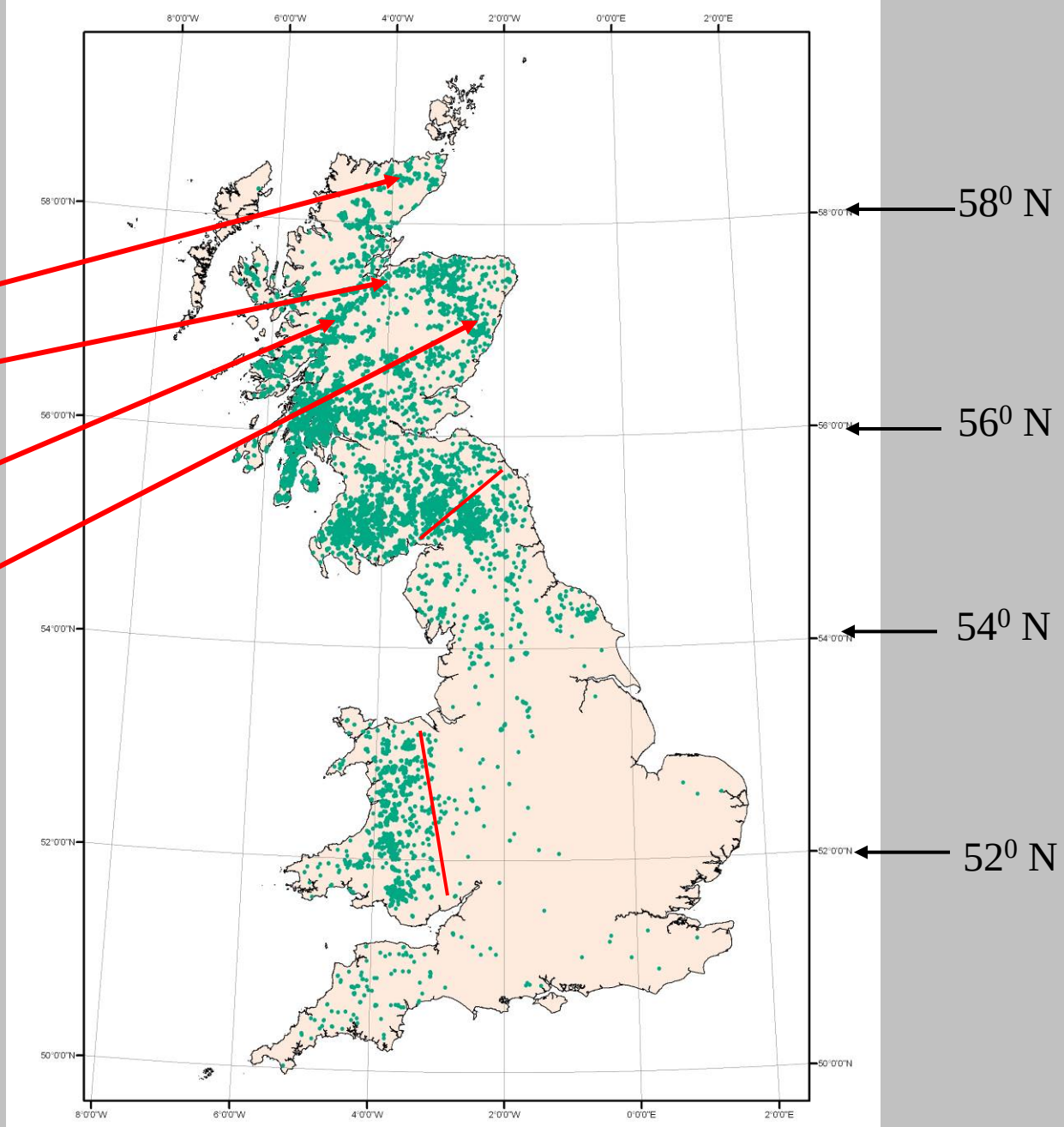
Locations of the main mixture experiments

Strathy

Culloden

Inchnacardoch

Drumtochty



All were afforestation sites

Outline experiment details

Site	Planted	Main treatments	Plot size (ha) and ***reps***	Soil type	Soil N status
Inch….	**1965**	SS, SS/larch, SS/LP all +/- N	0.1 - ***5***	Peaty gley to deep peat	**Low-very low**
Strathy	**1965**	SS +/- N, SS/larch, SS/LP	0.1 - ***3***	Deep peat	**Very low**
Drum…	**1967**	SS +/- N, SS/larch, SS/LP	0.1 - ***3***	Ironpan	**Moderate**
Culloden	**1969**	SS, SS/Scots pine +/- cultivation and drainage	0.08 - ***2***	Indurated gley	**Low**

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Mixture pattern and other features

- At Inchnacardoch, Strathy and Drumtochty the two species were planted in alternative groups of three plants in alternate rows. The intermediate row was a pure row of the nurse species. Result a **75:25 nurse: spruce** mixture;
- At Culloden, the two species were planted in a 3 row: 3 row mixture of each species. Result a **50:50 nurse: spruce** mixture.
- Standard fertiliser input for all treatments was about **125 kg P ha^{-1}** and **200 K ha^{-1}**. In pure Sitka spruce plots, nitrogen inputs varied from **650-2000 kg N ha^{-1}** on a 3 year cycle. All rates are for the amount of element applied;
- There has been **no thinning** in these experiments.

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Results in the early 1980s

Early height growth (m) of Sitka spruce pure and in mixture

Site	Age	Treatment				Signif.	5%LSD
		SS and larch	SS and pine	SS plus N	SS minus N		
Inchnacardoch	20	**8.9**	**8.4**	**9.8**	**6.1**	**	1.5
Strathy	20	**6.5**	**6.4**	**5.4**	**2.6**	***	1.0
Drumtochty	16	**7.1**	**5.2**	**7.2**	**6.5**	**	1.4
Culloden	18	-	**8.2**	-	**5.3**	**	1.4

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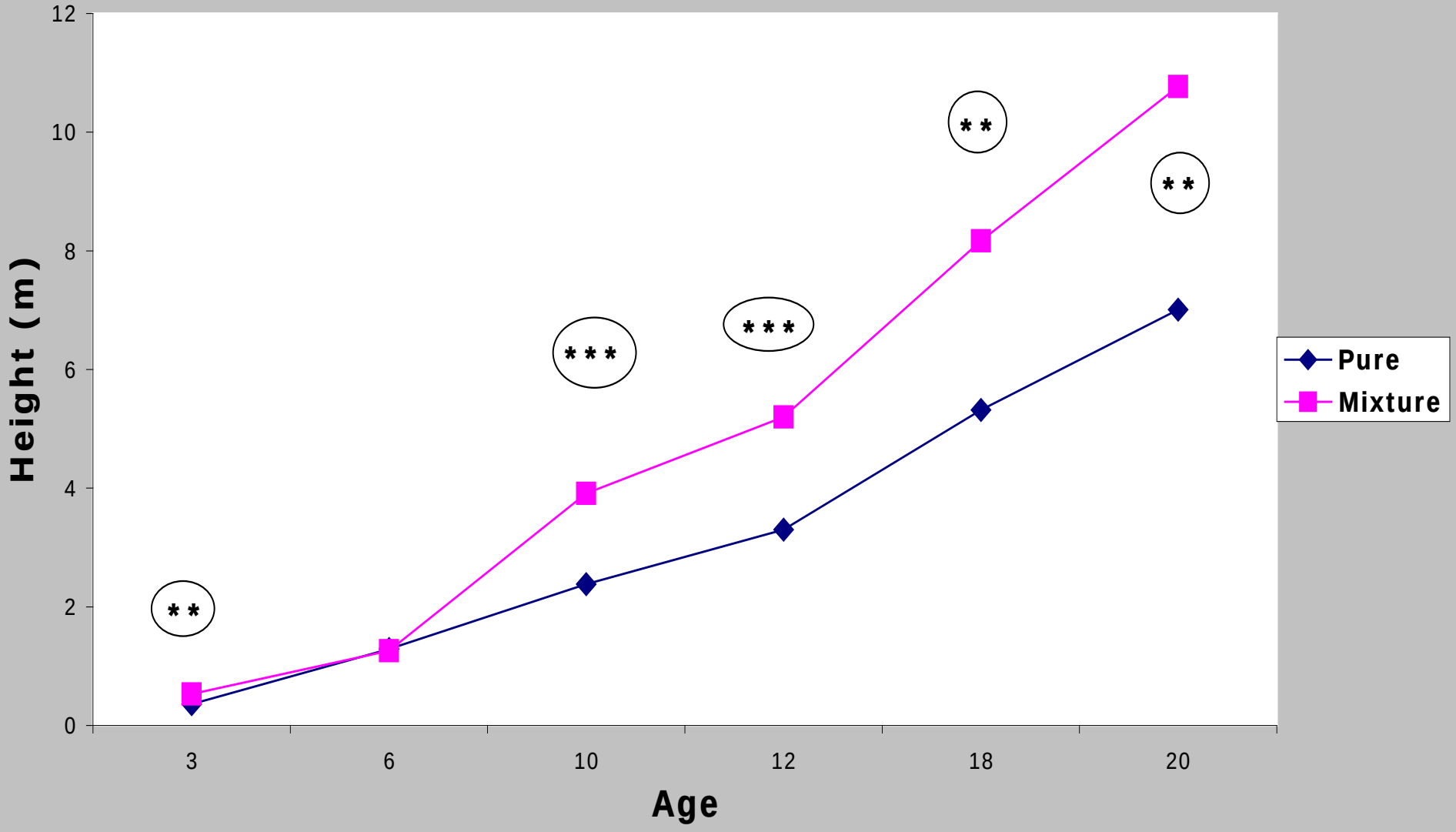
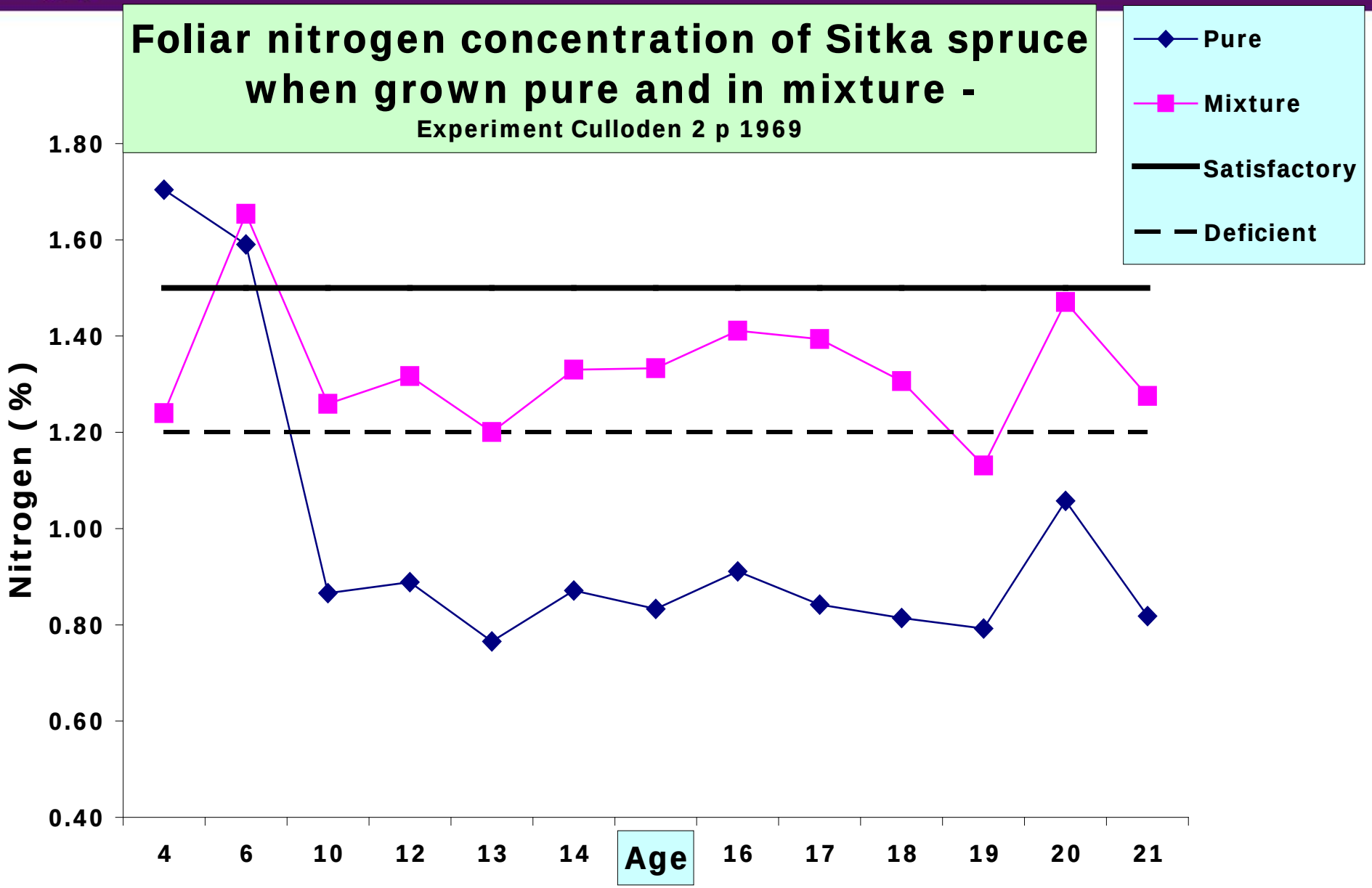
Height growth of Sitka spruce pure and in mixture with Scots pine:

Experiment Culloden 2 p 1969



Foliar nitrogen concentration of Sitka spruce when grown pure and in mixture -

Experiment Culloden 2 p 1969



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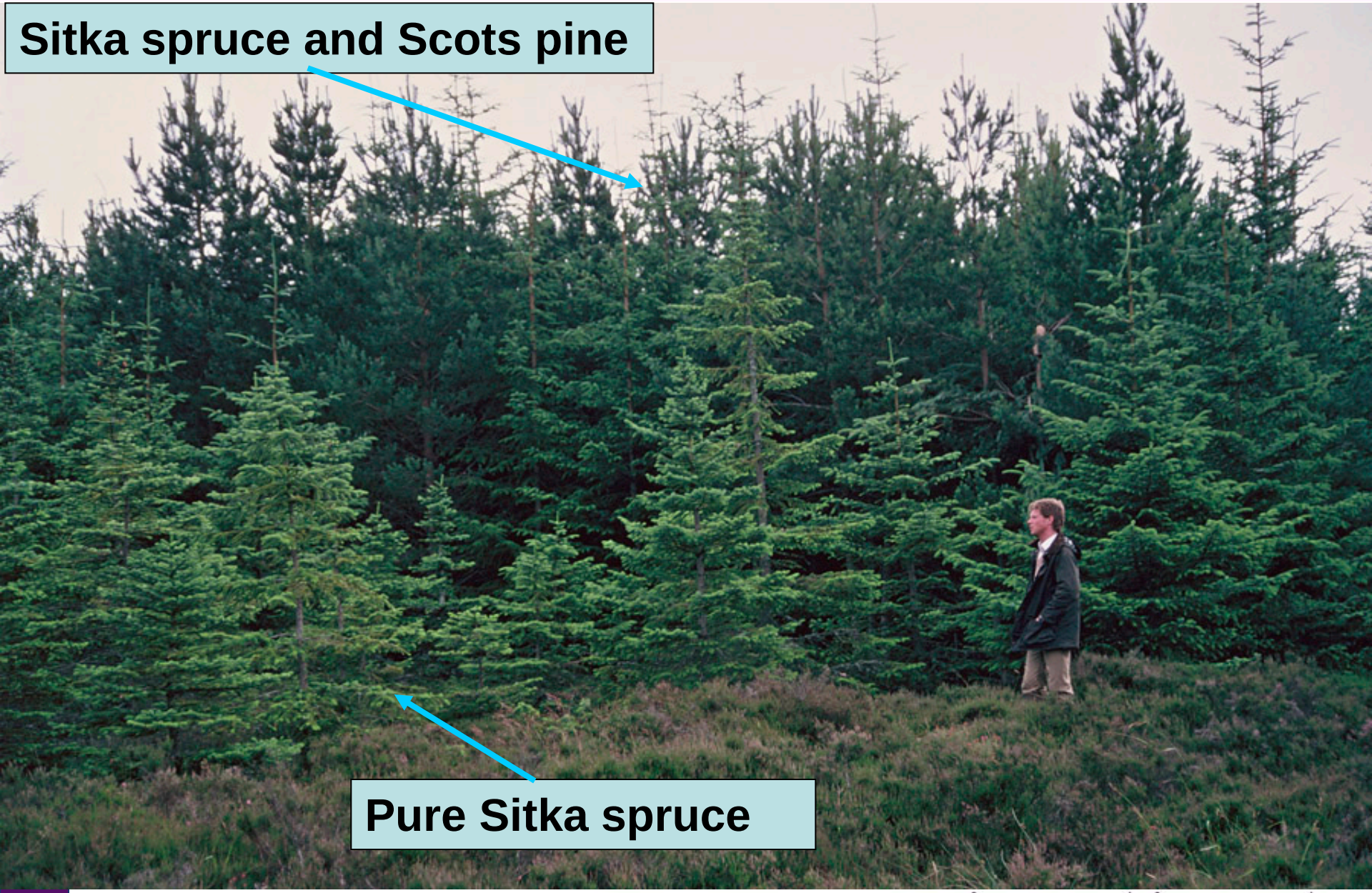
Culloden experiment at 15 years



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Causal mechanisms

- Greater litterfall and hence N content in mixed stands;
- More rapid turnover of N in mixtures due to greater microbial activity;
- Better aeration under mixed stands with deeper rooting;
- Enhanced N, P availability in soils in mixtures;
- Higher N concentrations in spruce in mixed plots due to soil availability;
- **Mycorrhizal associates of nurse species break down organic N – products available to spruce**.

Main references: Carey et al., ***1985***, Irish Forestry, 7-20; McKay & Malcolm, ***1988***, CanJForRes, 18, 1416-1426; Morgan et al., ***1992***, pp 65-85; Ryan & Alexander, ***1992***, pp 237-245. Williams, ***1992***, Plant & Soil, 144, 77-84; Williams, ***1996***, Plant & Soil, 182, 177-183; Cameron & Watson, ***1999***, Foreco, 122, 113-124.

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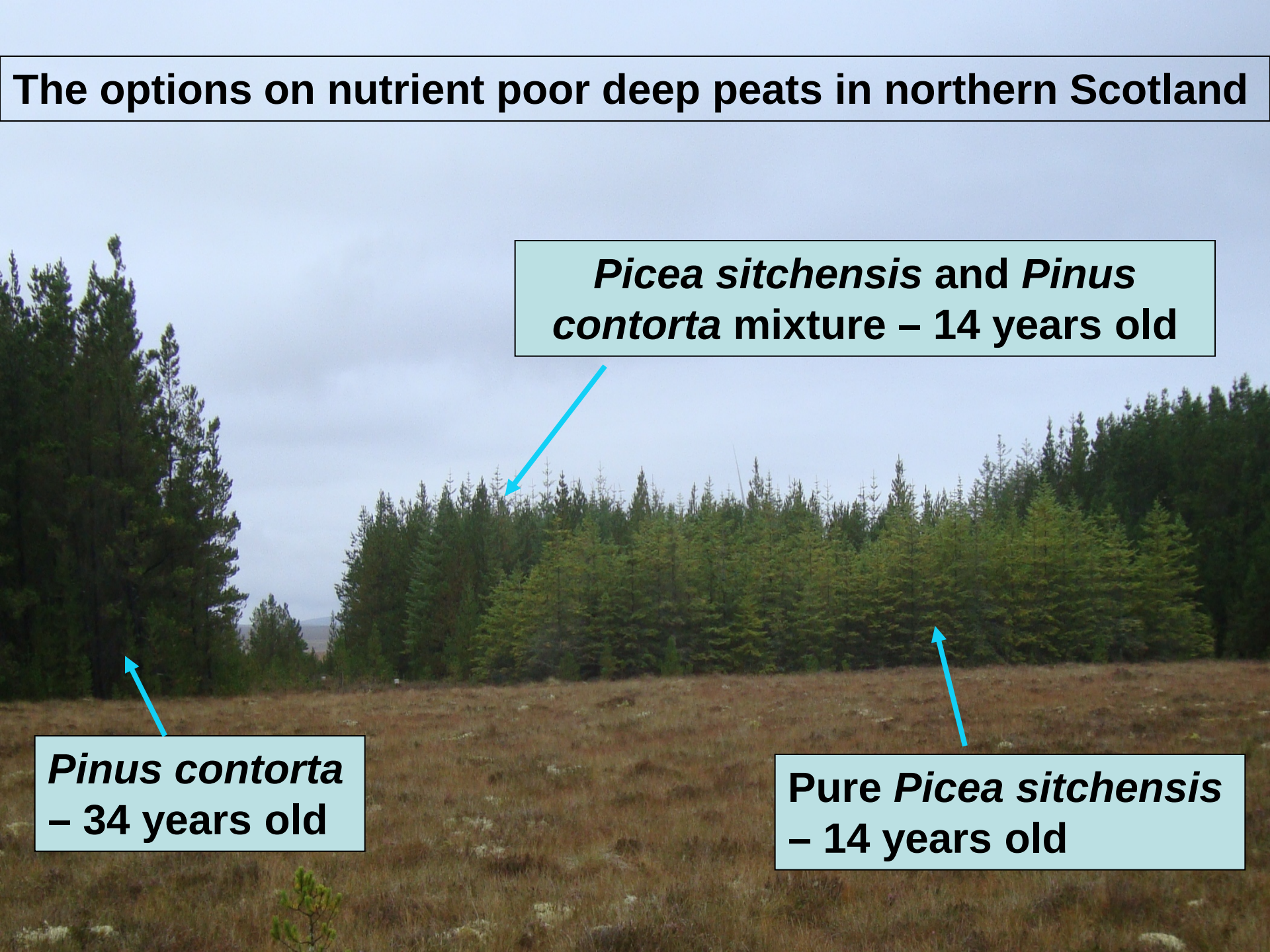
The options on nutrient poor deep peats in northern Scotland



Close-up of the two spruce plots

Estimated productivity

Calculated productivity (m^3 ha^{-1} yr^{-1})based on early height growth (m) of Sitka spruce pure and in mixture

These estimates suggested that private investors could make a good rate of return from planting mixtures on cheap land

Inchnacardoch	20	20	18	20	10
Strathy	20	12	12	8	6
Drumtochty	16	16	10	16	14
Culloden	18	-	16	-	10

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Large scale planting of Sitka spruce: pine mixes

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3. Reasons for the decline after 1990

Expansion into a sensitive landscape

‘Flow Country’ of northern Scotland

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Forestry expansion causes controversy – the Flow Country of North Scotland

Afforestation so fundamentally transforms the peatland ecosystem that it is effectively destroyed. […] In view of the importance of the peatland ecosystem, its replacement by a type of forest which is artificial and present over increasingly large areas of Britain […] amounts to a substantial net loss of nature conservation interest.

Birds, Bogs, and Forestry;
Nature Conservancy Council, 1988, section 6.6.

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Result of controversy

1. 1988. Government removes the tax concessions that had driven private sector new planting;
2. 1990 onwards. Move to towards direct grant payment for private sector planting with higher funding for environmental benefits (e.g. broadleaves rather than conifers)

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4. What has happened in these experiments since the 1990s?

Process

1. **2010 onwards** – revisit the experiments and make a (final) assessment;
2. **Two main questions**:
    1. Had the growth projections of the 1980s been fulfilled?
    2. Was there evidence of overyielding in the mixtures?
3. Also consider the **implications for sustainable management of planted spruce forests** on nutrient poor soils in Scotland

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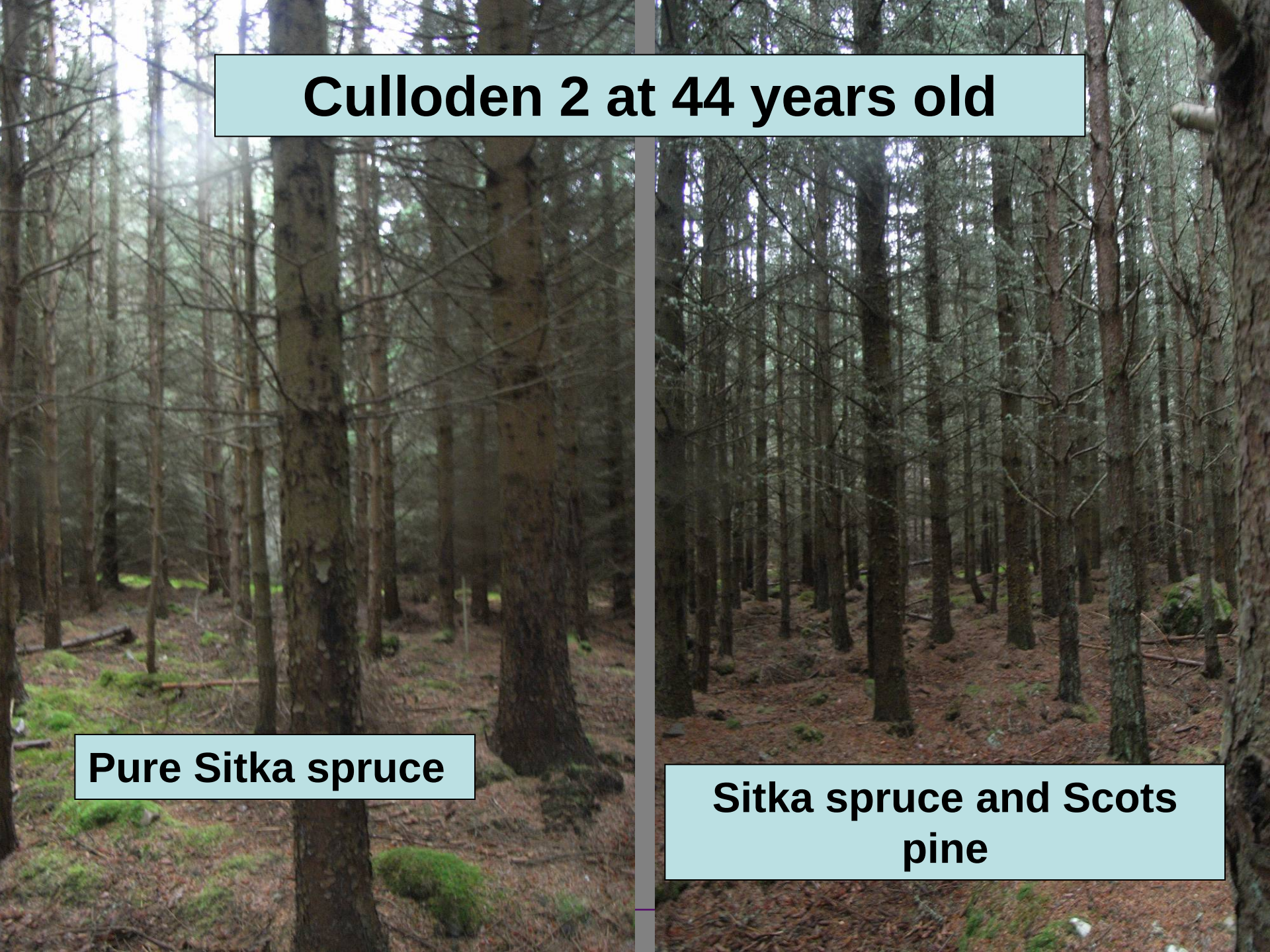
Culloden 2 at 44 years old



Pure Sitka spruce

Sitka spruce and Scots pine

Results in the 21st century (1)

Height growth (m) of Sitka spruce pure and in mixture at close to rotation age

Except on the most nutrient poor site (Strathy), mixture benefits are less than were found at canopy closure

		larch	pine		N		
Inchnacardoch	45	21.4	20.6	20.9	19.2	ns	3.7
Strathy	47	18.3	20.3	19.7	8.9	***	2.3
Drumtochty	44	26.1	22.8	23.5	24.0	*	2.2
Culloden	42	-	24.0	-	21.9	*	1.9

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Results in the 21st century (2)

1. **On the 3 poorer sites, basal area of the mixed stands still higher than pure Sitka spruce unless latter is boosted by intensive N inputs.**
2. **Mixtures are self-thinning towards spruce dominance**

Tuoch		(87%)	(70%)				
Strathy	47	36.3 (100%)	70.8 (30%)	64.6	17.8	***	13.6
Drumtochty	44	77.1 (78%)	72.0 (93%)	76.4	74.3	ns	10.7
Culloden	42	-	64.6 (67%)	-	43.7	*	15.6

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Achieved productivity

Treatment productivity (m^3 ha^{-1} yr^{-1}) at rotation age of Sitka spruce pure and in mixture

No consistent evidence of under or over-prediction of productivity

Site	Age	SS and larch	SS and pine	SS plus N	SS minus N
Inchnacardoch	45	**14** (20)	**14** (18)	**14** (20)	**12** (10)
Strathy	47	**12** (12)	**14** (12)	**12** (8)	**<6** (6)
Drumtochty	44	**20** (16)	**16** (10)	**16** (16)	**16** (14)
Culloden	42	-	**18** (16)	-	**16** (10)

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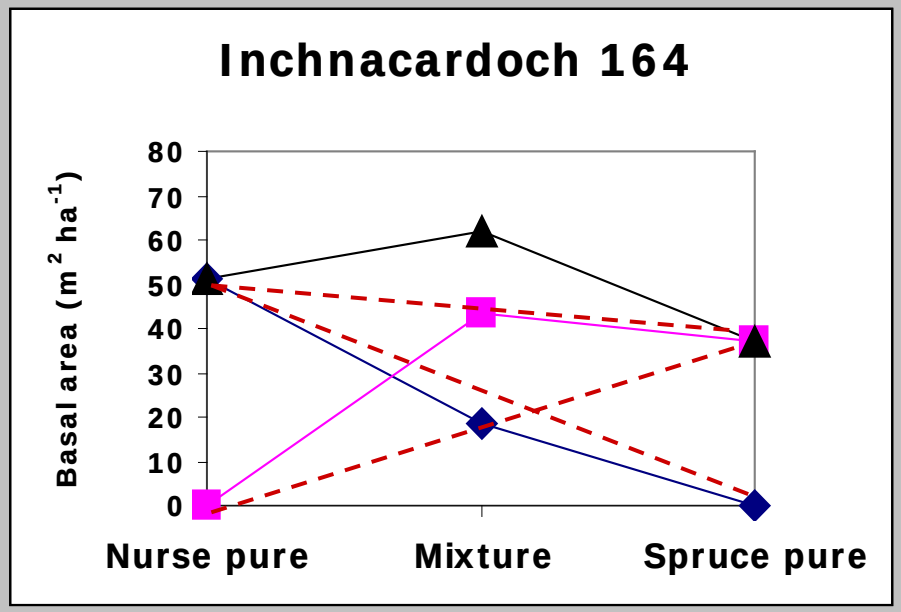
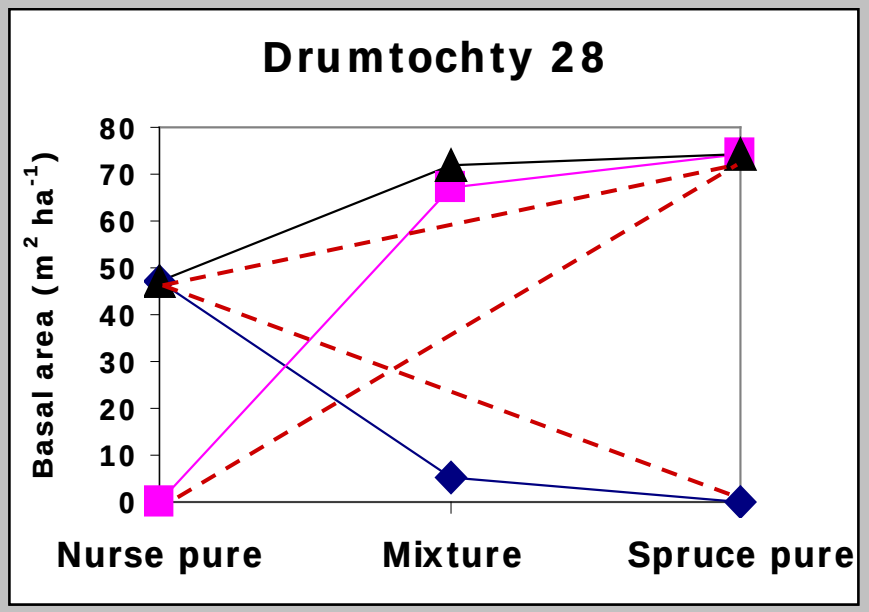
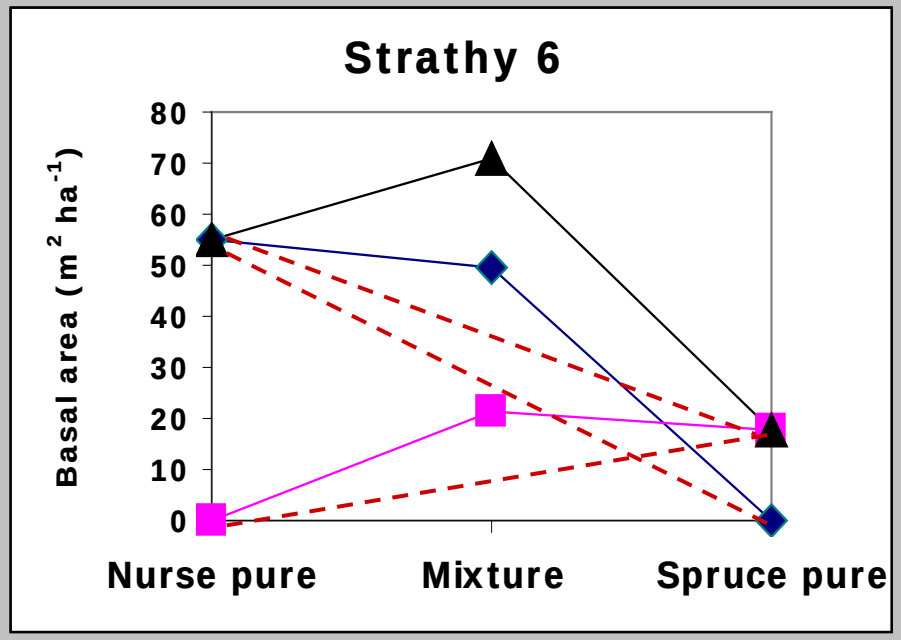
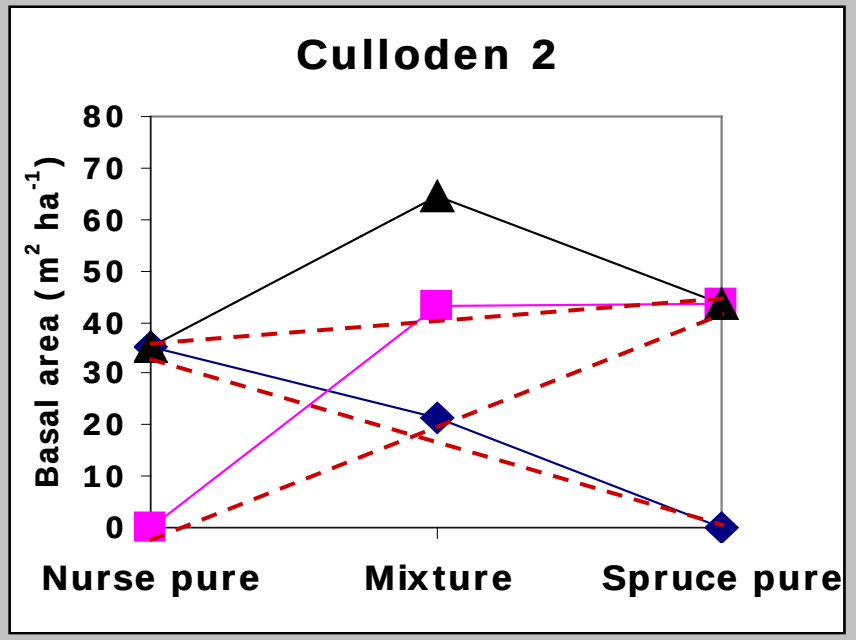
Analysis of overyielding

Black=Total, Blue=pine, Mauve = spruce









Conclusions

1. **Overyielding** is found at **all sites** (i.e. the mixture performs better than the average of the two species);
2. **Transgressive overyielding** found at the **three poorer** sites (i.e. mixture performs better than the more productive of the pure species);
3. There is **facilitation between species** at time of canopy closure, reflected in improved N nutrition;
4. After canopy closure, **competition between species** favours the more shade tolerant spruce with greater leaf area:
5. Predictions of productivity at canopy closure **did not overestimate** eventual outcome.

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Knowledge gaps

- What happens to the beneficial mycorrhizal species after canopy closure and/or after harvesting?
- Do the mixtures have any impacts on timber quality;
- Does the mixture effect require a minimum percentage of the nurse species (15%?);
- Does the nurse provide any benefit for the root anchorage (and wind stability) of the spruce?
- How to incorporate this effect in models of stand growth and/or in guidance on species choice?
- Others ….

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Practical implications

1. On nutrient poor soils in northern Britain, the use of nursing mixtures offers a way of maintaining yields without intensive inputs;
2. Reflected in current guidance that mixtures of lodgepole pine and Sitka spruce should be a preferred option for replanting forests on nutrient poor soils;
3. The results emphasise the difficulty of predicting mixture performance from growth of pure stands (hence the need for networks like EuMIXFOR);
4. Potential vulnerability of the nurse species to deer browsing may need to be carefully managed.

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Mixtures are good for wildlife too: northern Goshawk chicks in a mixture experiment in northern Scotland