Bill Bealey
& Mark Sutton
Centre for Ecology & Hydrology

Agroforestry Systems for Ammonia Abatement (SAMBA)

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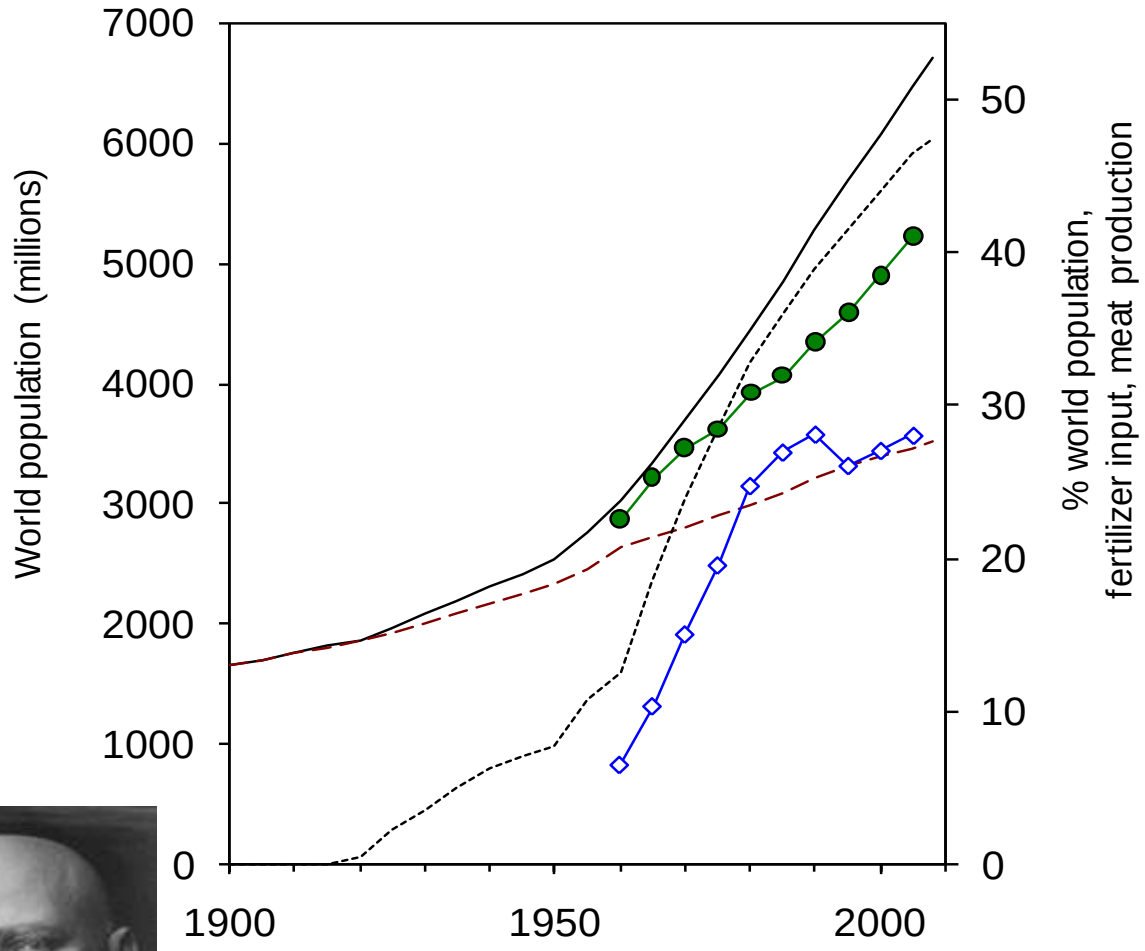
Ammonia feeds the world



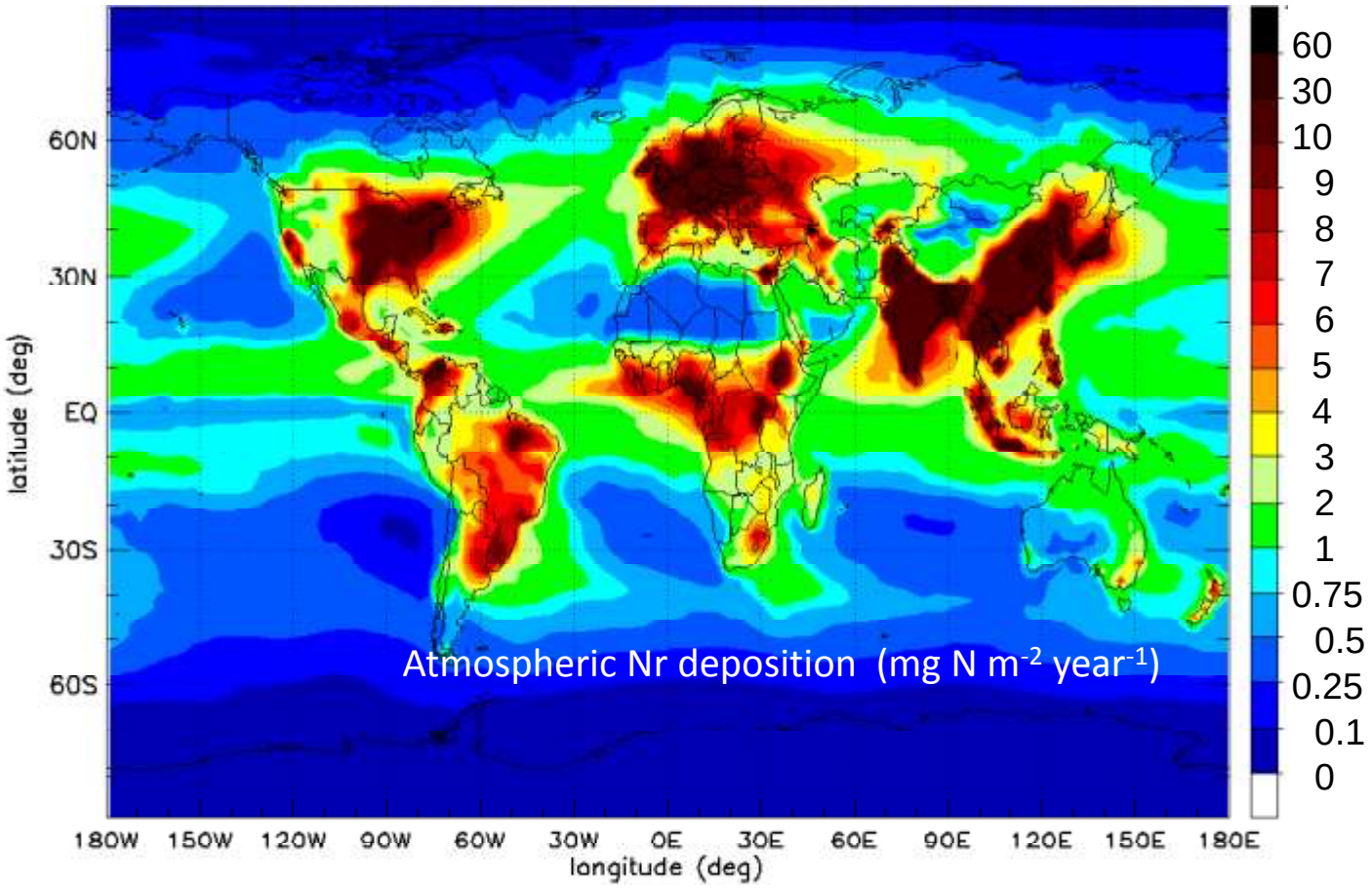
& Hydrology

Erisman et al. 2008 Nature GeoScience

Global N_r production and dispersion

Human N_r Production: ($Tg\ yr^{-1}$)
1860: 15
1995: 156
2005: 191

2005 sources:
Haber Bosch: 121
Biol N fixn: 45
NOx emission: 25



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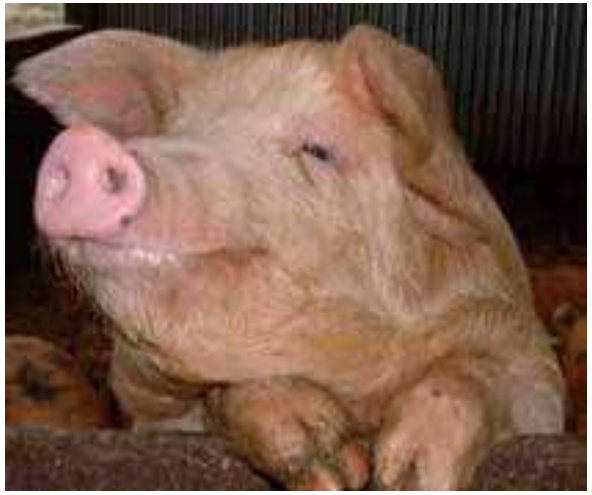
Galloway et al. 2008 Science

Ammonia Sources

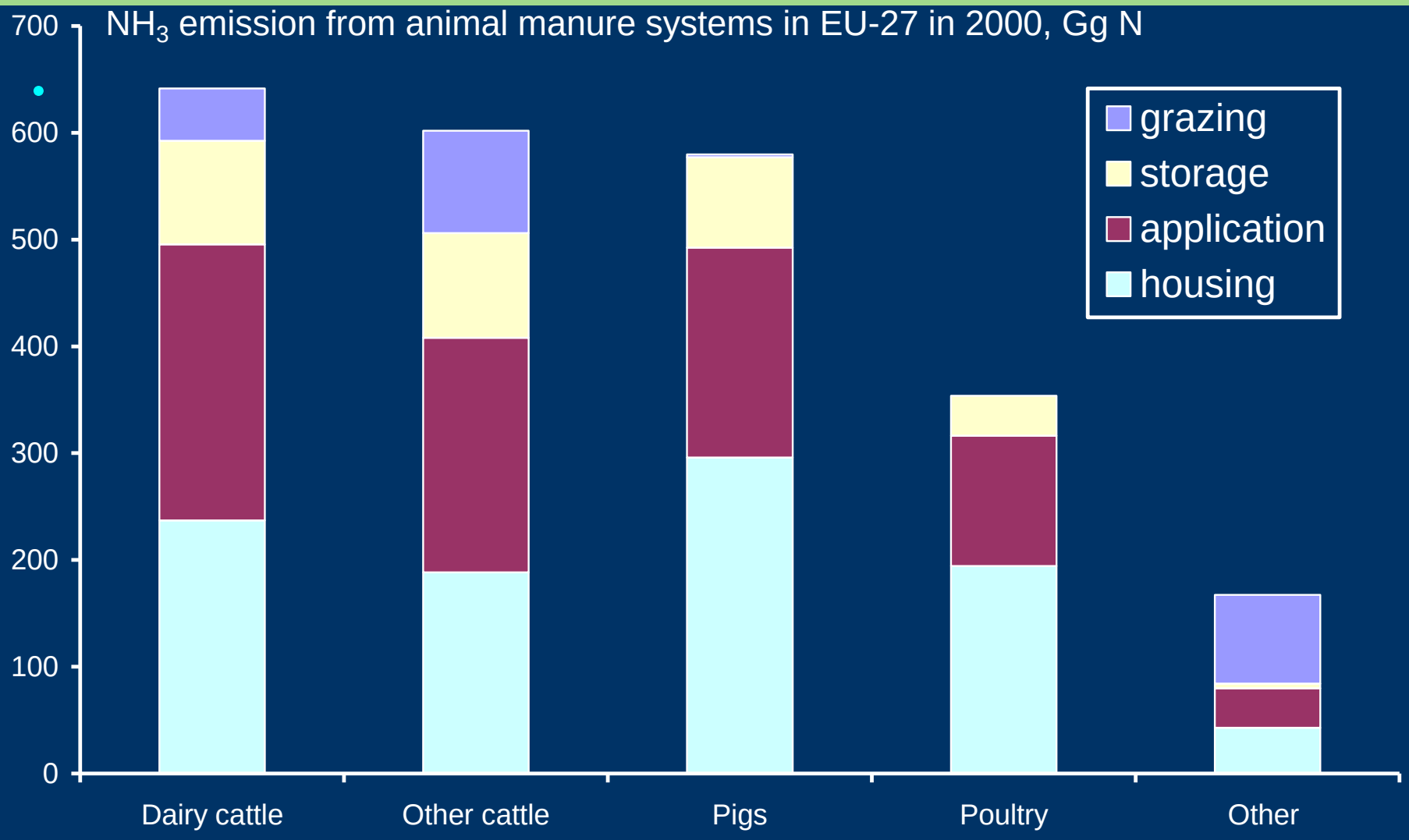


25,939,838 Layers in the UK (2008)
(38% free-range)
109,858,933 Broilers

420,588 sows in the UK (2008)
2,993,583 fatteners in the UK (2008)
(various weights)

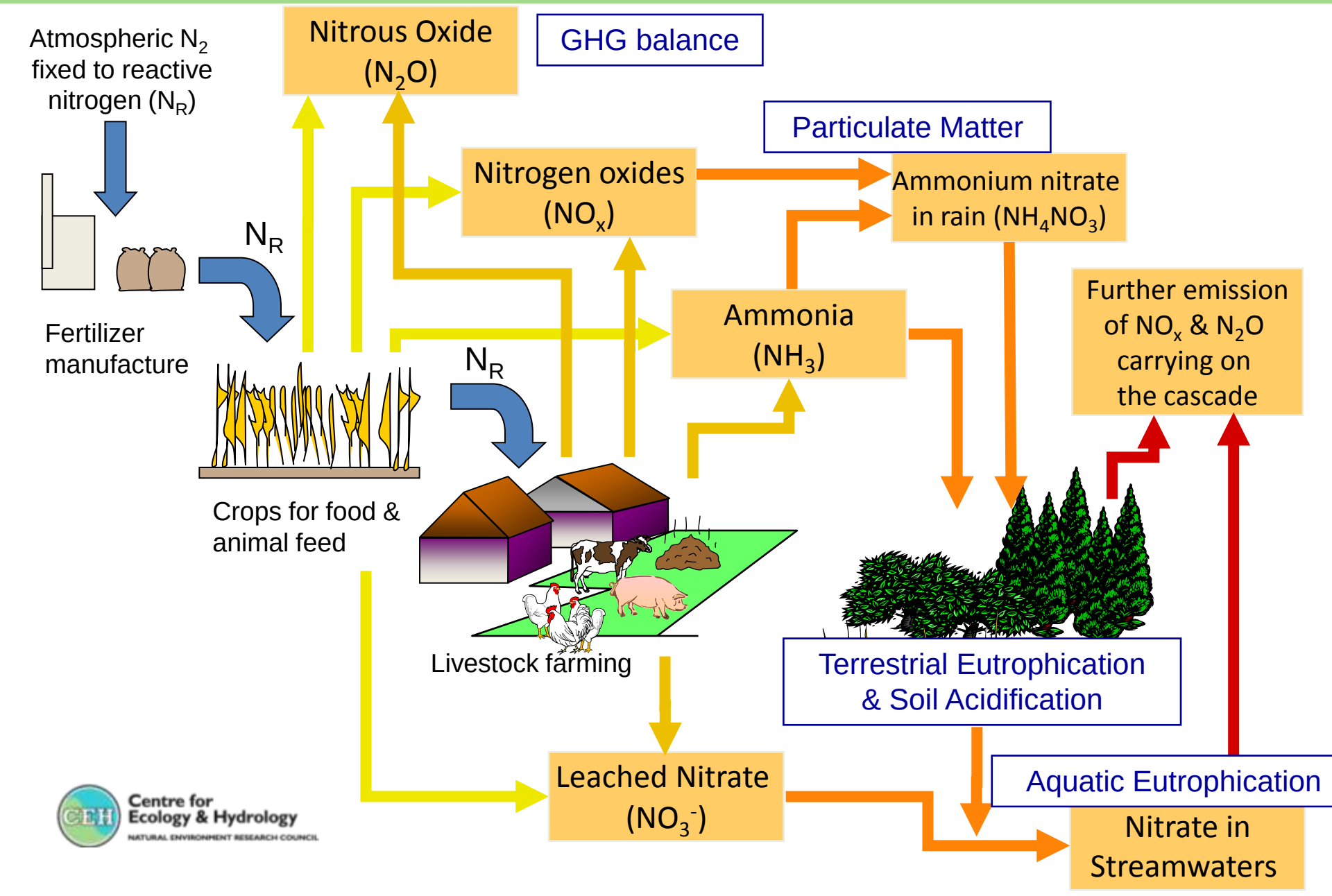
Centr
Ecolo

Animal manures the main source of ammonia



Plus 10% from fertilizers + 10% from other sources

The Nitrogen Cascade



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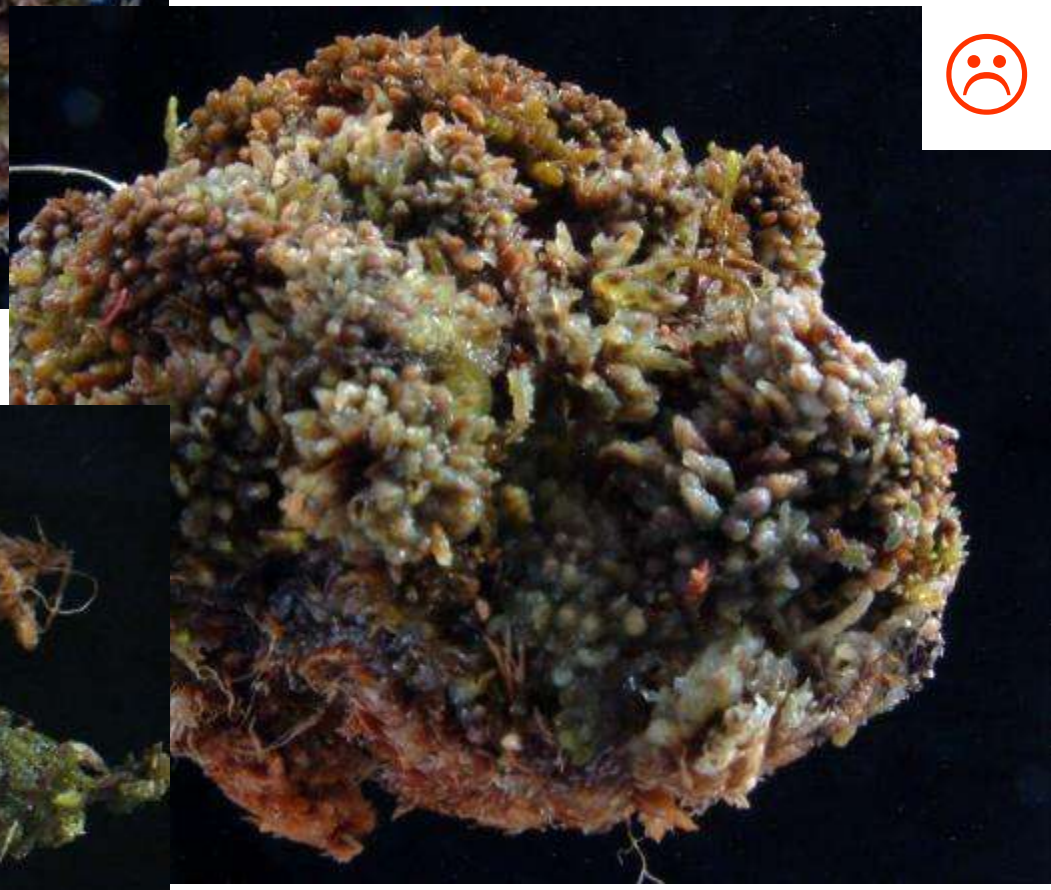
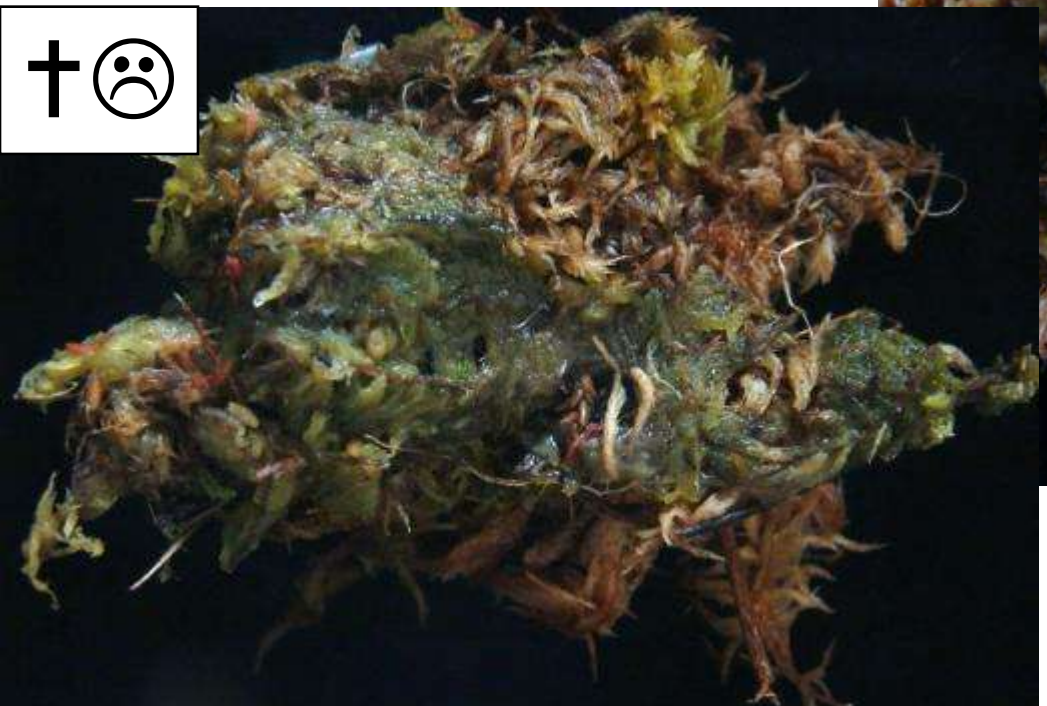
Ammonia Impacts on biodiversity

Lichen: Cladonia uncialis

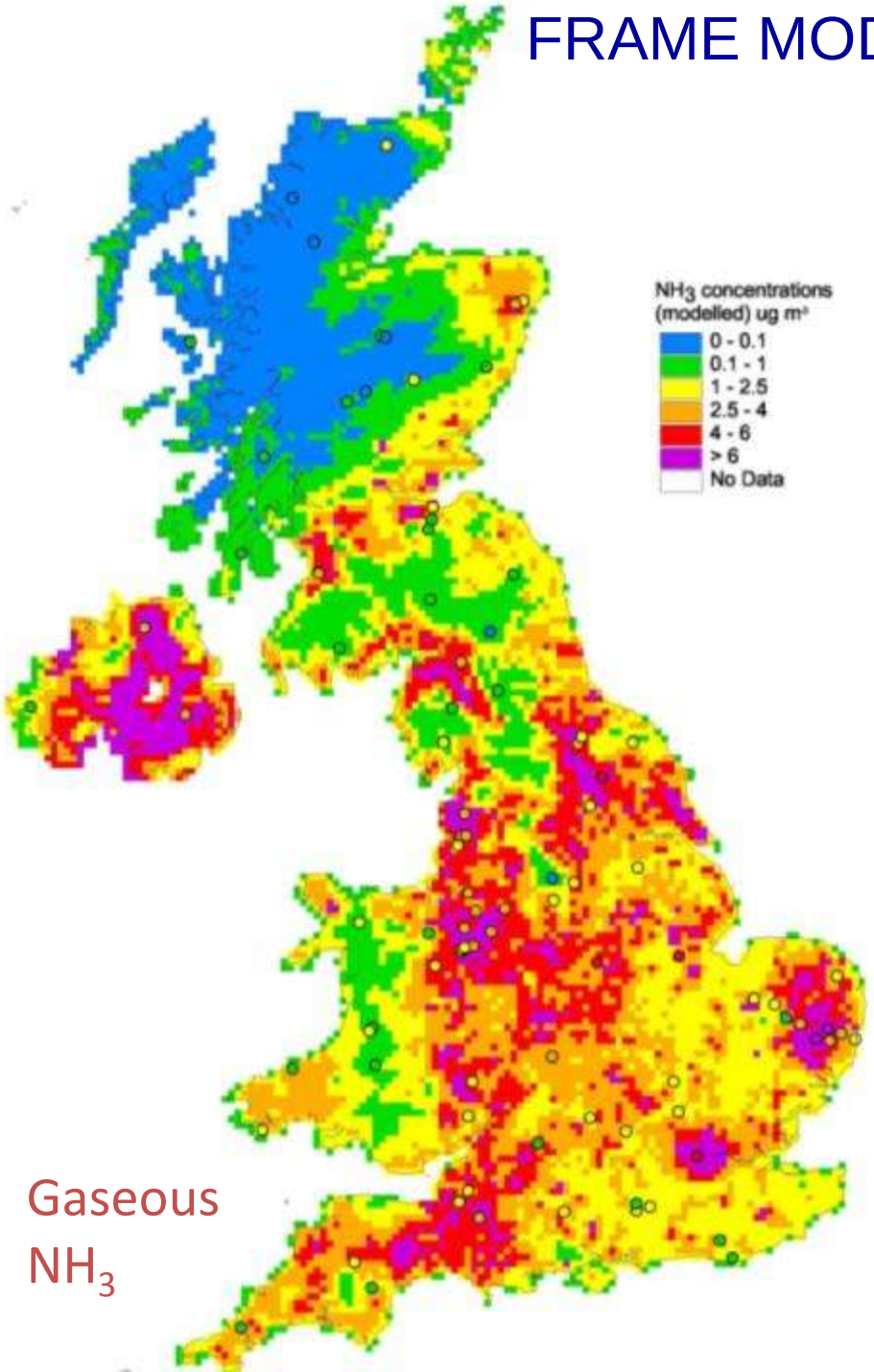

Lichen: Cladonia portentosa
Site 17

Bog moss
Sphagnum imbricatum



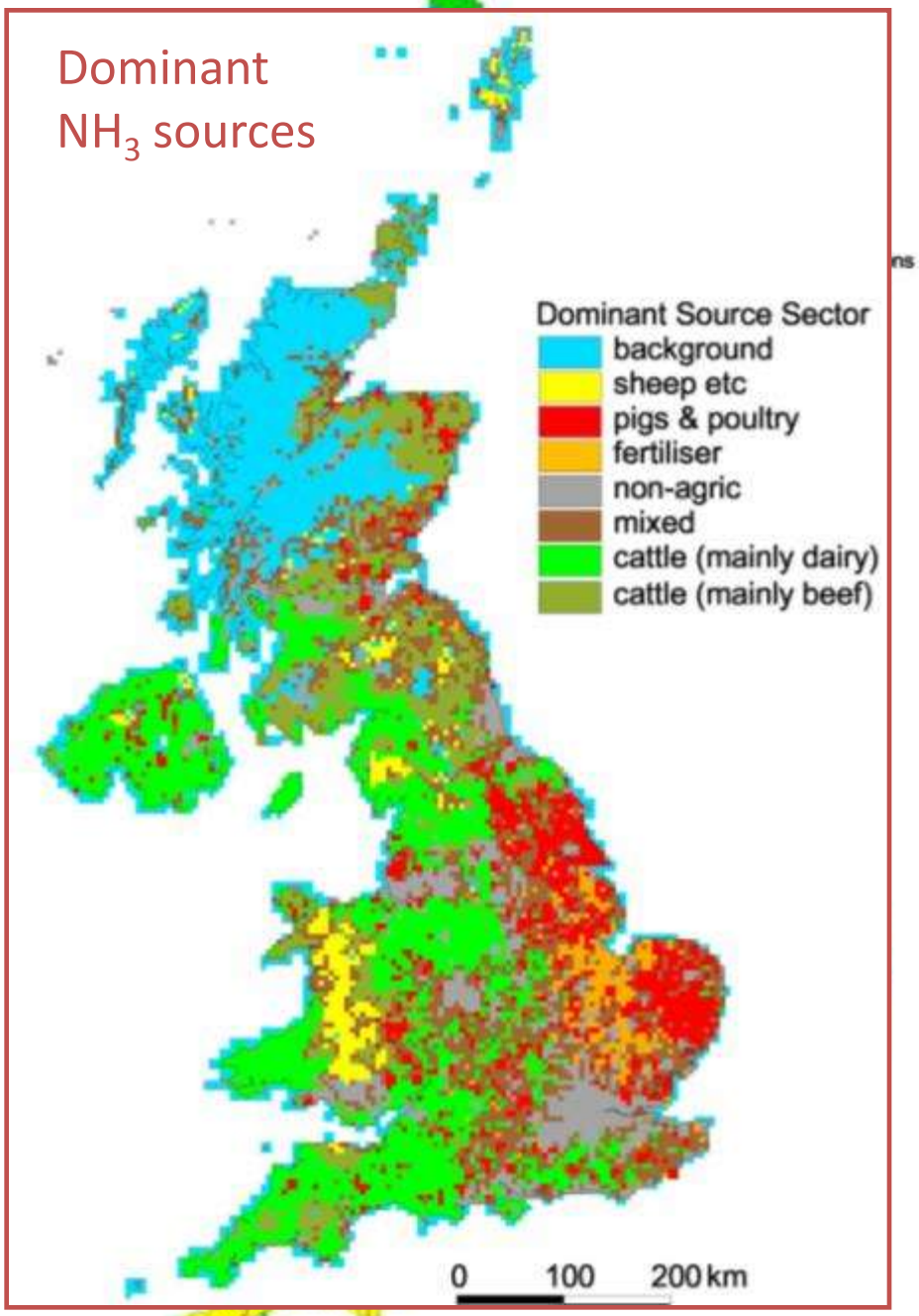


FRAME MODEL & UK NETWORK

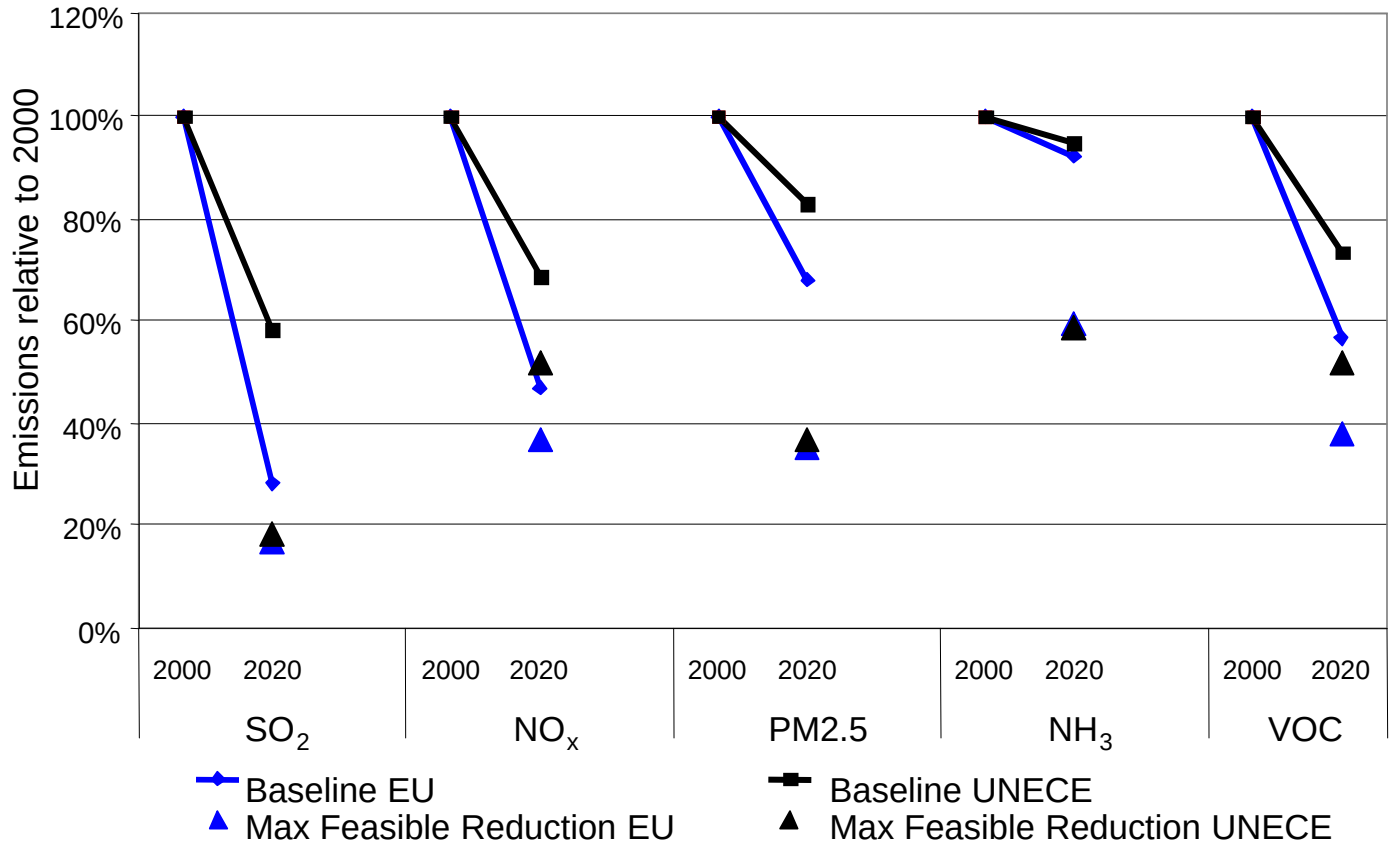


Gaseous
NH_3

Dominant
NH_3 sources



THE SUCCESS OF EUROPEAN AMMONIA POLICIES



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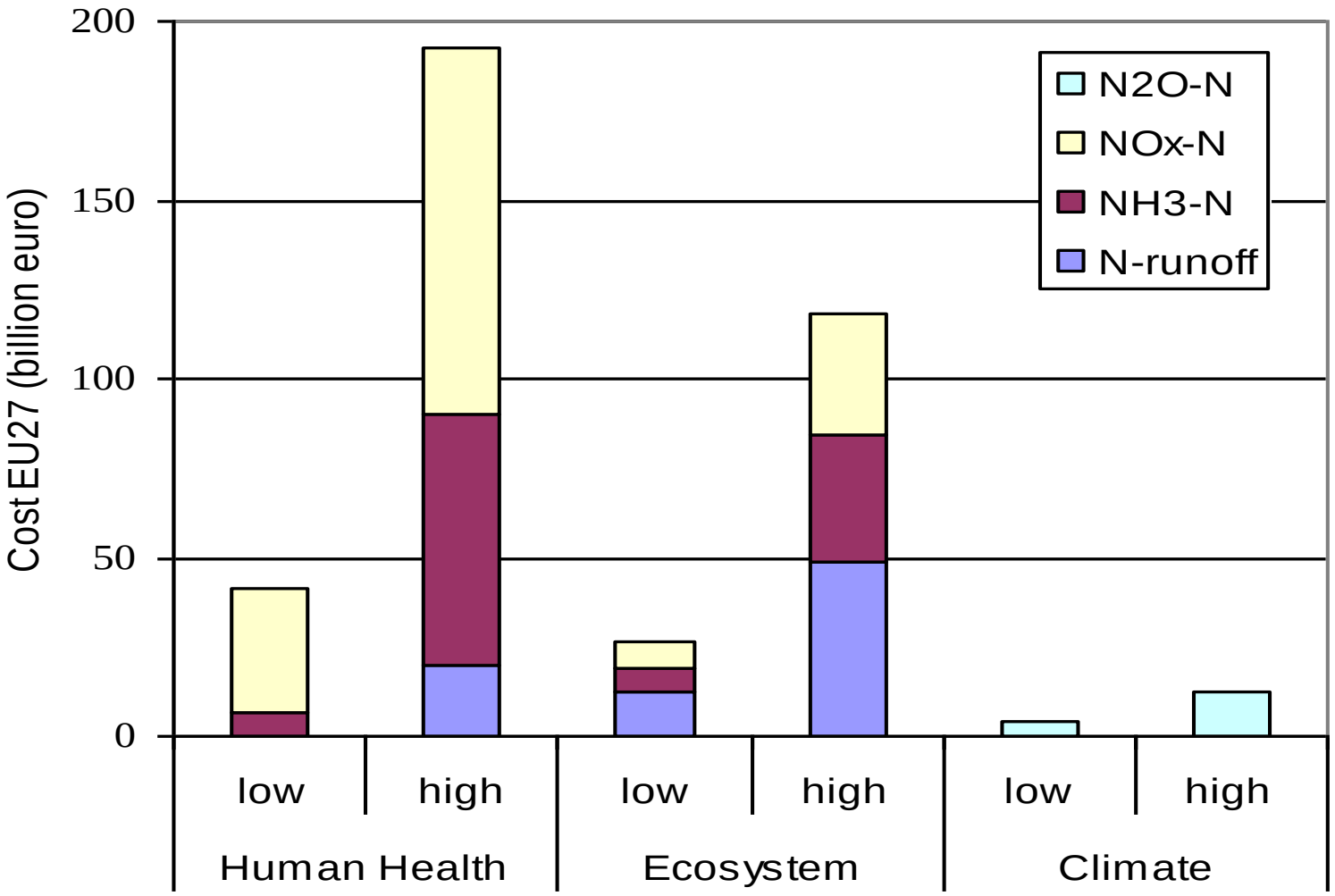
LRTAP
Long-range Transboundary Air Pollution

Social damage of nitrogen pollution in EU27 in 2000



European Nitrogen Assessment (2011)
Plus UNECE CLRTAP-WGSR-47 documents

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Regulation in the UK

- IPPC Directive – Integrated Pollution Prevention Control

- NECD – National Emission Ceiling Directive (297kt NH_3)

- The Habitats Directive

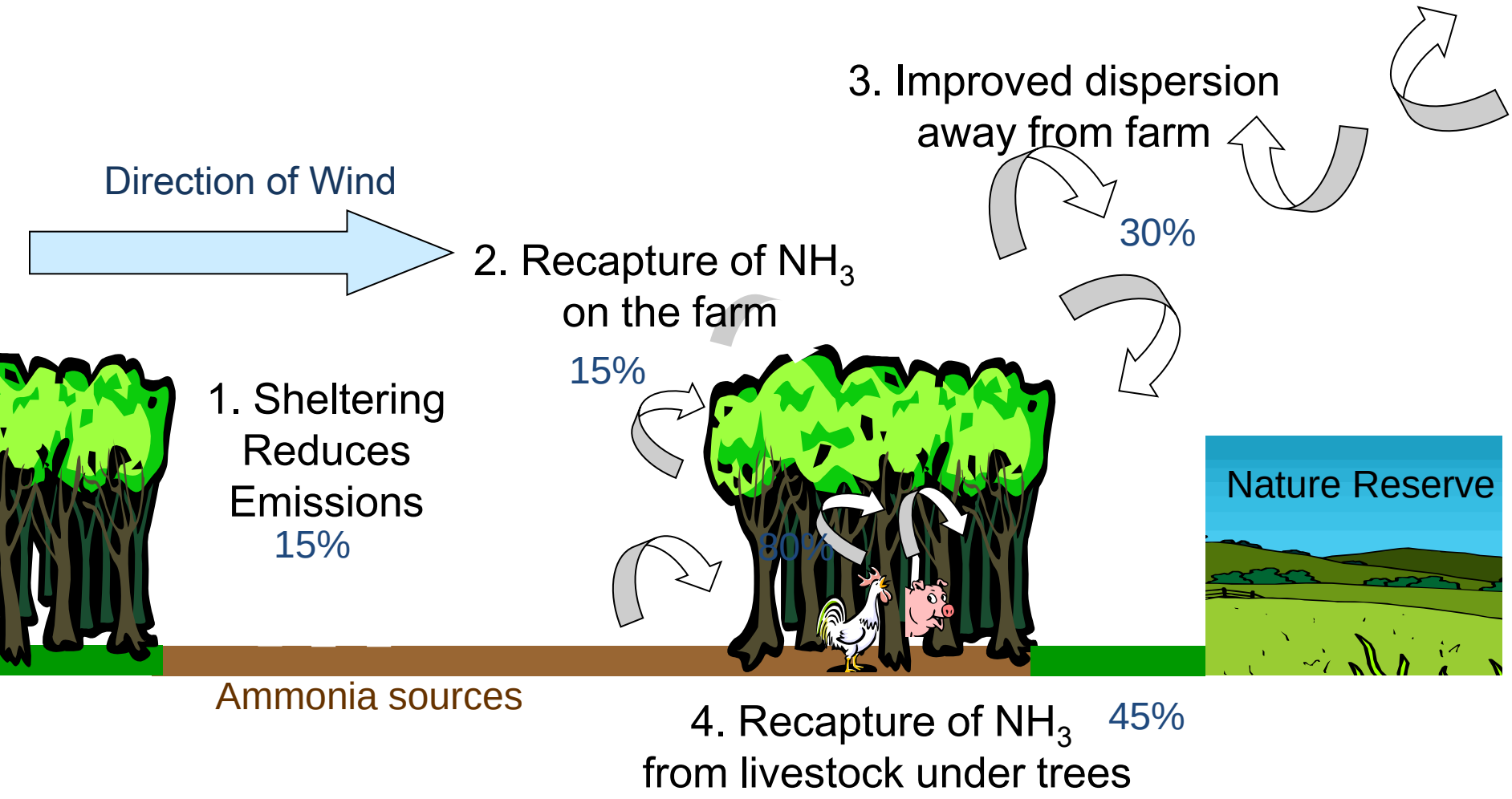
- CLTRP – Convention on Long-Range Transboundary Pollution

SAMBA Objectives

To assess the potential of the different abatement measures:

a) *Re-capture* & *increased dispersion* by shelterbelts and similar woodland features: *quantification >> measurements & modelling*
b) *Animals under trees* (**silvo-pasture**): demonstrate practical feasibility of ammonia abatement through case studies

Four-way benefit of trees for ammonia mitigation



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Daniela Famulari

C. Braban, M. Coyle, C. Helfter, E. Grigorova, E. Nemitz, S. Leeson, M.A. Sutton, S. Y. Tang, M. Twigg, M. Theobald, A. White
Centre for Ecology & Hydrology

A. Robertson
Birmingham University

Agro-forestry experiments

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QUANTIFYING NH_3 RECAPTURE BY TREE BELTS

Side view of the Air Flow Lab (Silsoe)

Front view

- 28 *Picea Abies* (2m tall) on 5 rows, straw bales as floor
- 16 Growth lights for photosynthetic activity
- Variable temperature and RH, measured continuously

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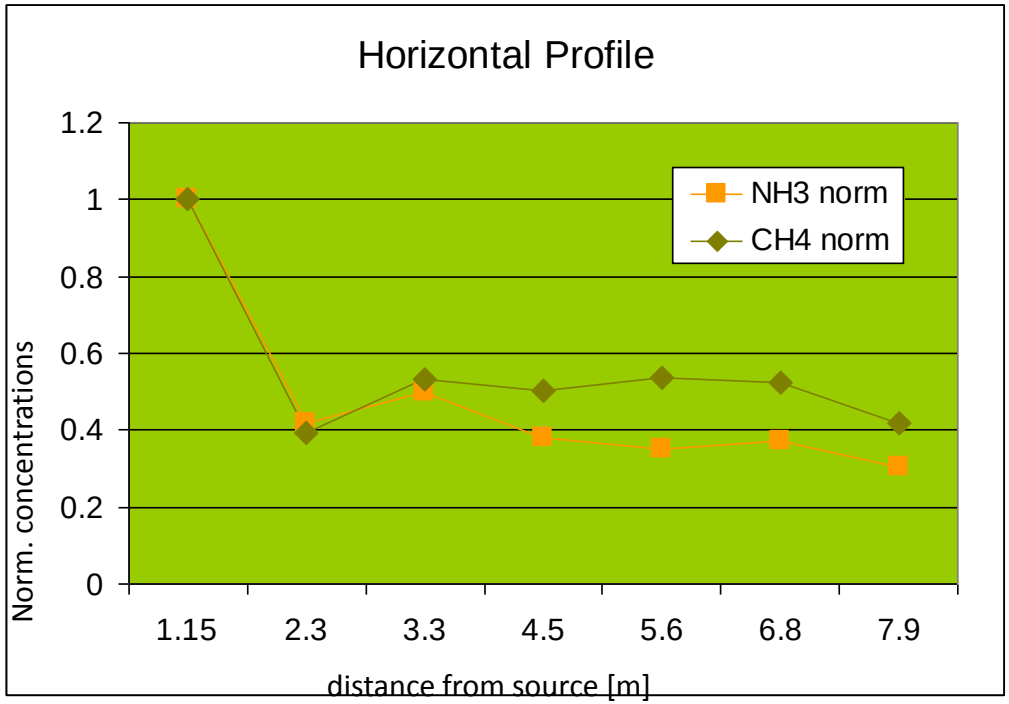
QUANTIFYING NH_3 RECAPTURE BY TREE BELTS



- Normalised concentrations of NH_3 and CH_4 at increasing distances from the source
- Factors of NH_3 recapture range between 2% and 18%

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NH_3 ABATEMENT BY SILVO-PASTORAL PRACTICES

Noble Foods: Din Moss Farm

Noble Foods: Freuchie Mill Farm

FAI Farm

2 transects at each farm: one wooded downwind one clear

Measurements made July 2009 – January 2010

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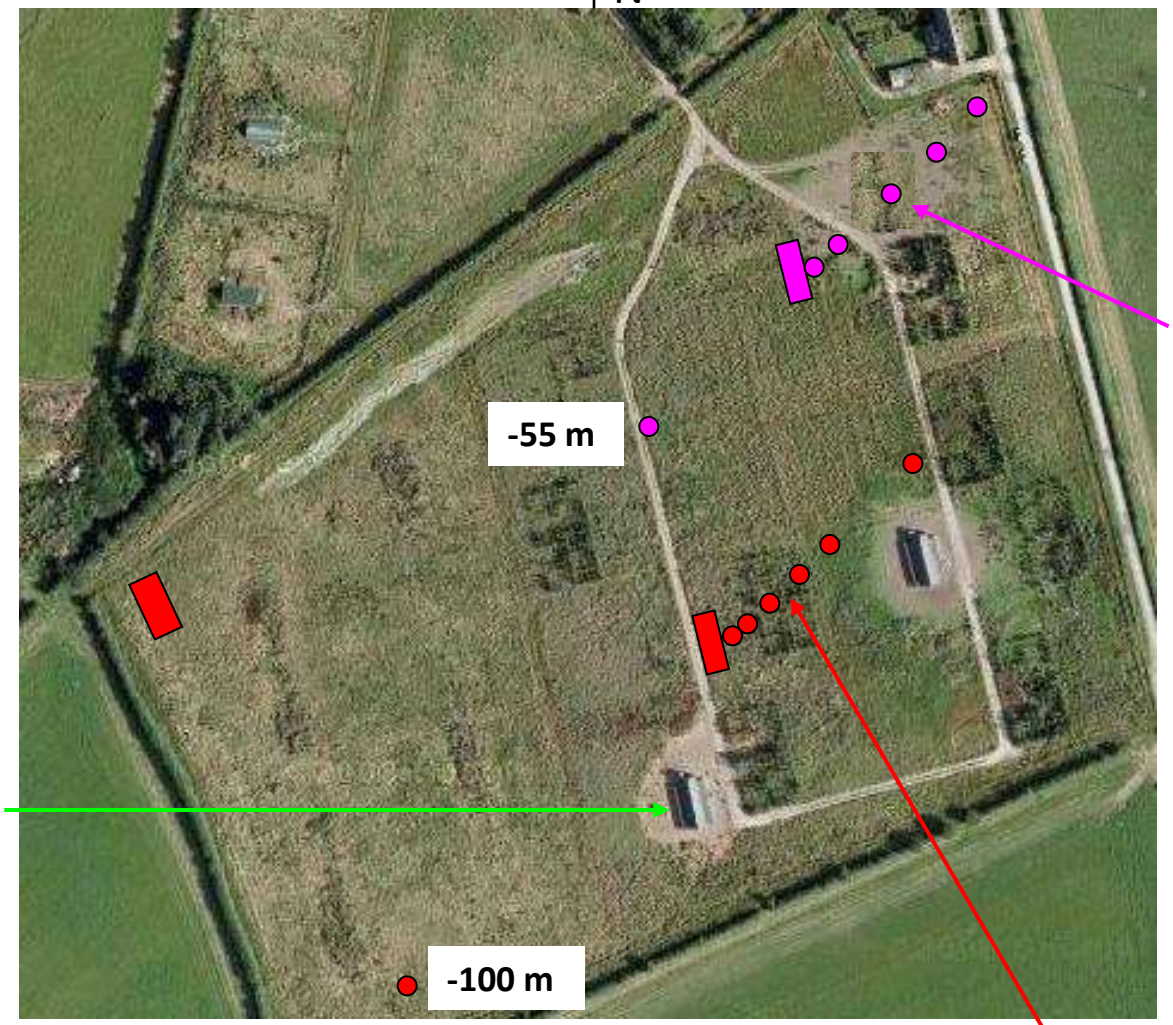
FAI Farm : With thanks to Paul Cook. Janet Coleman, Mike Colley and other FAI staff



PINE experiment site.
Houses cycled every 100 days.

Open: House JA9
Downwind Transect:
7, 15, 30, 50, 77m

Empty

Woodland: House JA8
Downwind Transect:
2.5, 5, 10, 20, 30, 50m

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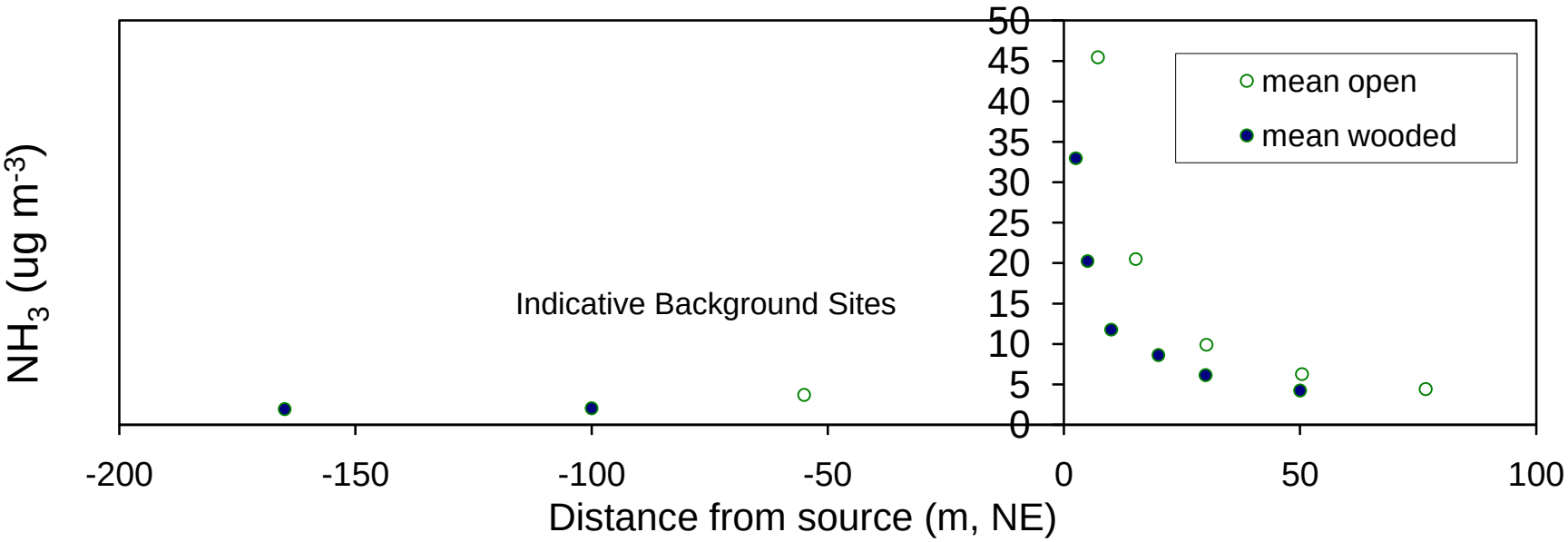
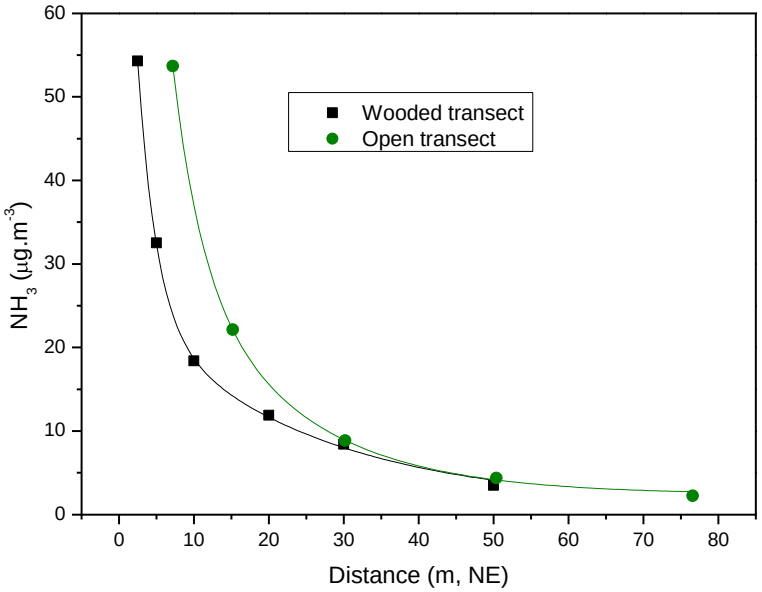
Results from full measurement period: Wytham



- NH_3 concentrations significantly lower for each measurement period
- 10-25% less ammonia on open transect beyond trees



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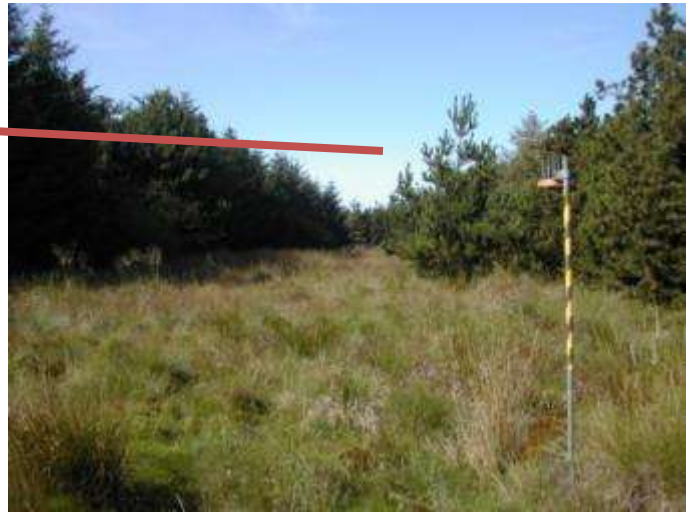
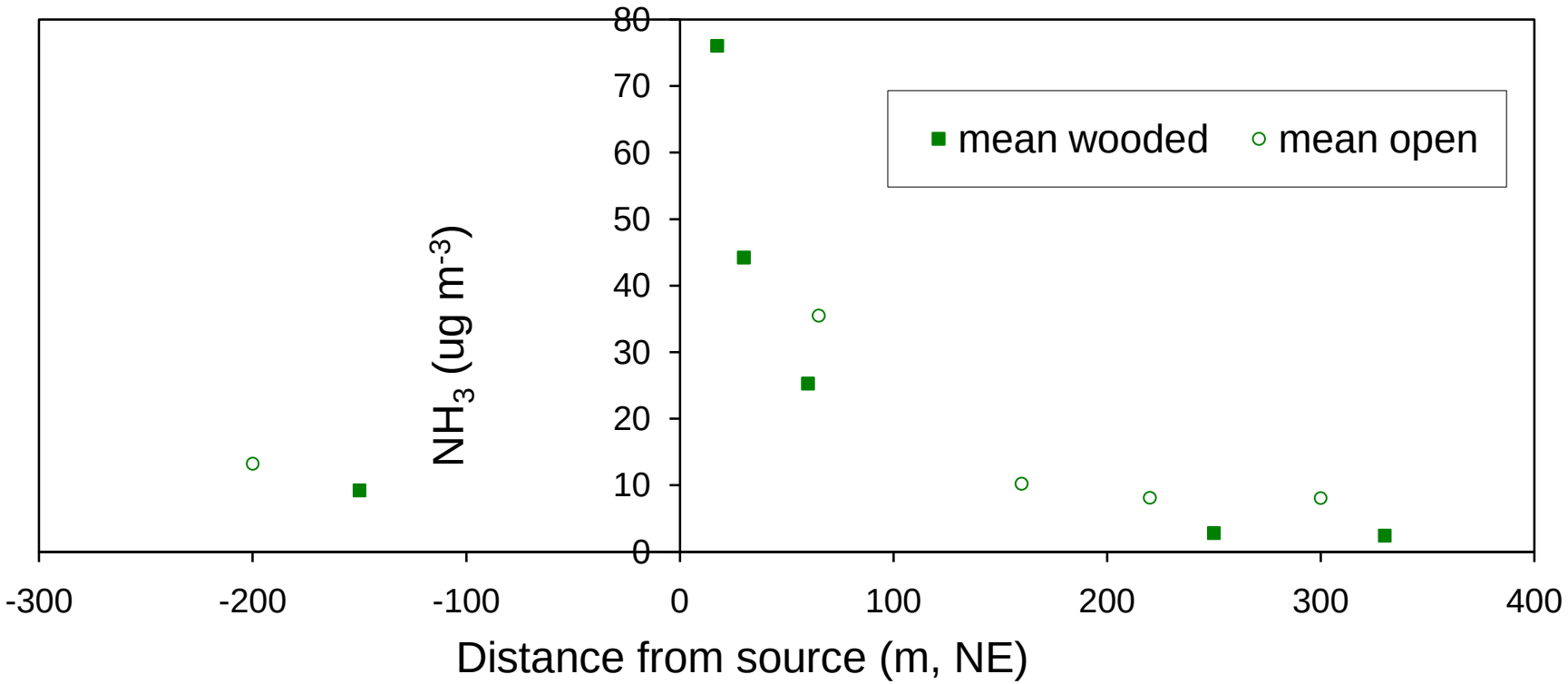
Fife Woodland Chicken Farms: Din

Poultry houses in pre-existing conifer woodland: two contrasting transects



Din Moss conifer Transect



- Comparison between open and wooded transect difficult due to complex background (see "background" measurements on LHS of graph)
- Wooded transect ammonia concentration is at regional background level at > 250 m compared with open transect which is still ~ 10 mg..m-3
- Detailed modelling of site will allow recapture and dispersion effect to be seen more clearly.

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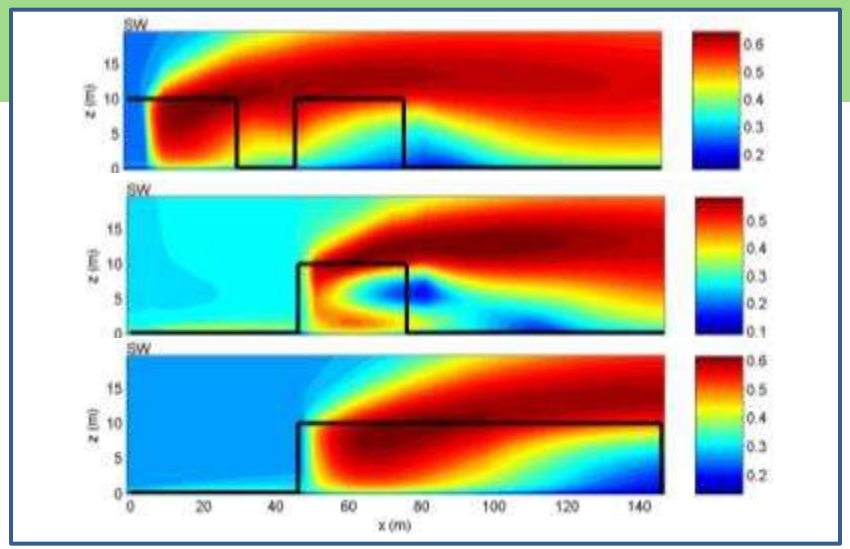

Benjamin Loubet
French National Institute for Agricultural Research
Bill Bealey
Centre for Ecology & Hydrology

Modelling the recapture efficiency of farm woodland structures

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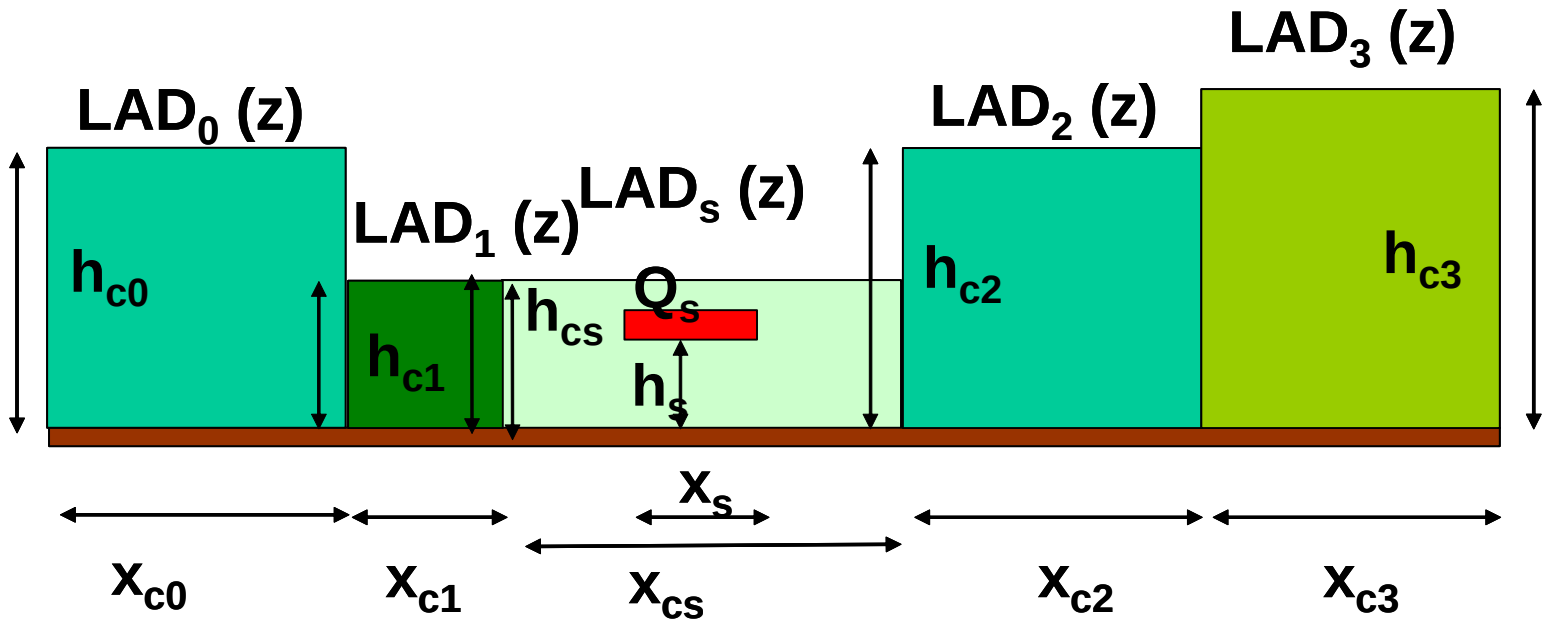
MODDAS & AQUILON MODELS - General Scheme

General scheme of the woodland and source geometry that will be tested.



MODDAS - **MO**del of **D**ispersion and **D**eposition of **A**mmonia over the **S**hort-range in two dimensions

AQUILON - is a turbulence model designed for within canopy transfer *(Foudhil et al 2006)*

LAD – Leaf Area Density
(LAI – Leaf Area Index)
h – height
X – width of canopy
Xs –source width
Q – source strength

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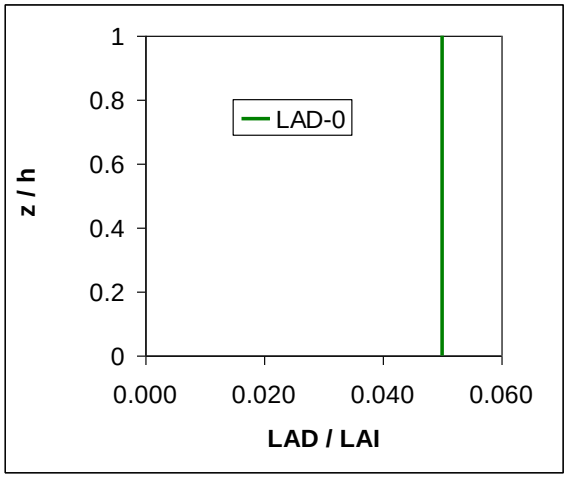
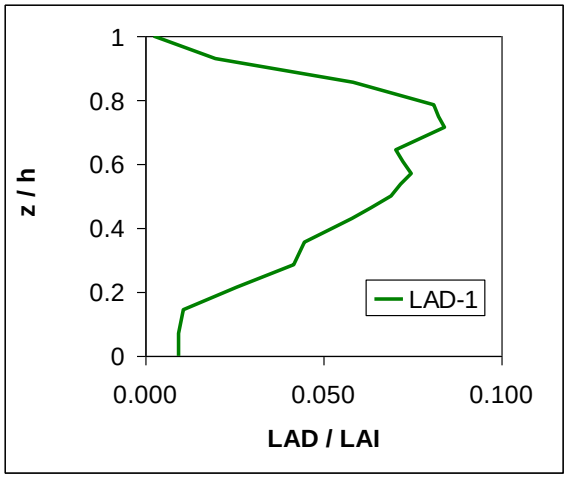
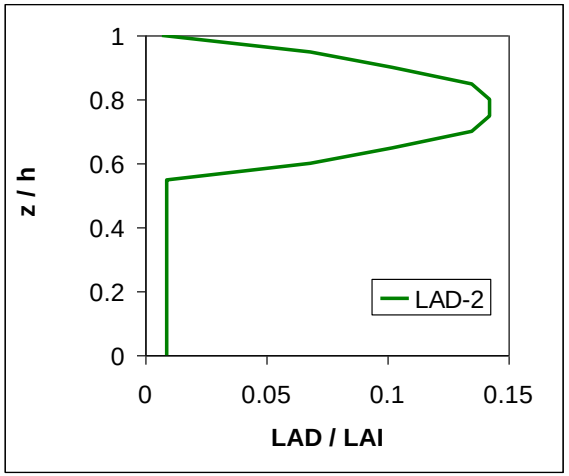
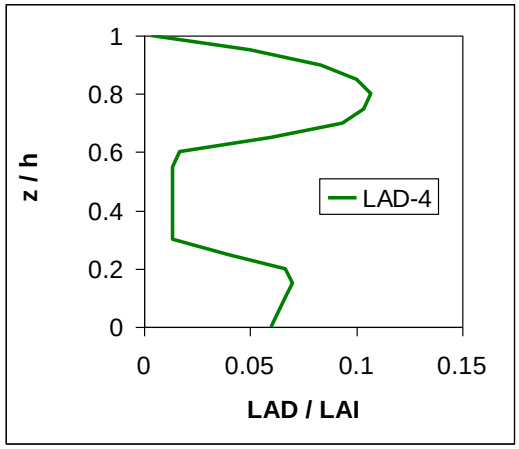
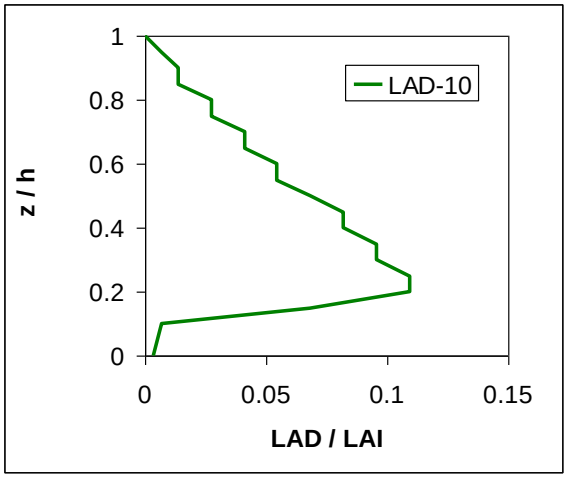
Trees characteristics - LAD











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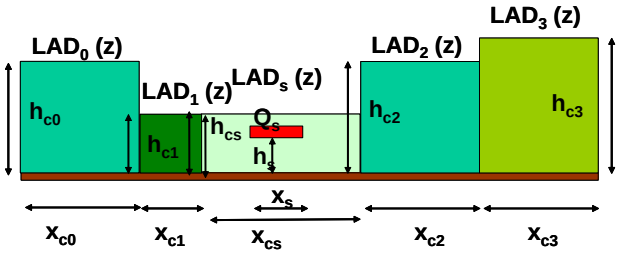
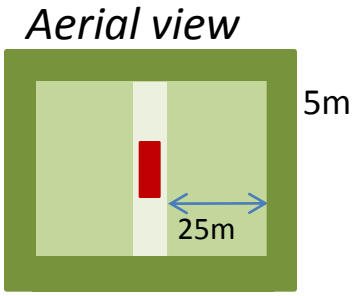
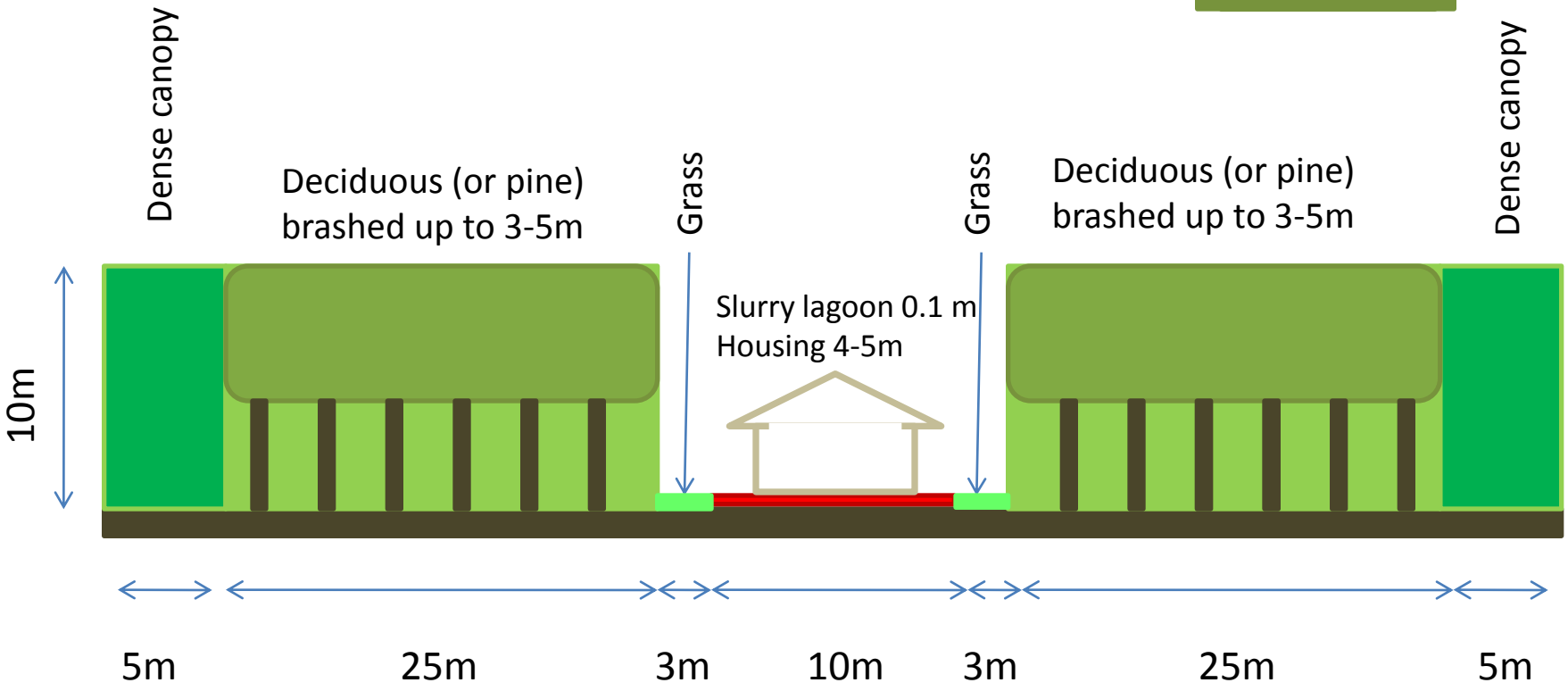
SCENARIO 1: SLURRY LAGOON/HOUSING







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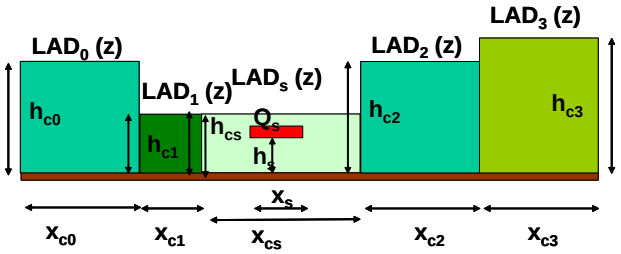
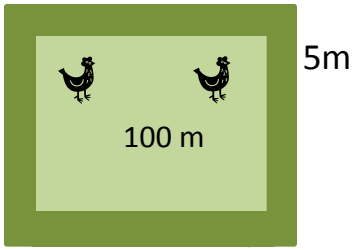
SCENARIO 2: CHICKENS UNDER TREES



Aerial view

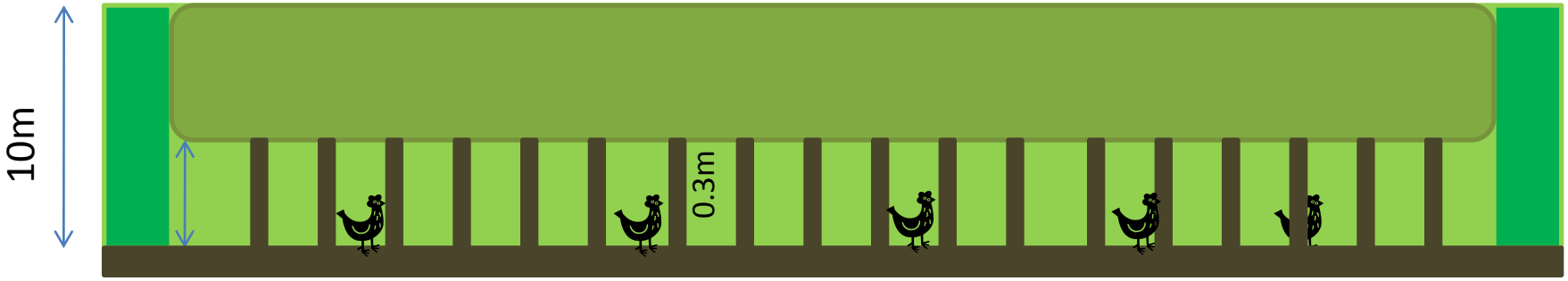


Dense canopy

Deciduous (or pine) brashed up to 3-5m

Chicken roaming under the canopy on the ground, 0.3m

Dense canopy



5m 100m 5m

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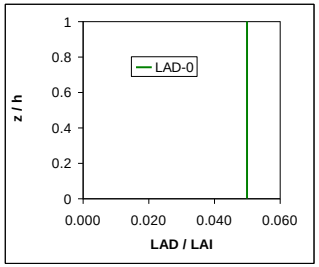
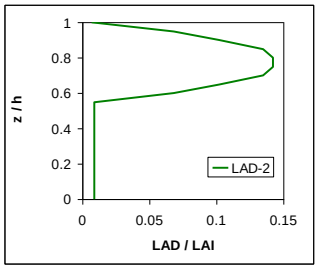
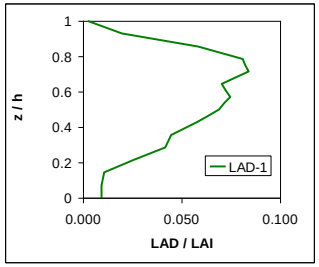
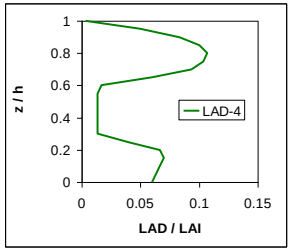
HOUSING SCENARIO & RESULTS

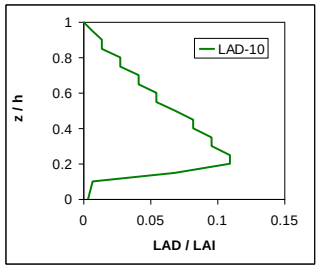
Model run	design	main canopy width	LAI	Height (m)	LAD profile	Back-stop width (m)	LAI	Canopy height (m)	Source (kg NH3-N)	% deposited	% deposited before main canopy	% deposited in main canopy	% deposited in back-stop
housing_1	symmetrical	30	6	10	0	0	-	-	300	**16%**	2%	14%	0%
housing_4	assymmetrical	30	6	10	0	0	-	-	300	**17%**	0%	17%	0%
housing_13	assymmetrical	25	3	10	10	5	6	10	300	**12%**	0%	9%	2%
housing_15	assymmetrical	25	3	10	2	25	6	10	300	**16%**	0%	5%	11%
housing_16	assymmetrical	25	3	10	2	50	6	10	300	**25%**	0%	5%	20%
housing_17_2	assymmetrical	50	3	10	10	50	6	10	300	**27%**	0%	15%	12%











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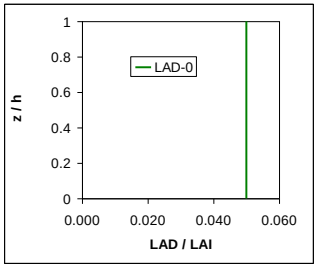
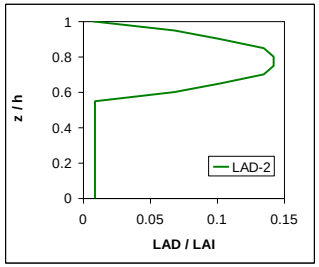
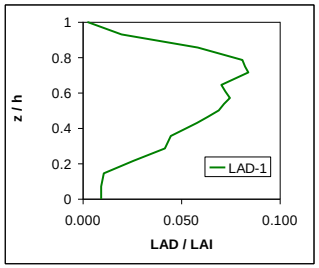
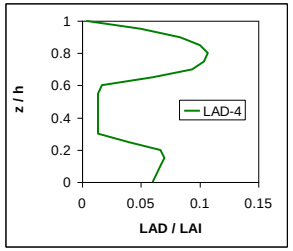
CHICKENS UNDER TREES SCENARIO & RESULTS

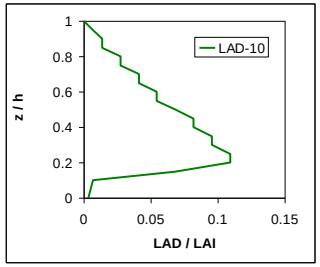
Model run	design	main canopy width (m)	LAI	height (m)	LAD profile	Back-stop width (m)	LAI	Canopy height (m)	Source (kg NH3-N)	% deposited	% deposited before main canopy	% deposited in main canopy	% deposited in back-stop
understorey_1	symmetrical	100	3	10	0	0	-	-	625	**15%**	0%	15%	0%
understorey_3	symmetrical	100	3	10	0	10	6	10	625	**20%**	0%	17%	4%
understorey_4	symmetrical	100	3	10	0	25	6	10	625	**28%**	0%	20%	8%
understorey_5	symmetrical	100	3	10	0	50	6	10	625	**37%**	0%	25%	13%
understorey_7	symmetrical	100	6	10	0	50	6	10	625	**60%**	0%	50%	9%
understorey_8	symmetrical	100	6	10	1	50	6	10	625	**49%**	0%	45%	4%











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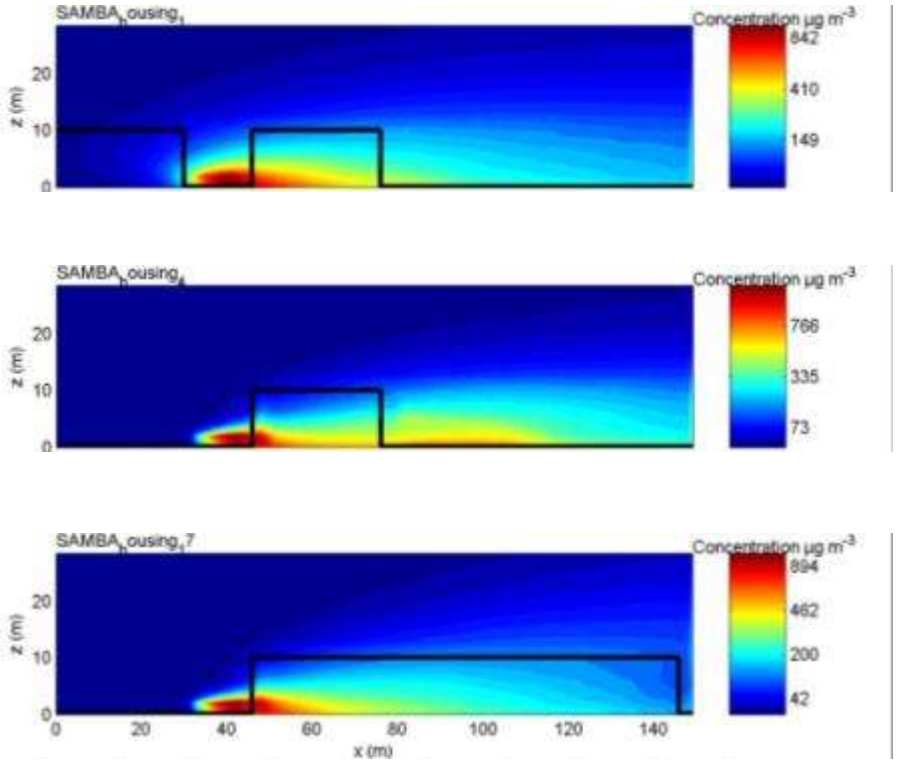
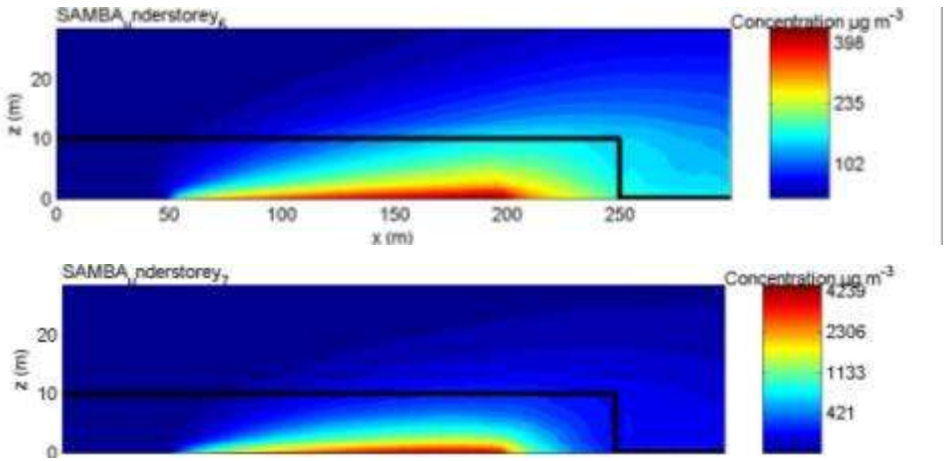
Concentration fields



Concentration field in “housing” runs 1 (16%), 4 (17%) and 17 (27%).



Concentration field in “chicken-understorey” with varying LAIs runs 6 LAI1 (22%) and 7 LAI 6 (60%) - due to the very small level of turbulence and wind speed in the canopy

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Modelling Conclusions

- Results indicate
  - LAI and LAD play an important role in recapture efficiencies
  - 20% recapture potential for housing/lagoon with trees downwind (25m main canopy & 25m backstop)
  - 45% recapture for understorey livestock (100m main canopy & 25m backstop)

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Profitability/cost implications for farmers

Daniel L Sandars

defra Department for Environment Food and Rural Affairs

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Agroforestry systems for ammonia abate

Description

Cost Centres Over view

- Obtaining the land
- Ground preparation
- Planting
- Staking & guarding the trees and or perimeter fencing
- Fertilising & spraying for weed control – first 5 years
- Routine maintenance activities
  - brashing, thinning, hedge trimming
- Managerial oversight

Income streams

- Woodland Grant Scheme (England)
  - Broadleaves £1800/ha and/or Conifers £1200/ha with 80% payable on establishment and 30% 5 years later
- Farm Woodland Payment (England)
  - £300/ha per annum for the first 15 years –ex arable AAPS land
- Single Farm Payment
  - £244/ha per annum

Timber sales

- Standing broadleaves
  - Yield 2.3 m^3/annum ≈ 0.1-0.14 m^3 per tree @ 40 years ≈ £10 m^3
- Standing conifers
  - Yield 5.7 m^3/annum ≈ 0.1-0.3 m^3 per tree @ 40 years ≈ £10 m^3
- NB: harvesting assumes a continuous cycle of thinning and renewal from 40 years –not clear felling at maturity. Shrub & hedge components are assumed managed as part of maintenance costs

Tangible environmental benefits

- Carbon sequestration, £ 25/tCO_2e
  - The above ground biomass represents a significant store of carbon over annual arable.
  - From year 40 we assume that this is managed at equilibrium – no net carbon sequestration
- Ammonia recapture, £1840/tNH_3
  - We assume that the canopy –recapture efficiency grows linearly to achieve maximum annual recapture from year 40

1 ha woody belt overall costs and benefits, £k/ha

Assumes 2* 50,000 place layer units shielded with a downwind woody belt with a 25m backstop zone (1ha total area)

Discounted Income		Discounted Expenses	
Woodland grant	£ 1.4	Ground preparation	£0.1
Farm woodland payment	£ 3.5	Fertilising	£0.2
Single farm payment	£ 7.3	Spraying	£0.3
NH3 abatement	£ 92	Perimeter fencing	£ 6.4
C sequestration	£ 5.7	Planting costs	£ 4.8
Timber Income	£ 5	Managerial oversight	£0.8
		Backstop maintenance	£0.2
		Brashing/ thinning	£ 1
		Opportunity Cost	£ 18
TOTAL	**£ 115**		**£ 32**

Internal Rate of Return 15%

Woodland chickens + trees costs and benefits, £k/ha

Extra 0.8 ha of broadleaved in the paddock + 25m downwind backstop –total 1.675 ha new trees for 2500 layer-unit

Discounted Income		Discounted Expenses	
Woodland grant	£ 2.5	Ground preparation	£0.2
Farm woodland payment	£ 5.8	Fertilising	£0.4
Single farm payment	£ 6.3	Spraying	£0.6
NH3 abatement	£ 5.2	Perimeter fencing	£ 3.0
C sequestration	£ 9.3	Planting costs	£ 7.9
Timber Income	£ 9.2	Managerial oversight	£1.3
		Backstop maintenance	£0.4
		Brashing/ thinning	£ 1.7
		Opportunity Cost	£ 15
TOTAL	**£ 38**		**£ 21**

Internal Rate of Return 6.9%

Bill Bealey
Centre for Ecology & Hydrology
Peter Levy
Centre for Ecology & Hydrology

Carbon storage and woodfuel potentials

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Carbon Stocks - Forests Facts

- Forest ecosystems make an important contribution to the global carbon budget
- Potential to sequester carbon in wood and soil but potential to release it if forests are cleared
- Forests and woodlands in the UK contain around 150 million tonnes of carbon, and remove about 4 million tonnes of carbon from the atmosphere every year
- Total UK emissions of around 150 million tonnes of carbon a year
- Soil is the largest carbon reservoir in the UK, which stores about 6 billion tonnes of carbon.

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UK Upscaling – Land use

- UK ~243,610 square kilometres
- 11% forested -> 26,800 km^2 or 2,680,000 ha
- Agriculture land 18 million hectares (~3/4 grass or rough grass, bare fallow)
- Farm Woodlands:

	2008 population (birds)	birds per ha	land to be converted to forest (ha)
Layers	25,939,838	2,500	10,376
Broilers	109,858,933	4,000	27,465

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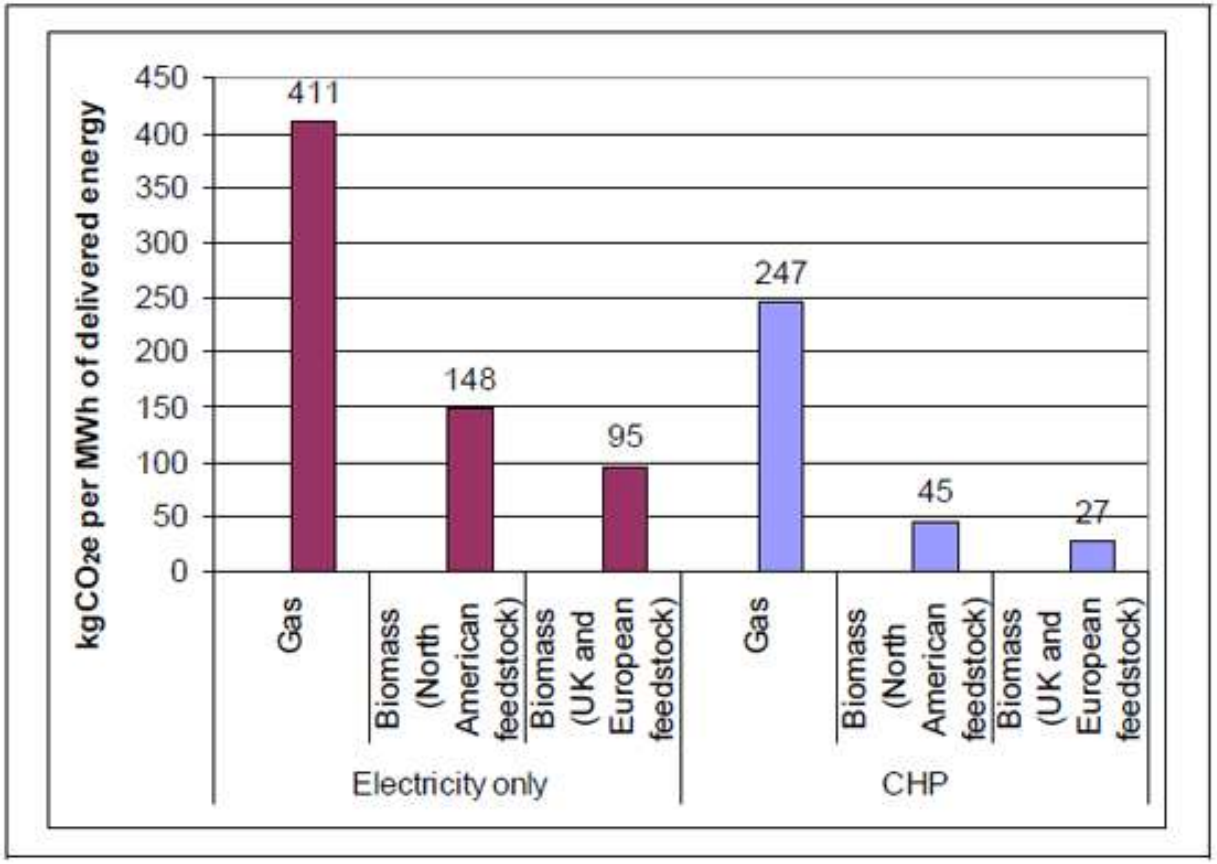
Carbon Stocks

- If stocks of carbon are increased by afforestation or reforestation additional CO_2 is removed from the atmosphere and stored in the tree biomass.
- By substituting for fossil fuels land used for woodfuel (bioenergy) production can provide significant emissions reductions.
- Woodfuel can be used for electricity and heat production

1. Woodfuel Potential - Electricity

	Wood	Gas-fired	Coal
on Full-life cycle emissions kg CO_2/Mwh	40-250	440	1007

This is the full life cycle of the wood production, land-use change, and transport etc.



Comparison of emissions from biomass and gas-fired power stations *(EA 2009)*

2. Woodfuel Potential – Domestic Heating

- For every tonne of woodfuel you can save 0.6 tonnes of coal (measured as kWh/tonne)

	dry mass (kg)	GJ	kWh	kWh/tonne
Wood fuel	550*	5.5	1527	2777
Household coal	1000	16.4	4554	4554

*every tonne of wood, you get around 550kg of dry matter (i.e. you lose nearly 50% to water loss) versus 1000kg of household coal. (table adapted from Keighley, 1996)

Year	Beech YC6 trees m3/ha	Sitka YC12 trees m3/ha	Total Timber Volume m3/ha	Beech YC6 thinnings m3/ha	Sitka YC12 thinings m3/ha	Total Thinning Volume m3/ha	Total Timber Volume
40	94	231	325	54	252	306	631
Scenario 1 (0.5 ha)	12	87	98	41	95	135	**234**
Scenario 2 (1.875 ha)	94	202	296	54	221	275	**571**
75	233	465	698	201	383	584	1282
Scenario 1 (0.5 ha)	29	174	204	87	144	231	**434**
Scenario 2 (1.875 ha)	233	407	640	201	335	536	**1176**

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Wood as fuel: a guide to burning wood efficiently by G. Keighley.
Forestry Commission, Edinburgh, 1996.

Carbon Credits & Offsetting

- By offsetting emissions the full effects of those emissions can be mitigated by reductions elsewhere in the world.
- The Shadow Price of Carbon (SPC) in 2007 used £93 per tonne carbon sequestered (£25 per tonne CO_2e) *(drawn from the Stern Review on the Economics of Climate Change)*
- Revised 'Carbon Valuation' in 2009 for non *EU Emissions Trading System* sectors to a price of £60 per tonne CO_2e in 2020 *(Carbon valuation in UK policy appraisal: a revised approach.* DECC 2009*)*

Carbon Credits & Offsetting

Based on the carbon stock model (CFLOW) we have get the following total carbon for each scenario and potential carbon credits:

- After 40 years – Scenario 1 (housing with trees) : 220 tonnes C (~£13k)
- After 90 years – Scenario 1 (housing with trees) : 275 tonnes C (~£16.5k)
- After 40 years – Scenario 2 (housing and free-range under) : 733 tonnes C (~£44k)
- After 90 years – Scenario 2 (housing and free-range under) : 1155 tonnes C (~£69k)

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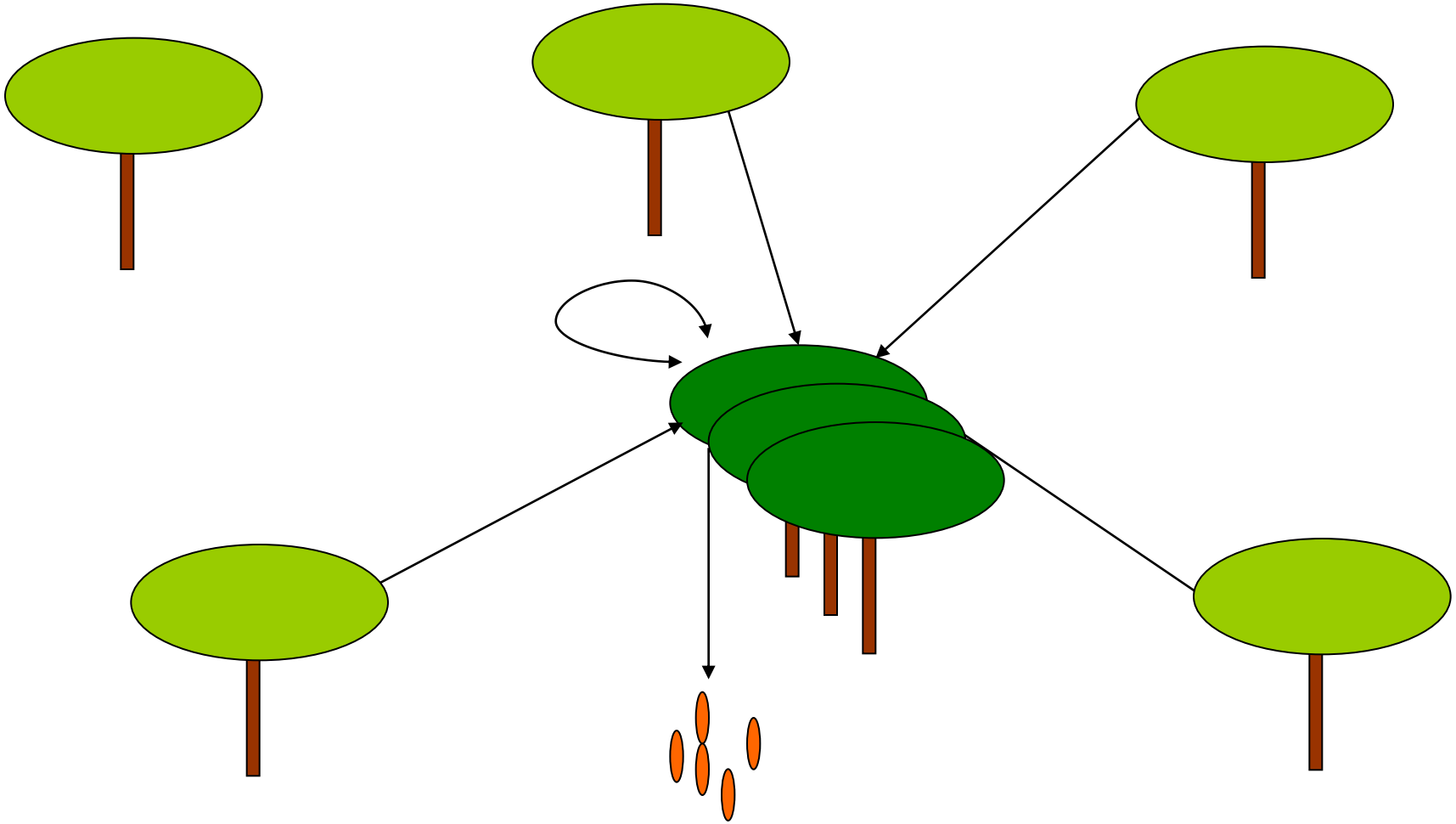
Biodiversity and gene flow in the landscape



We can influence the way genetic diversity moves in the landscape by managing for different tree distributions.

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Key Messages

- Ammonia emissions have increased substantially over 20th C facing major mitigation challenges
- Ammonia impacts occur in the rural environment, so that landscape structure has great capability to buffer these effects
- Livestock - agroforestry systems have an important role to play in reducing ammonia emissions and effects.
- Woodfuel
  - could provide a significant role in achieving the UK's emission reduction targets for CO2
  - is 4 times more efficient than coal based on the release of kg CO2 per MWh of delivered energy (x2 for gas)
- Farm Woodlands & Carbon
  - maintains the viability of agricultural woodlands and forests, preserves them for future generations
  - provides rural employment & diversification
  - acts as a pool for genetic diversity in the landscape

Agro-Forestry – Everyone's a

- Ammonia Abatement (& meeting regulations)
- Protection of Conservation sites
- Carbon Sequestration
- Fossil Fuel substitution using Wood Fuel
- Improved welfare of animals for outside systems
- Potential revenues for farmers and industry
- Screening of installations
- Improved flooding protection

Thank You


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Key Facts -Pigs

- Domesticated pig used intensively in Roman times, and during the Medieval period pigs were kept for long periods in forests feeding on acorns, beech nuts etc.
- Today pigs are used for woodland management clearing bracken and brambles, & aiding regeneration of seeds
- Trees for shelter and shade
- Meat premium for ‘woodland-reared’ pork
- A survey of Assured British Pig farmers found 74% of the farms housed sows indoors for breeding and the remaining 26% outdoors *(Fowler, 2008)*.
- 420,588 sows in the UK (2008)
- 2,993,583 fatteners in the UK (2008) (various weights)

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Fowler, T. (2008) The structure of the UK pig industry. British Pig Executive, November 2008.

Key Facts -Chickens

- Chickens natural range is the forests of South East Asia (Red Junglefowl) *(Collias & Collias, 1967)*
- Trees are multifunctional providing:
  - Shelter from wind and rain
  - Cover from predators
  - Shade from sun
- Trees encourage ranging *(Dawkins et al. 2003)*
- Free-range 'woodland-reared' poultry attract a premium (eggs & meat)
- 25,939,838 Layers in the UK (2008) (38% free-range)
- 109,858,933 Broilers

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N. E. Collias and E. C. Collias, A field study of the red jungle fowl in North Central India. *Condor* **69** (1967), pp. 360–386

M.S. Dawkins, P. Cook, M. Whittingham, K. Mansell and A. Harper, What makes free-range broilers range? In situ measurement of habitat preference, Animal Behav. 66 (2003), pp. 151–160. ,4

Trends in UK egg production systems

Changes in egg production systems 1946-2008, % of eggs

Year	Cage systems	Barn systems	Free range
1946	-	-	98
1951	8	12	80
1956	15	40	45
1963	27	56	17
1966	67	25	8
1976	94	2	4
1980	95	4	1
1986	93	2	5
1990	85	3	12
1996	86	3	11
2008	58	4	38

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FAWC 1998 and other sources