The role of knowledge intensive agriculture in sustainable development

Donal Murphy-Bokern

Thoughts on the application of science and technology in the 21st century

Syngenta 'Science Matters' Conference
9 September 2008

Murphy-Bokern Konzepte

UK government definition of Sustainable Development

A better quality of life for everyone, now and for generations to come. It requires 4 objectives to be met *at the same time*

in the UK and

the world as a whole

Murphy-Bokern Konzepte

What are the 4 Objectives?

- **Social progress which recognises the needs of <u>everyone</u>**
- **Effective <u>protection of the environment</u>**
- **Prudent use of <u>natural resources</u>**
- **Maintenance of high and stable levels of <u>economic growth</u>**

At the same time

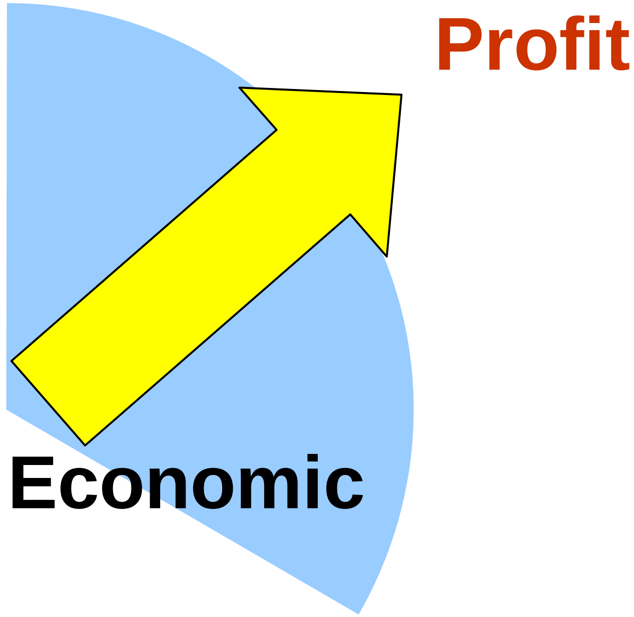
Murphy-Bokern Konzepte

How did Sustainable Development thinking emerge?

A little history…..

Murphy-Bokern Konzepte

19th Century policy – unrestrained growth and…



Murphy-Bokern Konzepte

social reform in the early 20th century

William Beveridge 1879 - 1963

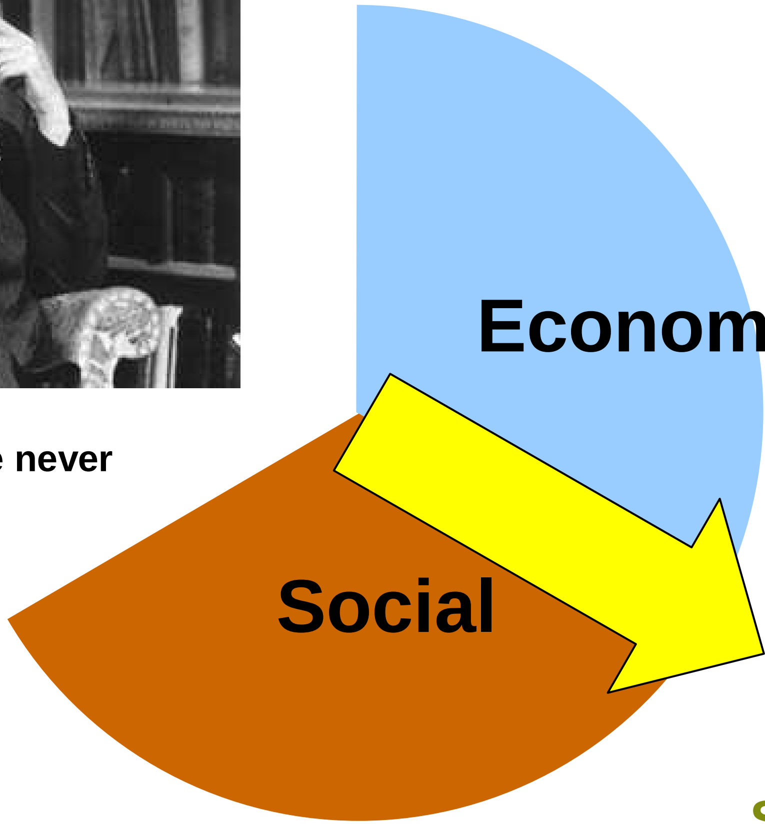
Murphy-Bokern Konzepte

led to widespread material prosperity

“Most of our people have never had it so good”

Harold Macmillan in 1957

Source: BBC



Social justice

A platform for addressing global issues with…

The **UN** was founded following World War II in **1945**

Source: United Nations Photo

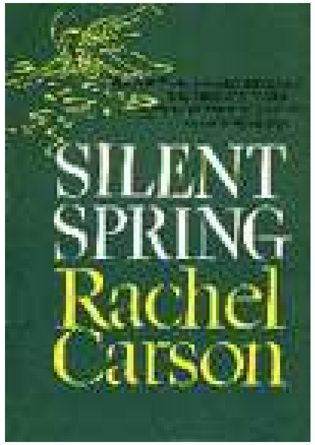
recognition of environmental effects

1962

Rachel Carson

published

'Silent Spring'



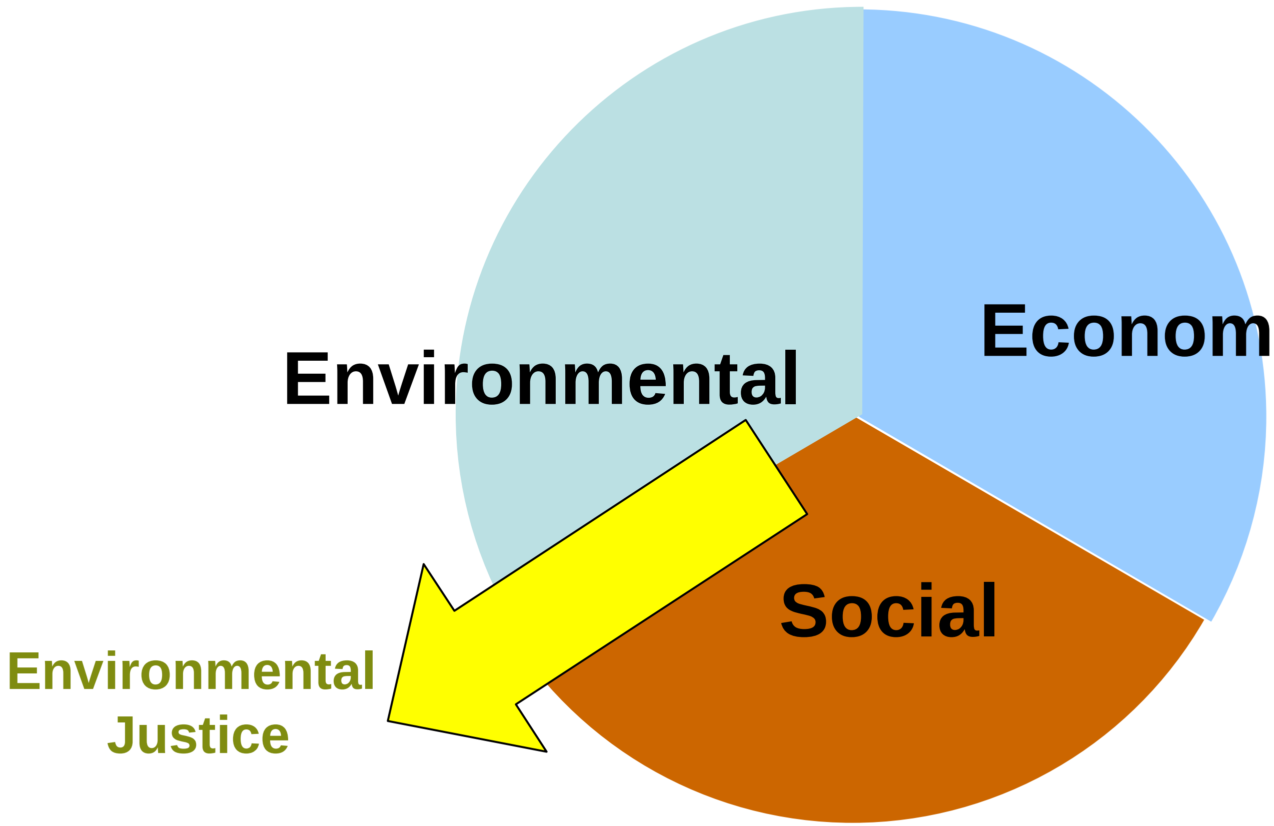
"Now, I truly believe, that we in this generation, must come to terms with nature, and I think we're challenged as mankind has never been challenged before to prove our maturity and our mastery, not of nature, but of ourselves."

and international campaigns

Source: Treehugger.com

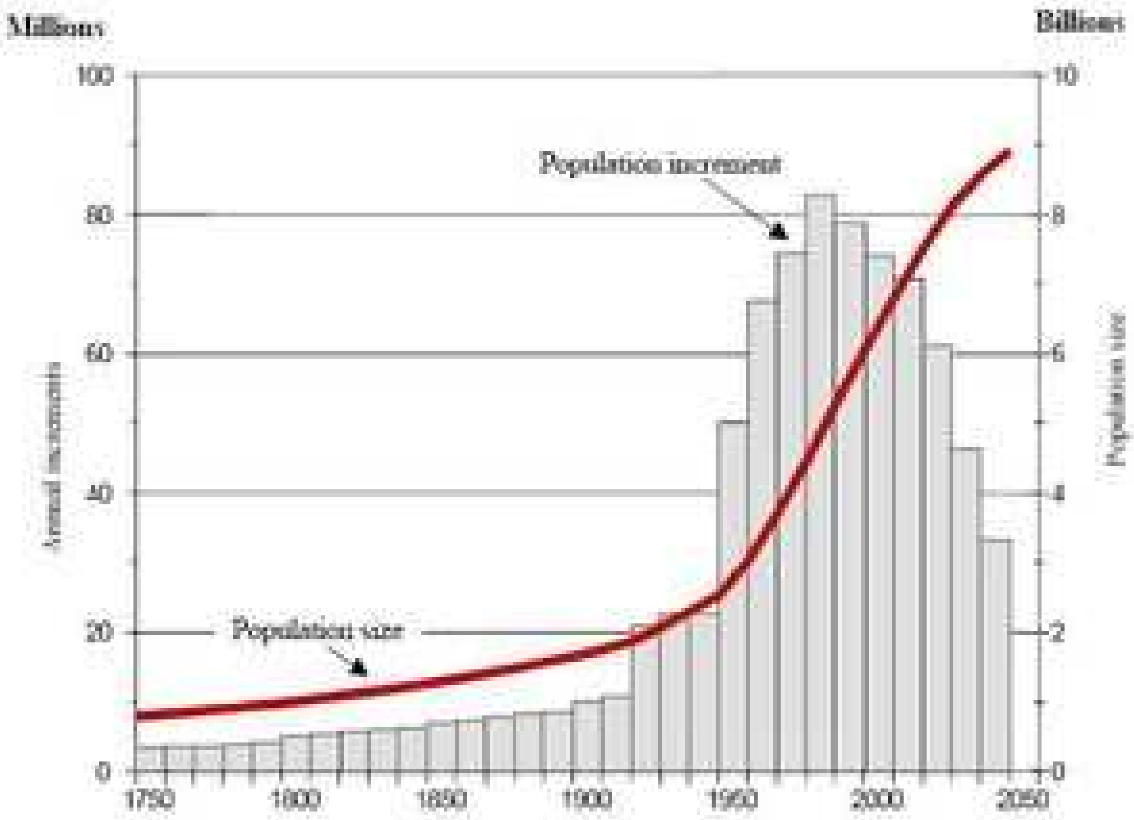
The first Earth Day, 20 million Americans took to the streets to demonstrate for a healthy, ***sustainable environment.***

led to a global demand for environmental justice



Murphy-Bokern Konzepte

Population growth and..



(Source :The World at six billion, UN)

"...if humanity fails to act, *nature may end the population explosion for us* - in very unpleasant ways...."
Paul Ehrlich, 1968 ‘The Population Bomb’

Murphy-Bokern Konzepte

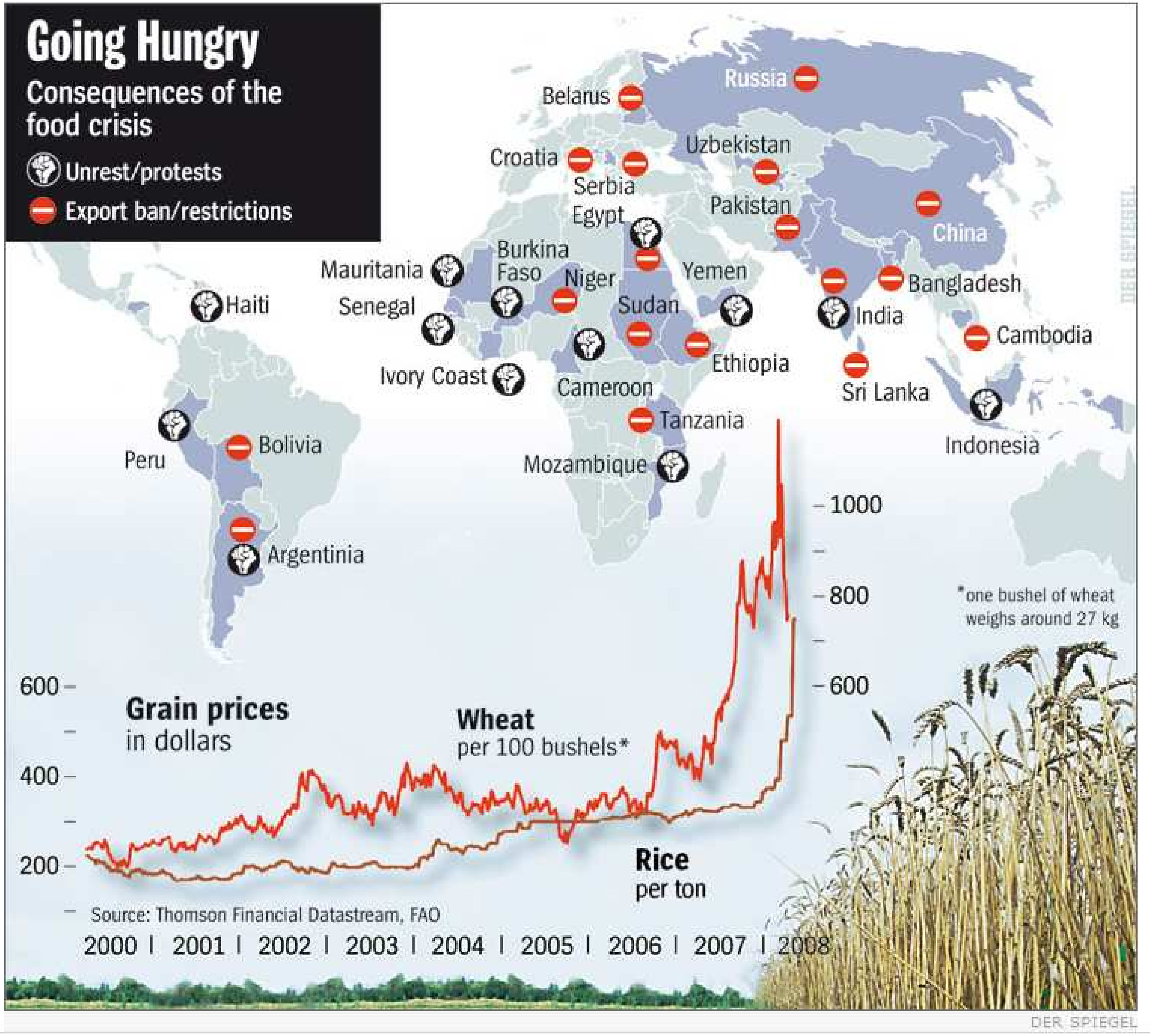
recognition of the finiteness of mineral resources

Source: BBC

1973: The year the lights went out

Murphy-Bokern Konzepte

and food in 2008, also refered to as…

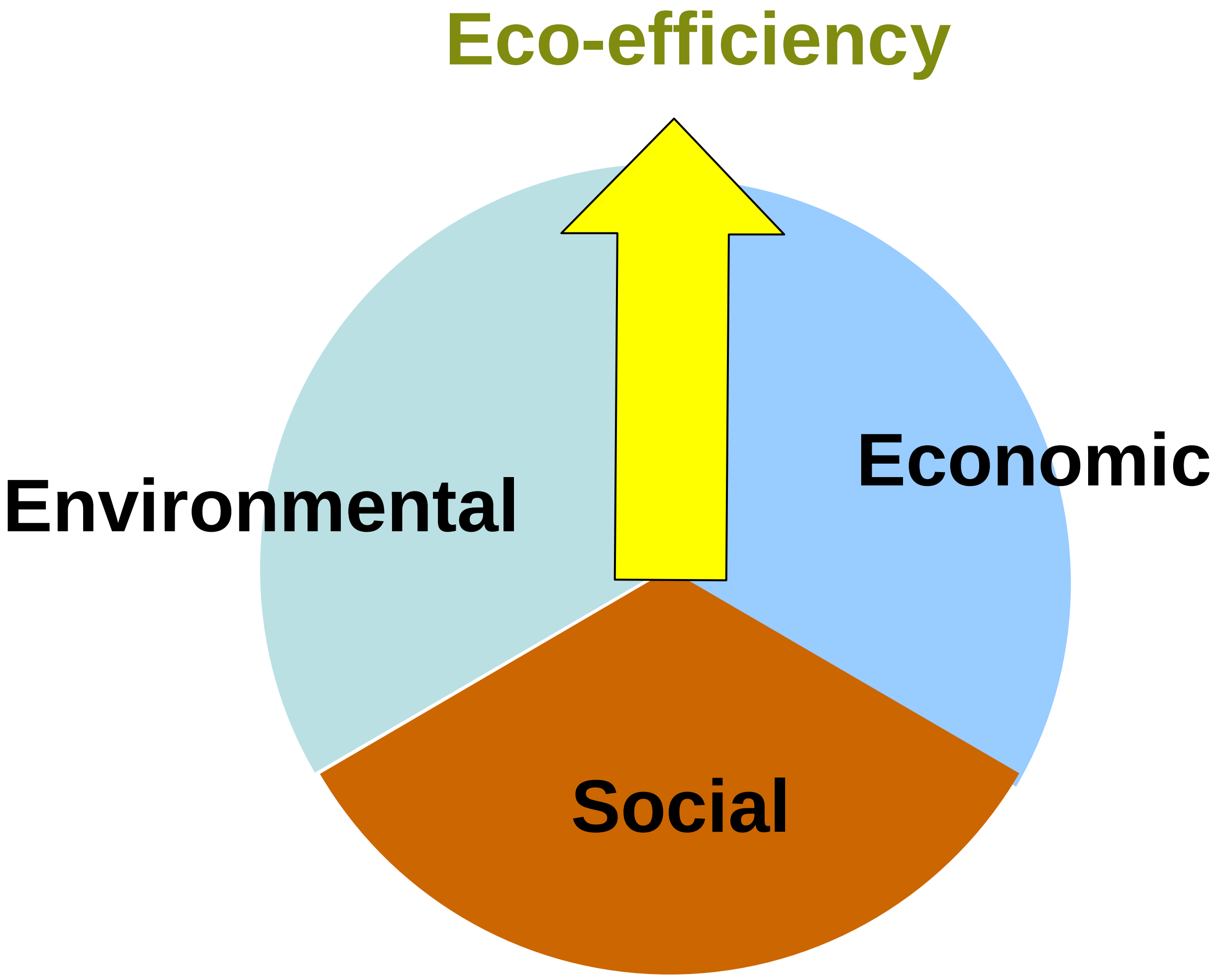


The resource crunch

“….there are important insecurities, often all too visible. And I believe that the resource crunch we now face is the fulcrum on which this all turns“.

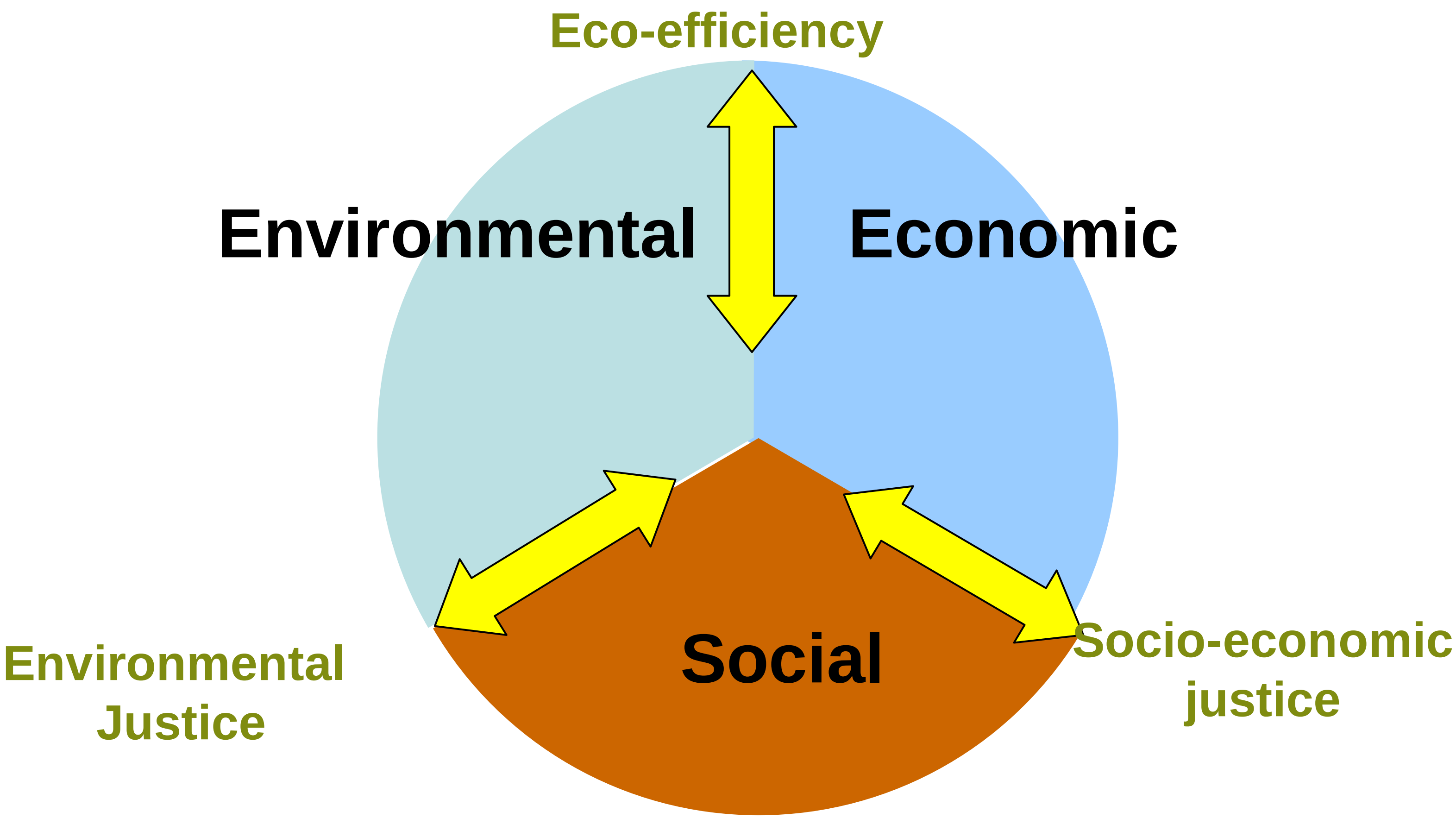
David Miliband MP, as Foreign Secretary

The third political objective: eco-efficiency



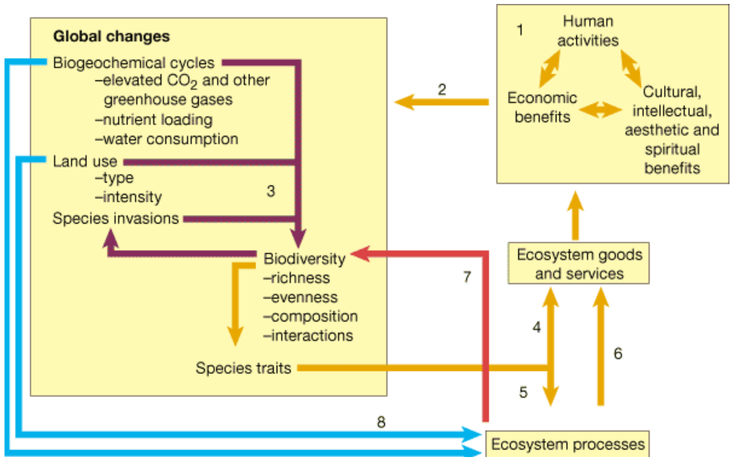
Murphy-Bokern Konzepte

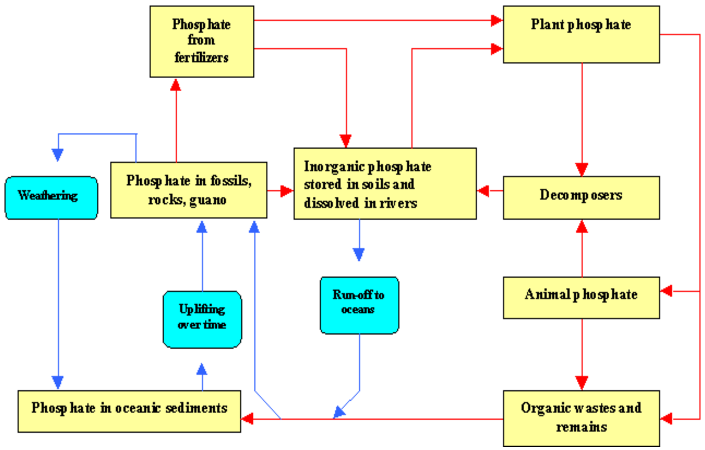
Development that meets the needs of the present without compromising the ability of future generations to meet their own needs (UN Bruntland Report in 1988).

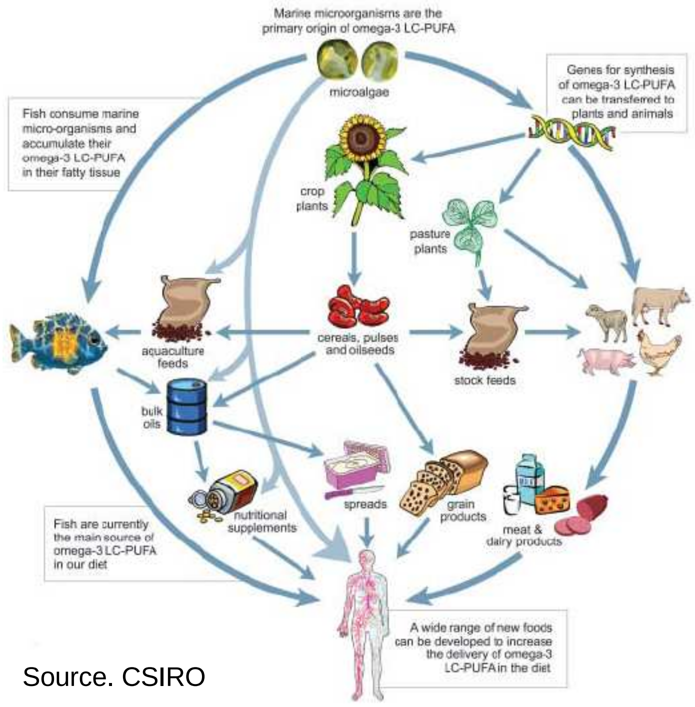


Murphy-Bokern Konzepte

Two key characteristics of sustainable development: a (closed) systems approach and…

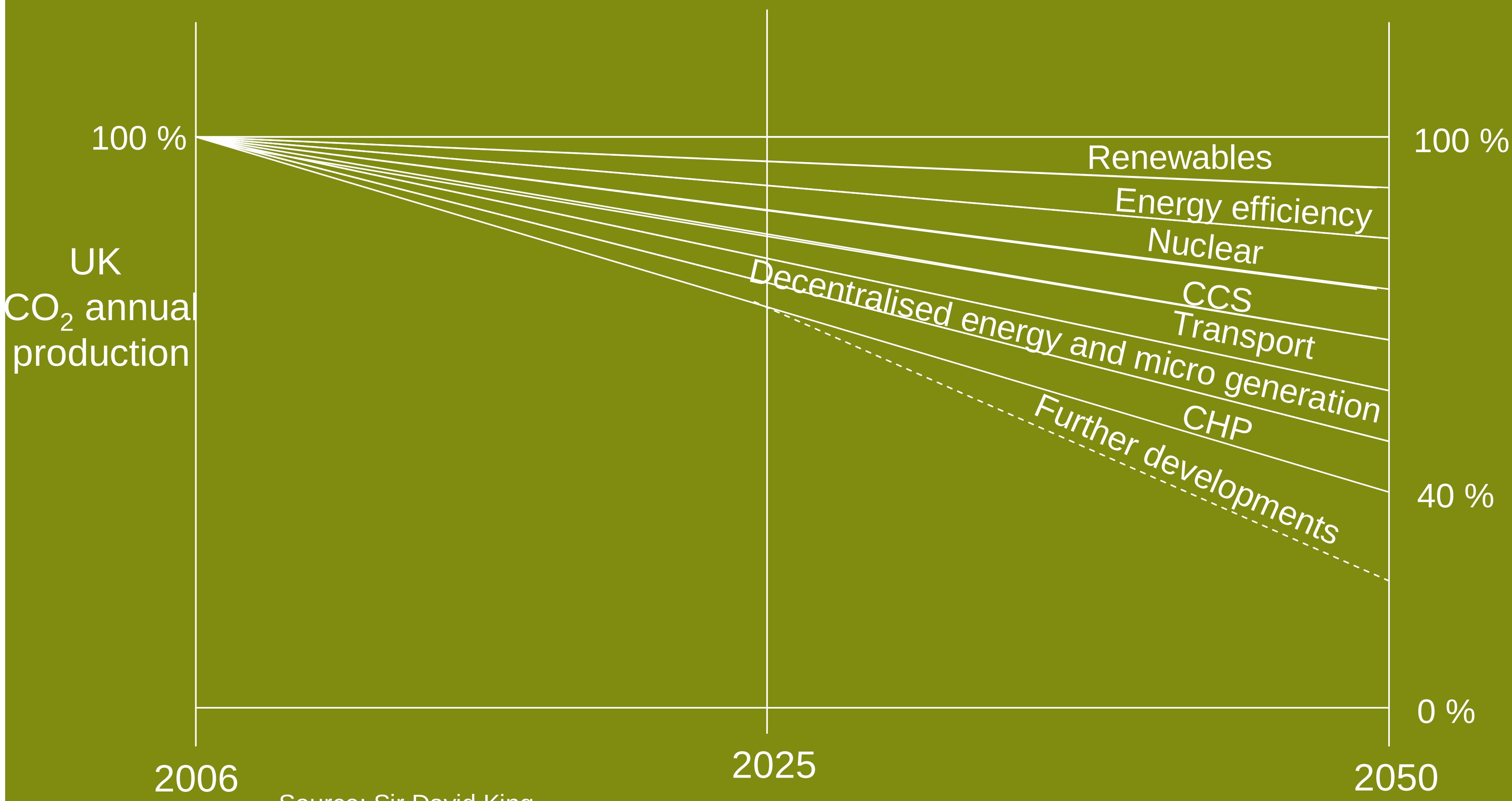






Source. CSIRO

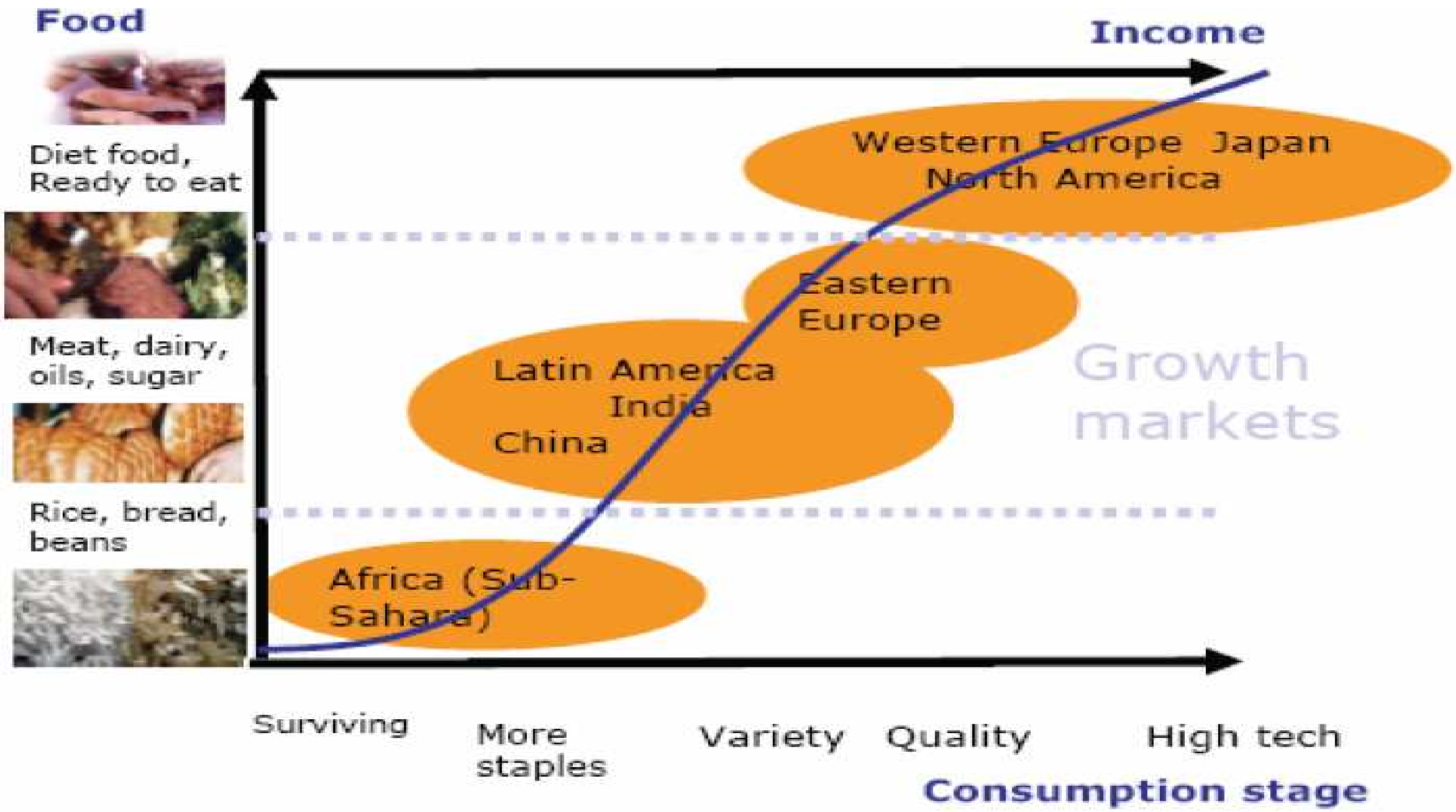
The wedges solution – illustrative
The solution is not this or that – it is this and that



Source: Sir David King

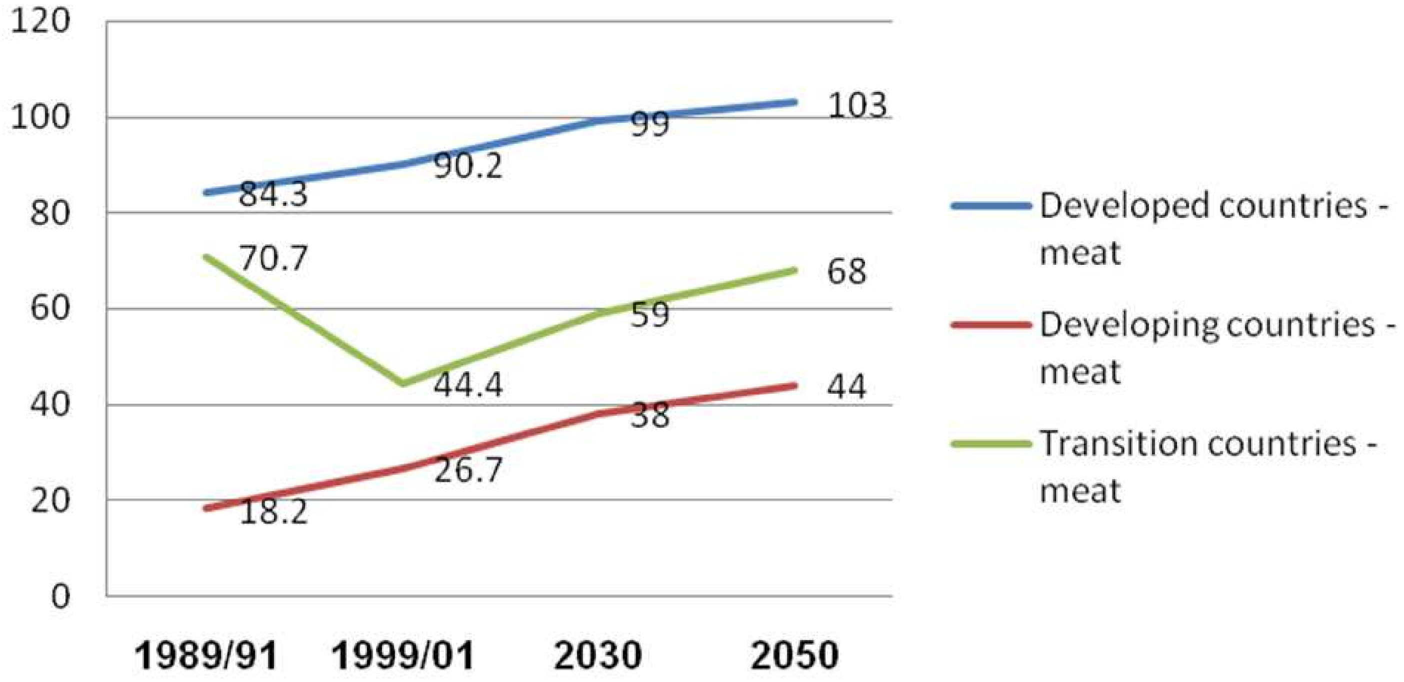
Sustainable development and food

Evolution of food choice and demand



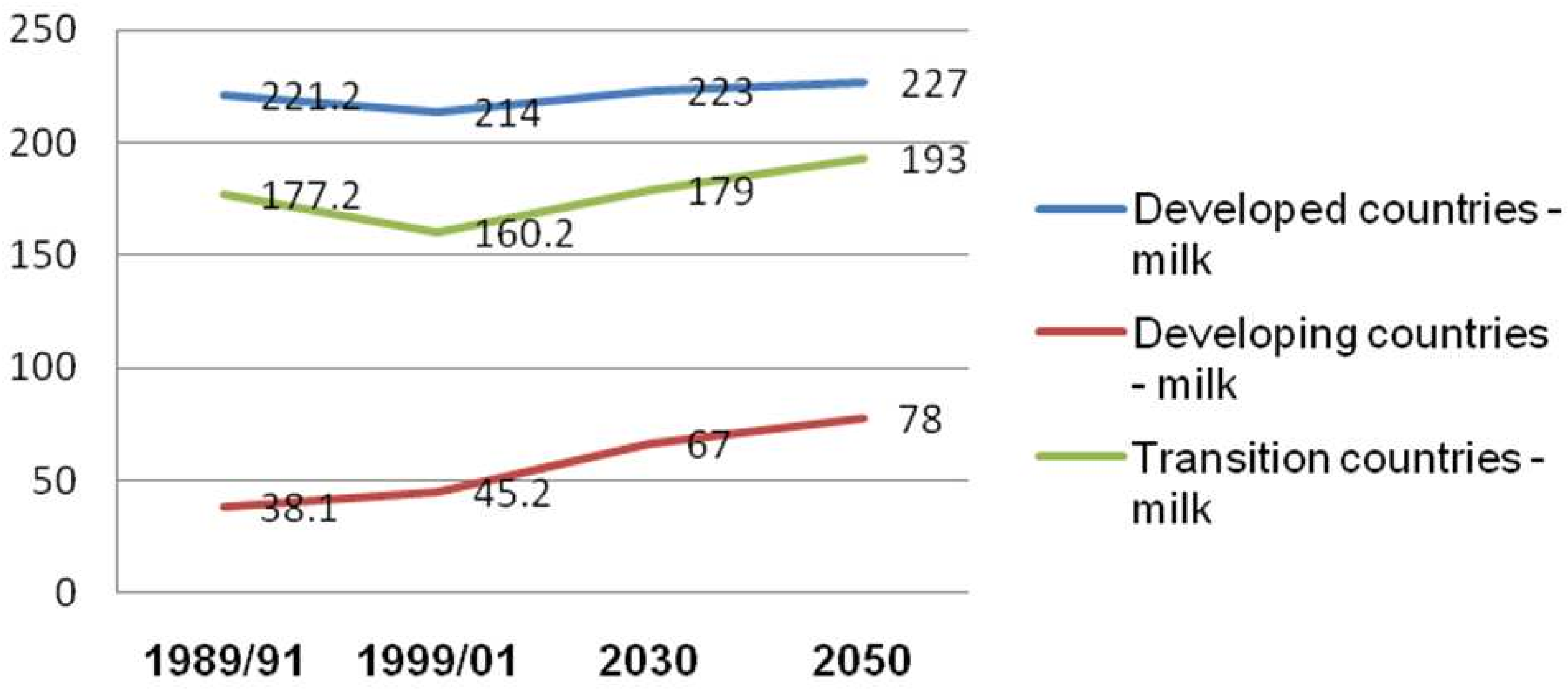
Source: Zwanenberg, Robobank

Projected trends in per capita consumption of meat products to 2050, kg/person/yr



Source: *World agriculture: towards 2030/2050* Interim report Global Perspective Studies Unit, Food and Agriculture Organization of the United Nations, Rome, June 2006. Presented by Tara Garnet

Projected trends in per capita consumption of milk products to 2050, kg/person/yr



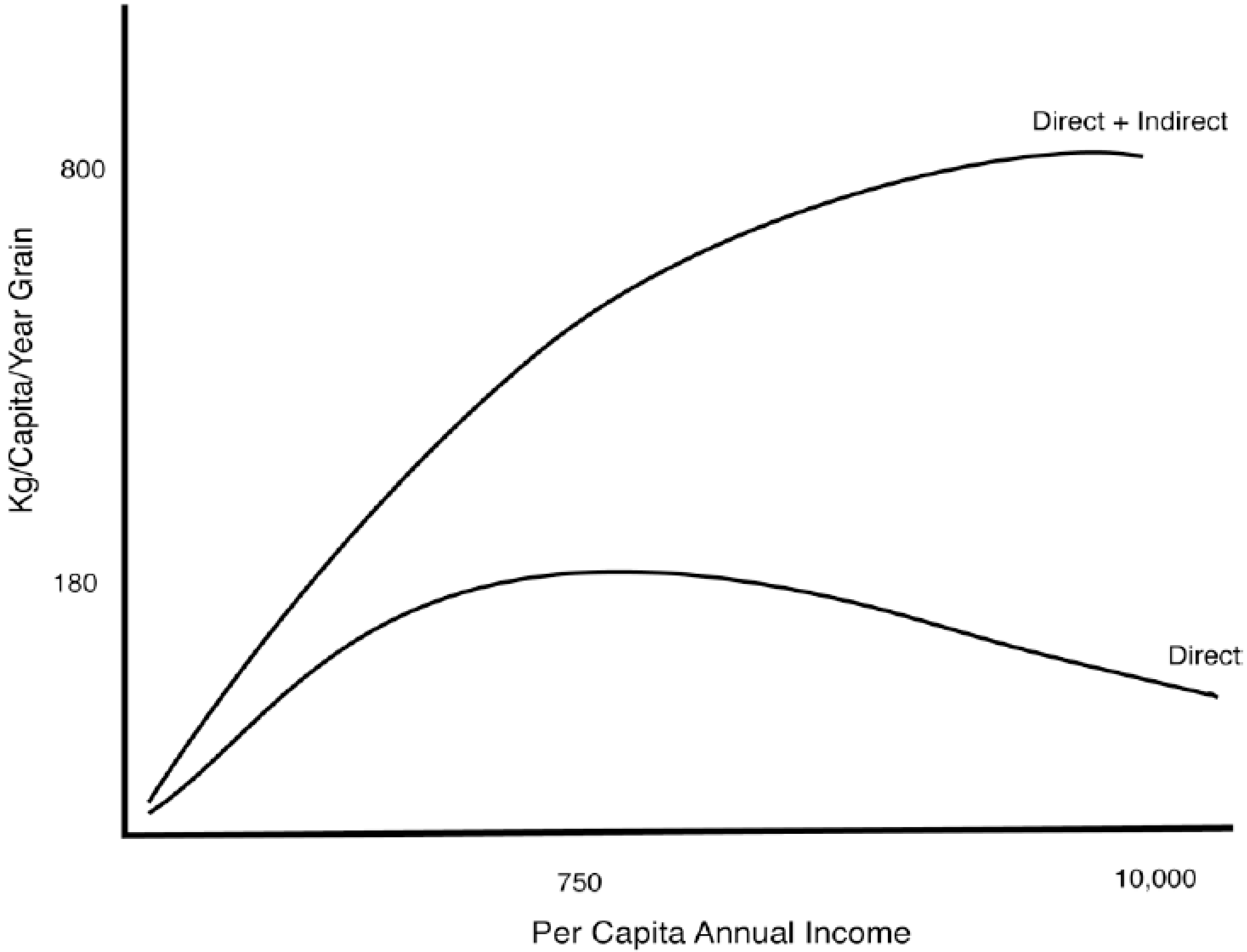
Source: *World agriculture: towards 2030/2050* Interim report Global Perspective Studies Unit, Food and Agriculture Organization of the United Nations, Rome, June 2006. Presented by Tara Garnet

Meat and dairy demand in 2000 and 2050

	2000 (population 6 bn)	2050 (population 9 bn)
Average *per capita* global demand - meat (tonne)	0.0374	0.052
Average *per capita* global demand - milk (tonnes)	0.0783	0.115
Total demand – meat (tonnes)	228	459
Total demand – milk (tonnes)	475	883

Source: Tara Garnet

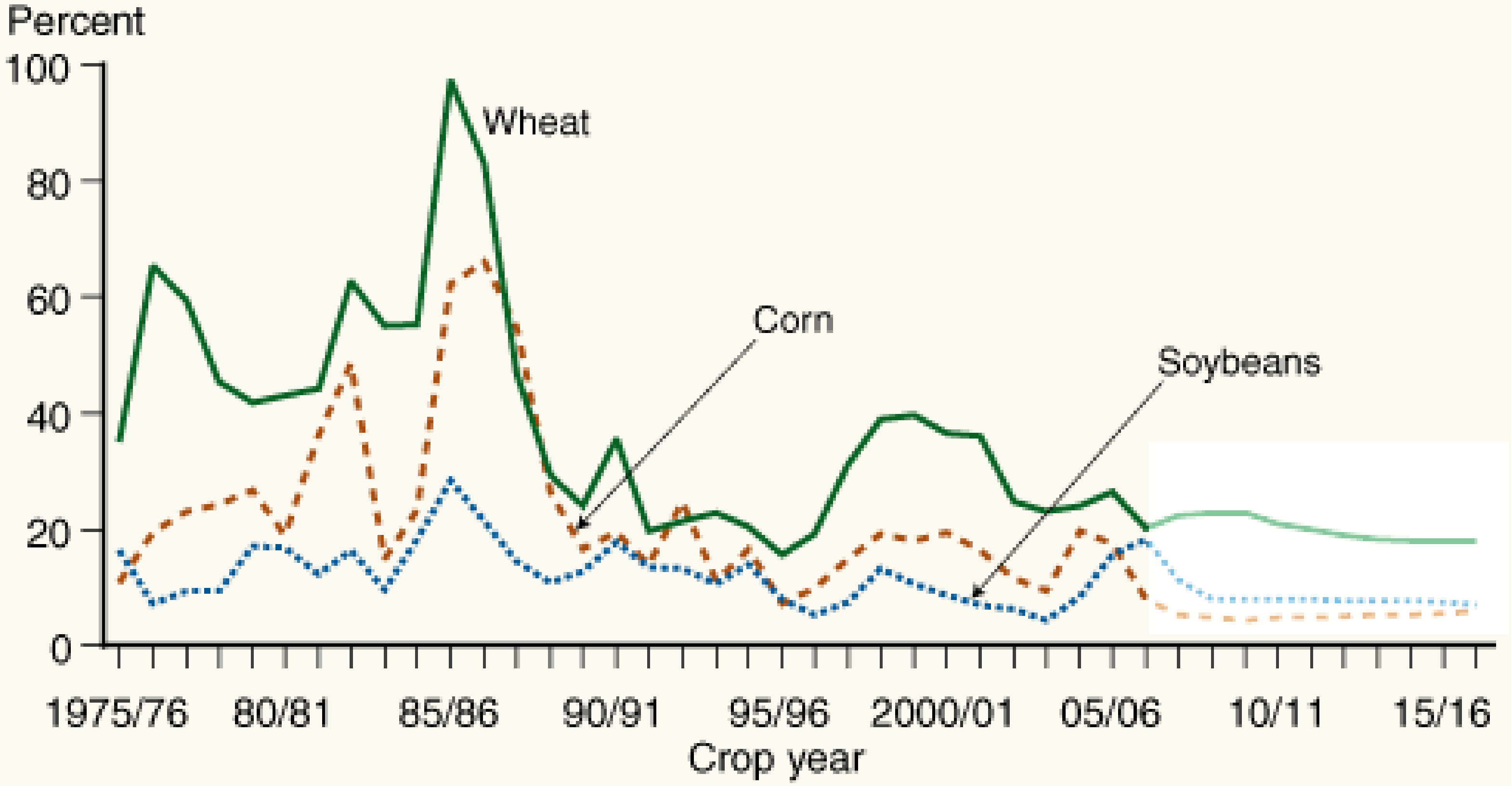
Direct and indirect grain consumption



Managing Food Production Systems for Resilience
Rosamond L. Naylor

All point towards a doubling in the demand for food by 2050

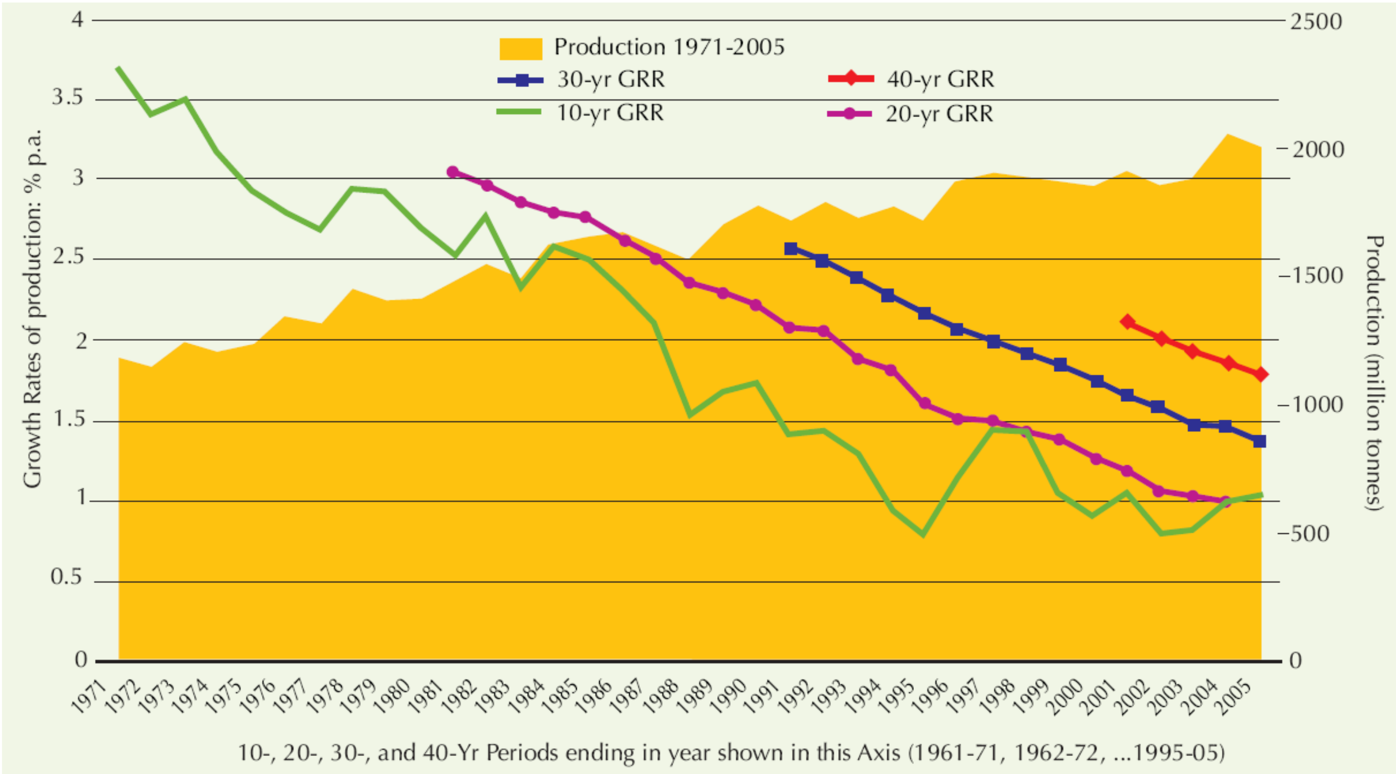
Stock-to-use ratios for corn, wheat and soybeans



Sources: Historical data, USDA, Economic Research Service; Projections, *USDA Agricultural Projections to 2016*, February 2007.

Murphy-Bokern Konzepte

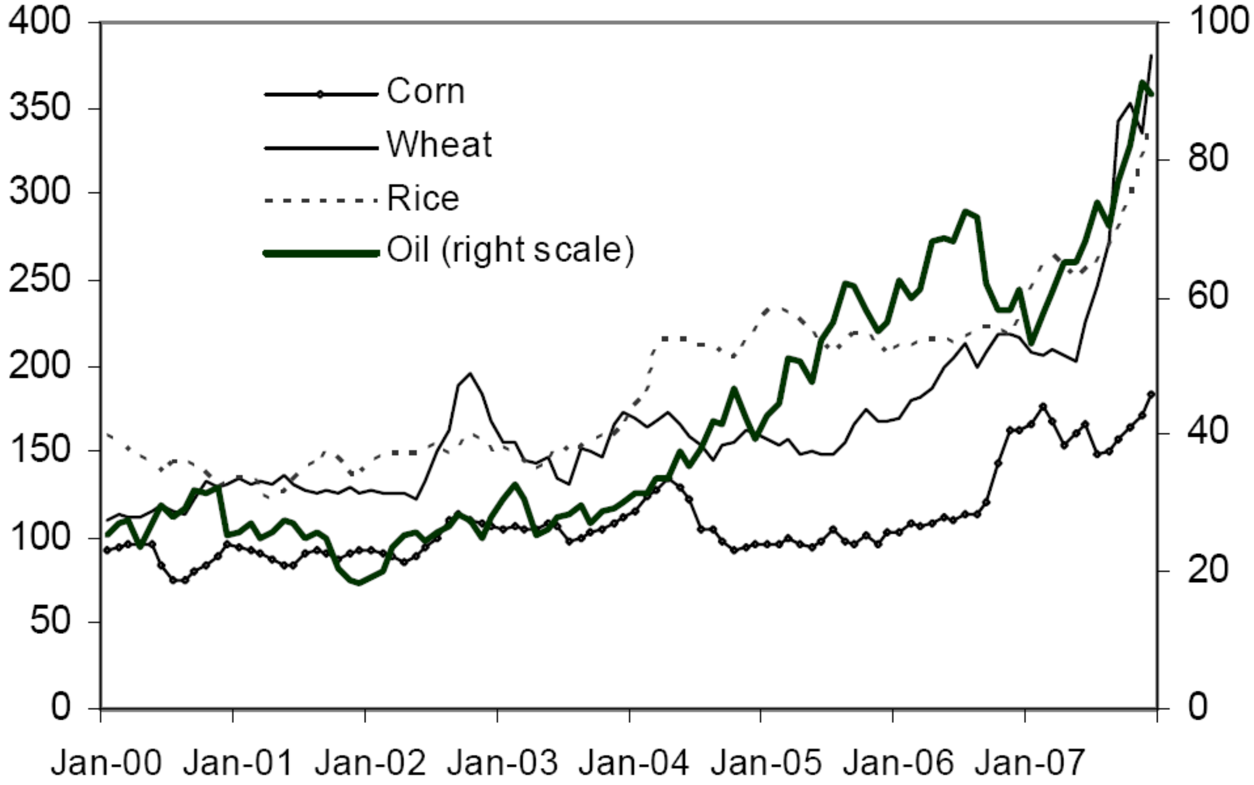
World cereals production: growth rates in successive 10-, 20-, 30- and 40-year periods



Source: FAO (2006). World agriculture: towards 2030/2050

Murphy-Bokern Konzepte

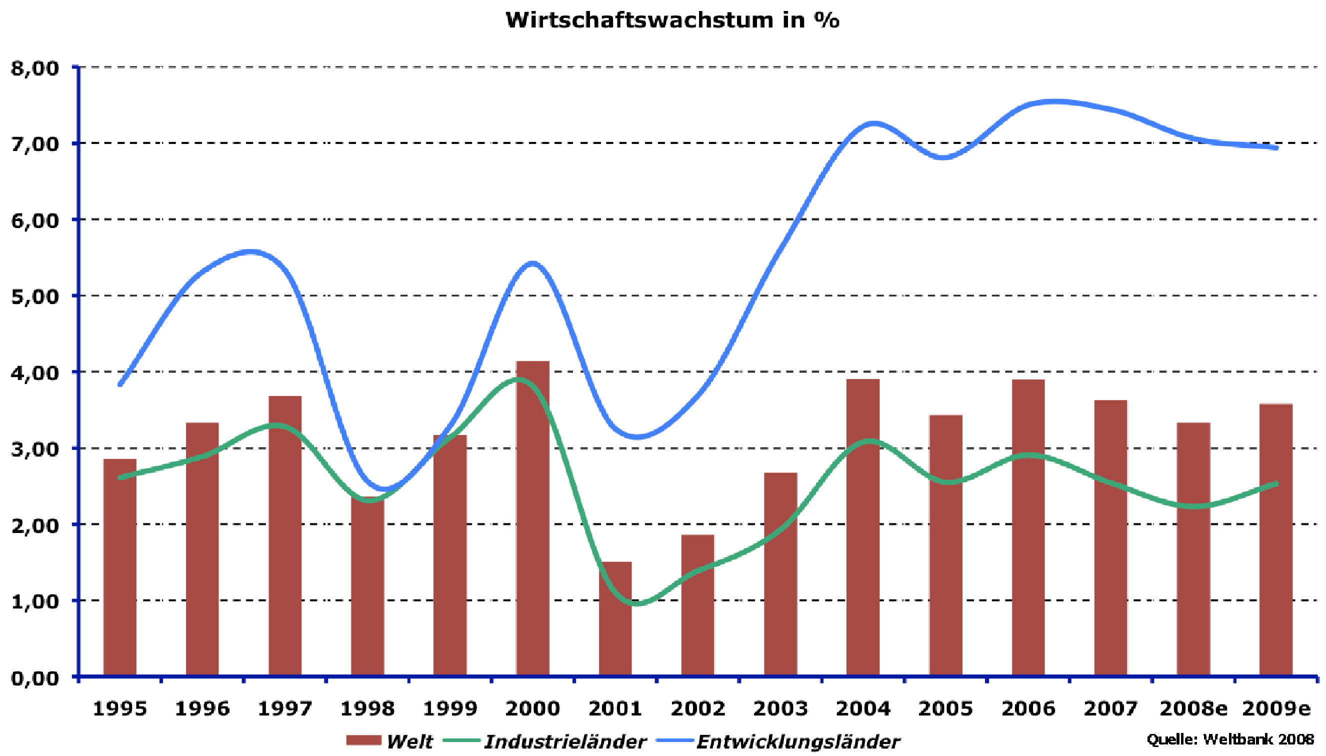
Commodity prices (US $/tonne) and oil (USD/barrel) January 2000 – January 2008



Source: FAO and IMF, 2008

Murphy-Bokern Konzepte

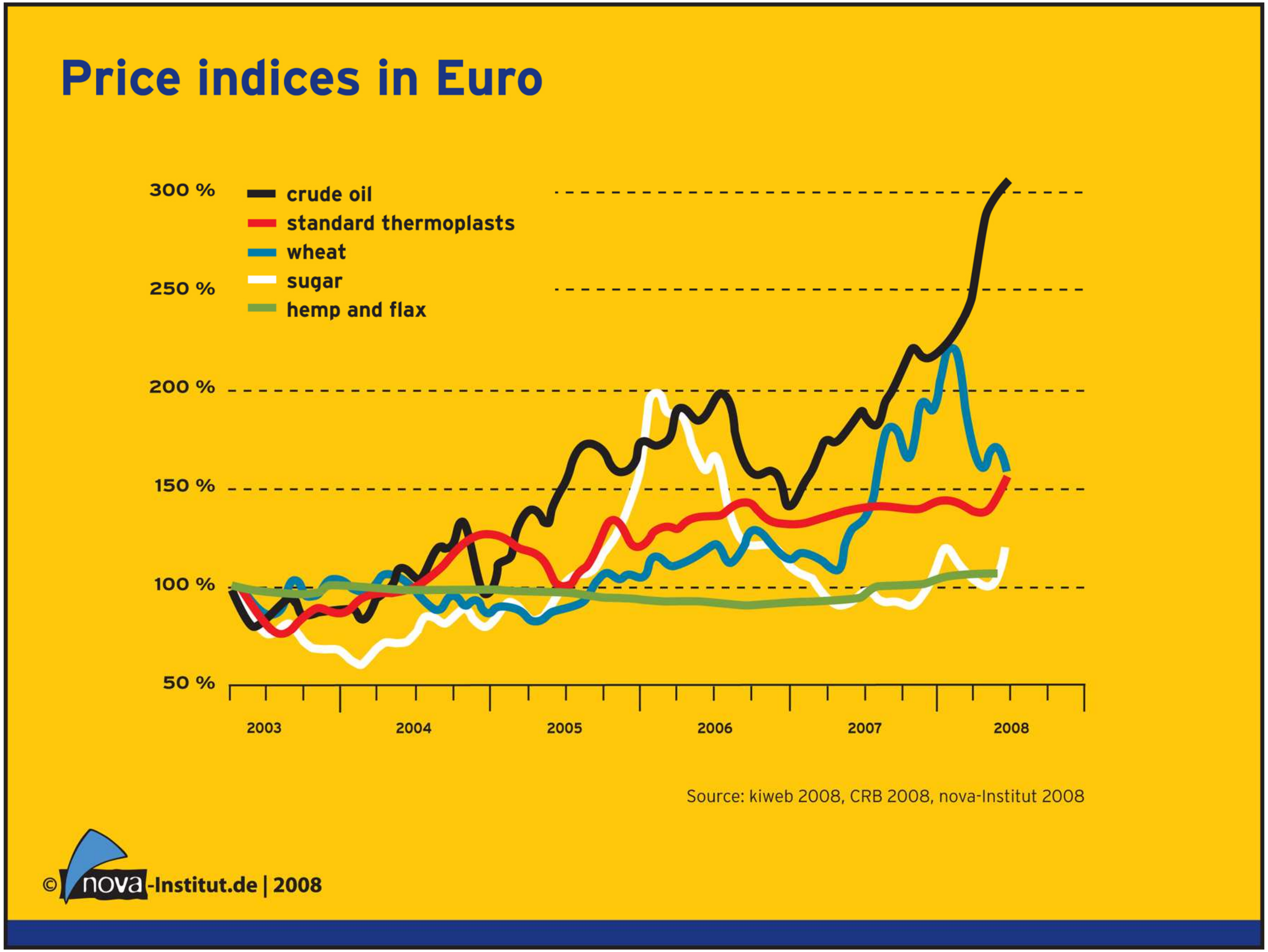
Is economic growth driving inflation?



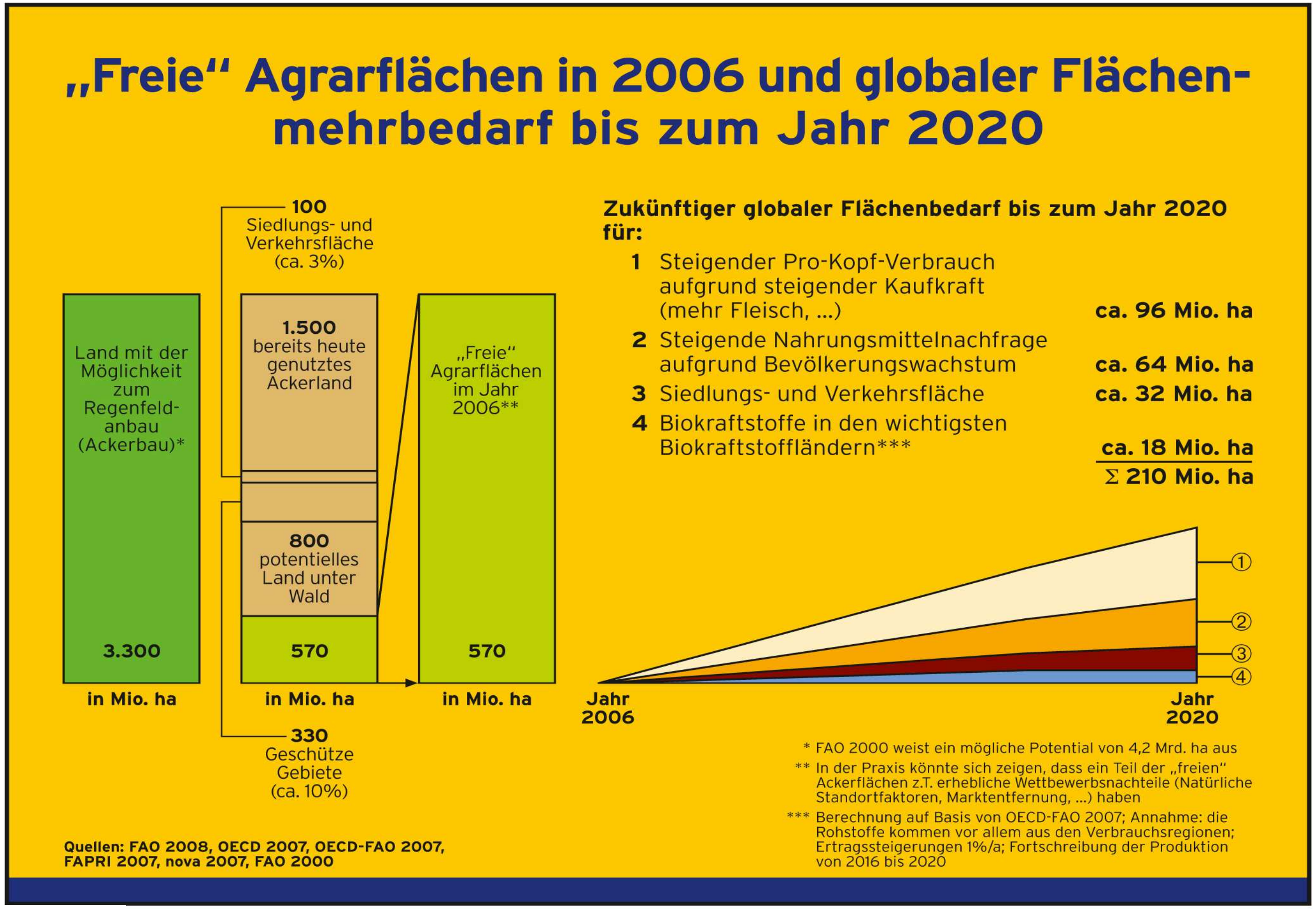
nova Institut für Ökologie und Innovation

Murphy-Bokern Konzepte

Commodity world-price indices



Demand for arable land to 2020 – one analysis

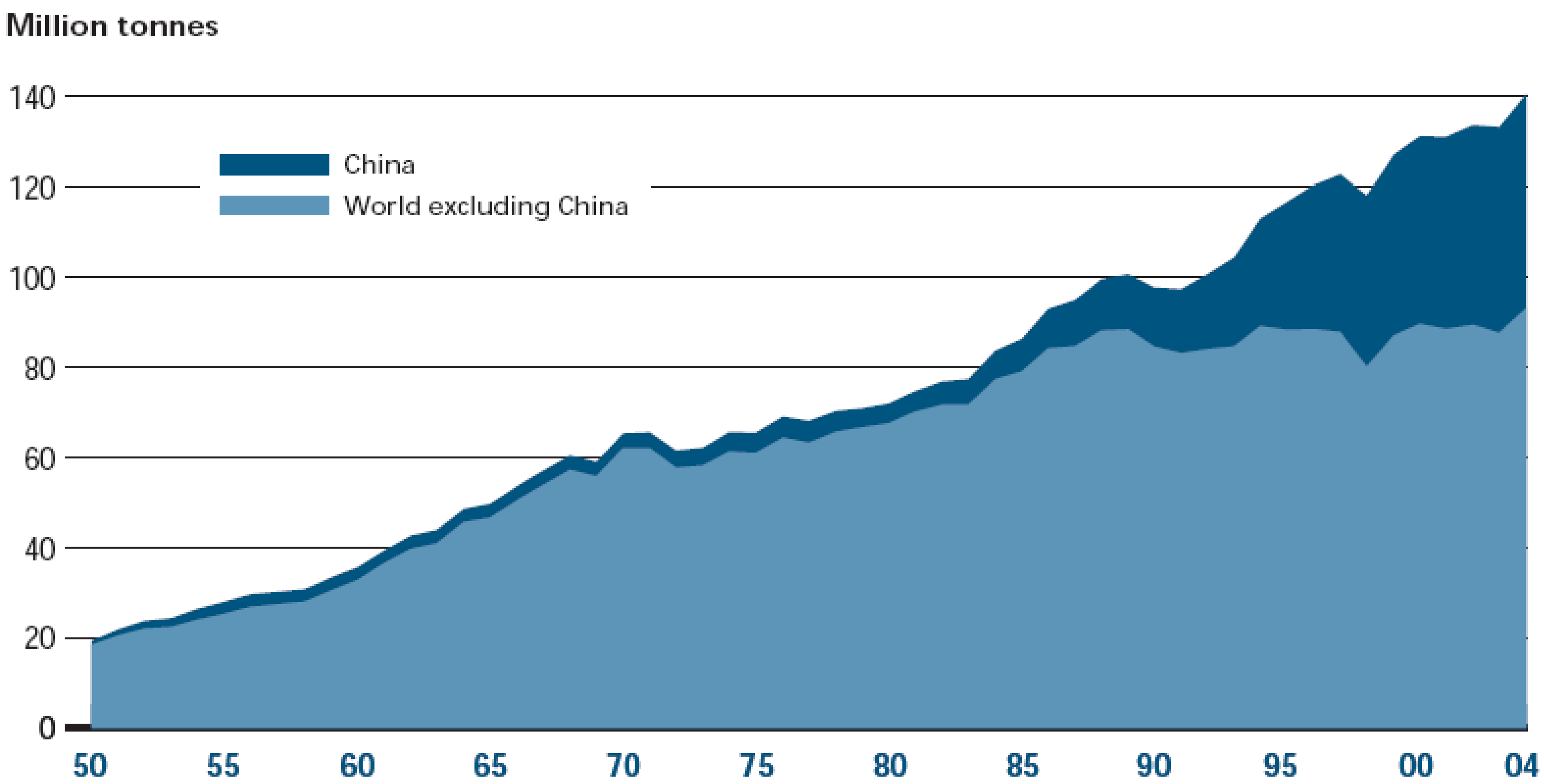


nova Institut für Ökologie und Innovation

Fishery resources: fished out

Picture source: Greenpeace

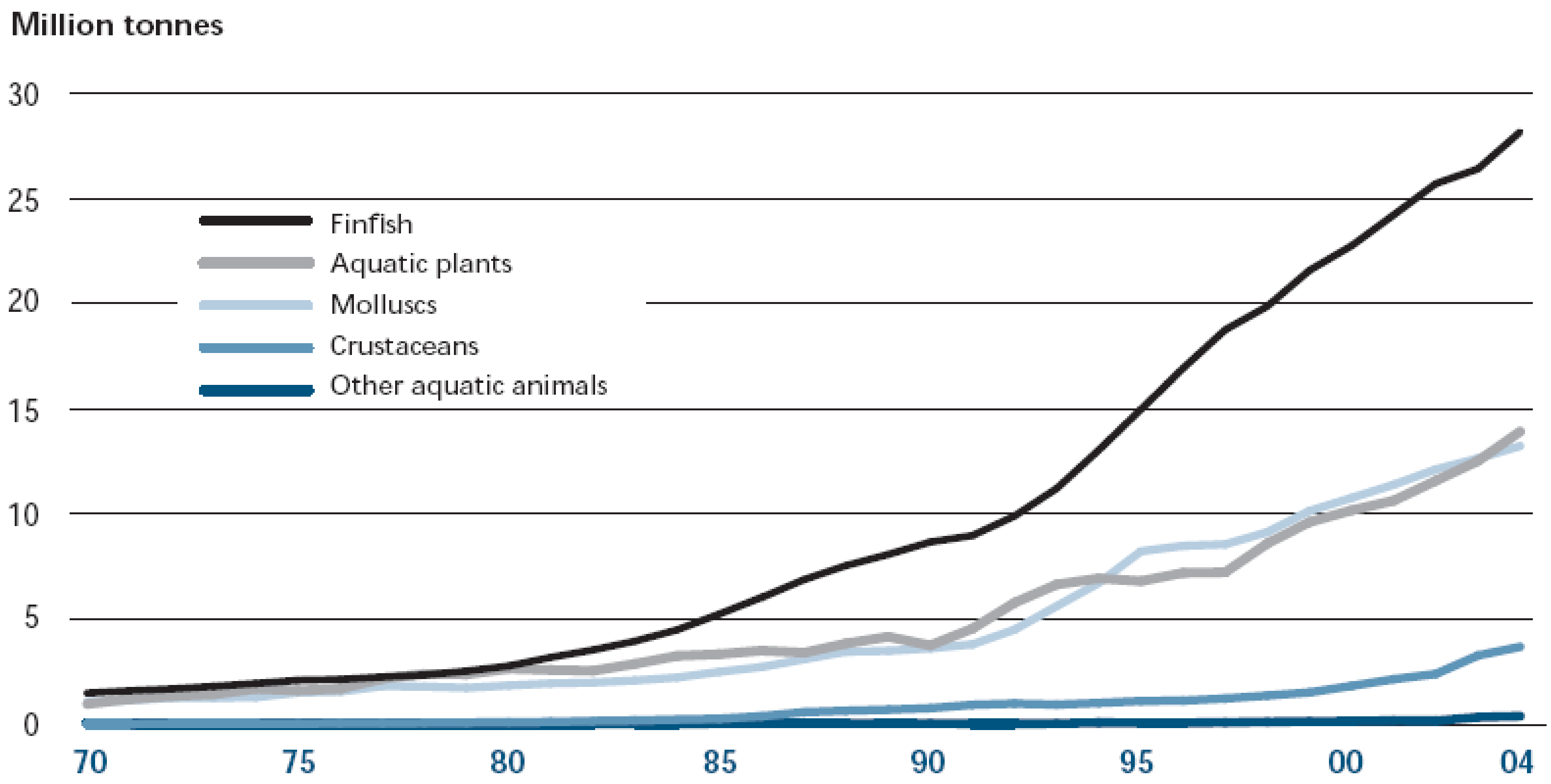
World fish capture and aquaculture production



Source: FAO 2006. State of world fisheries

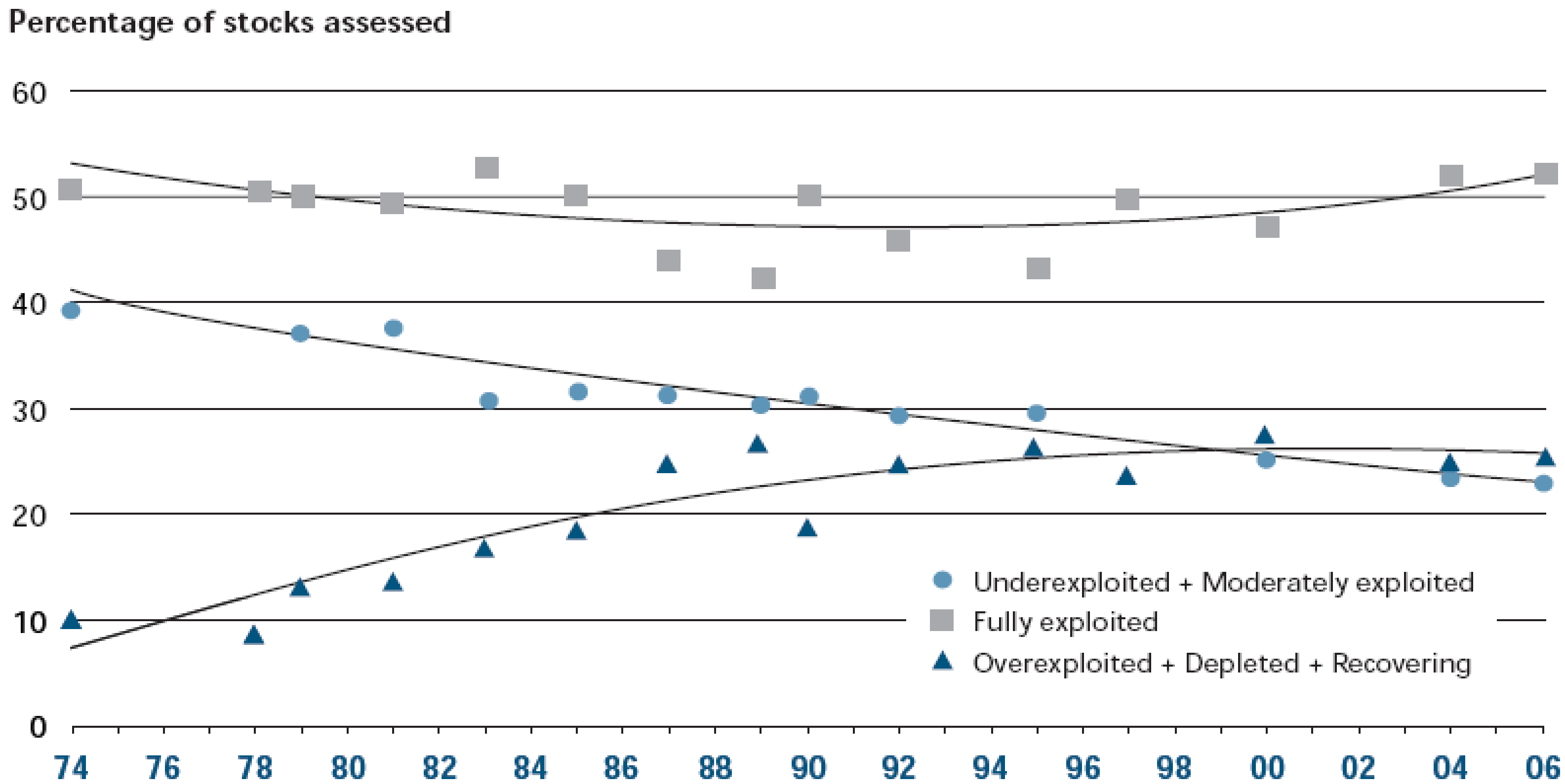
Murphy-Bokern Konzepte

Trends in world aquaculture production



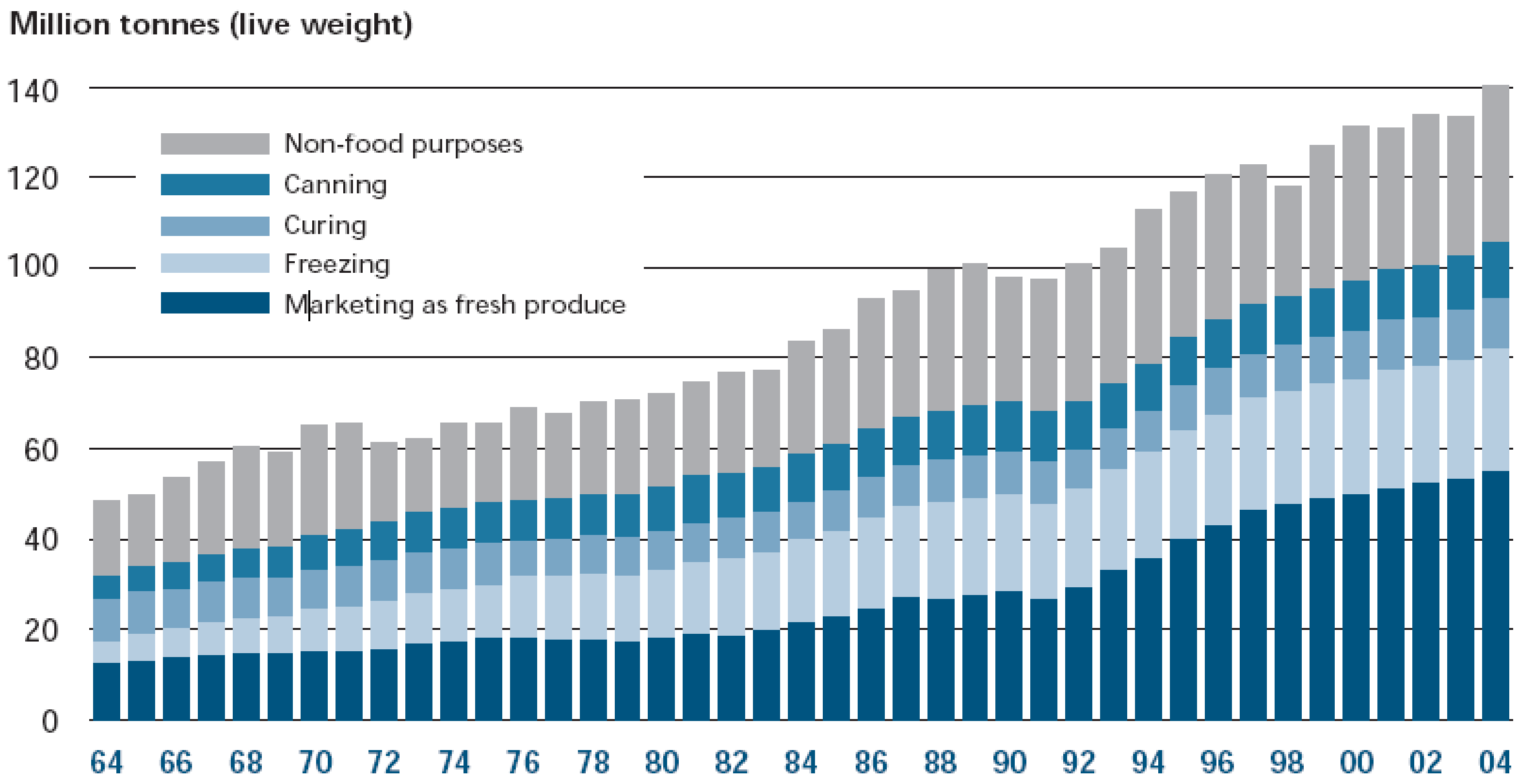
Source: FAO 2006. State of world fisheries

Global trends in the state of marine stocks since 1974



Source: FAO 2006. State of world fisheries

Ultilisation of world fisheries production 1964-2004



Source: FAO 2006. State of world fisheries

A quarter of a century after the introduction of milk quotas in Europe, we at last have clarity of purpose – "a renaissance"

"So here we have absolute clarity of purpose. Novel agricultural products and practices must be all about ensuring that wastage of water, essential nutrients and energy is kept to a minimum when we set the context as a necessity to elevate per hectare output and not increase the environmental footprint of agriculture. This is the truly 'green' agenda for global food production that all can embrace…."

Prof. Ian Crute

A second green revolution will be about overcoming constraints

It will be an ever-green revolution

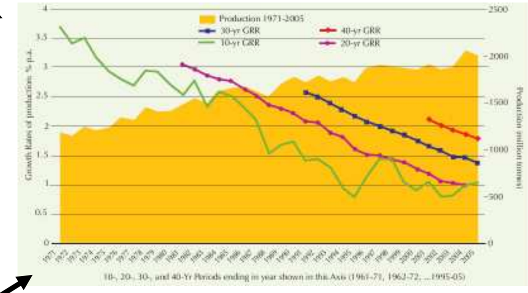
Climate change

Water availability

GHG mitigation

Soil degradation

Deforestation



Biodiversity

Water quality

Resources, e.g. P

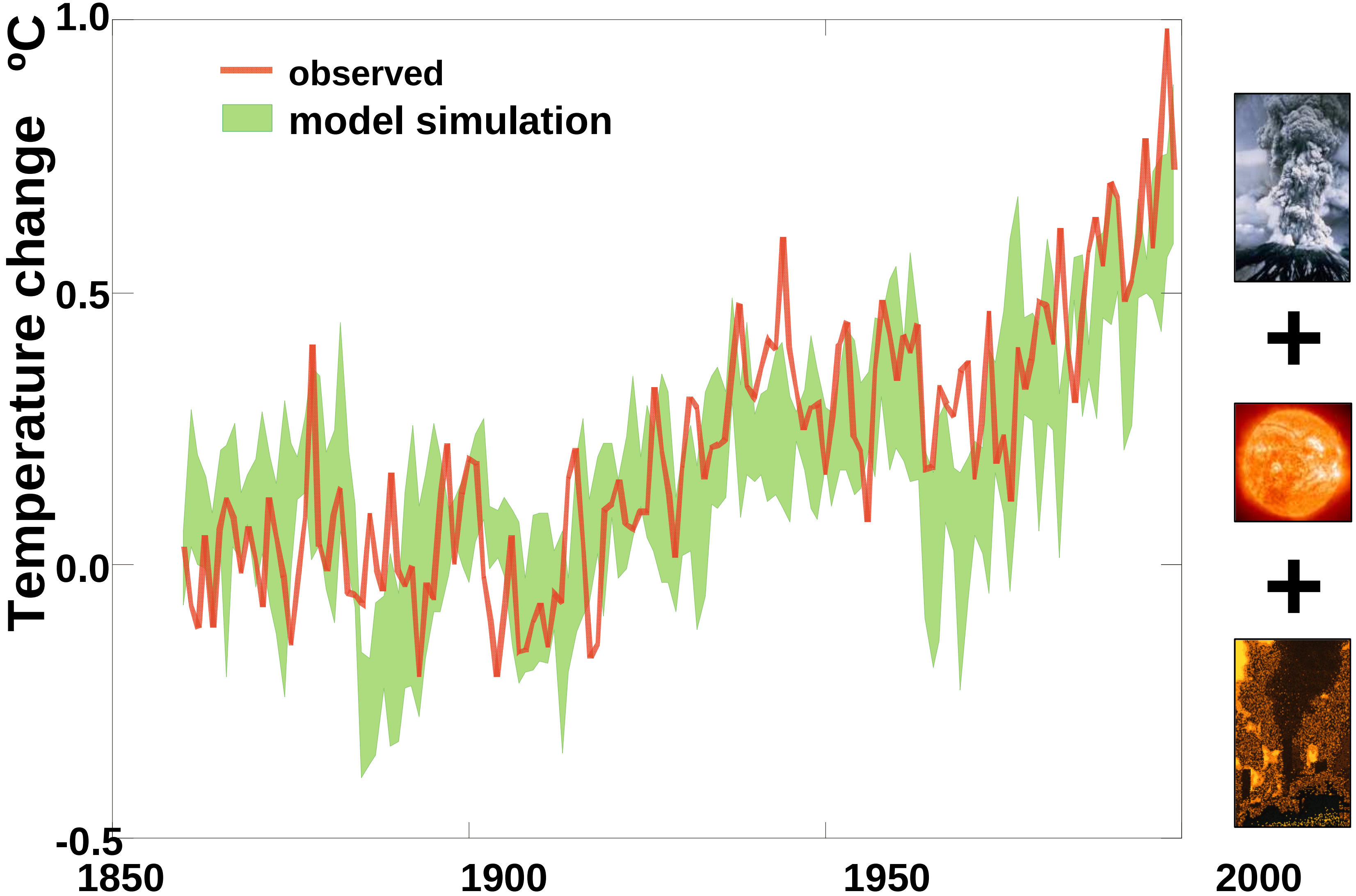
Murphy-Bokern Konzepte

Constraint 1 – Climate change

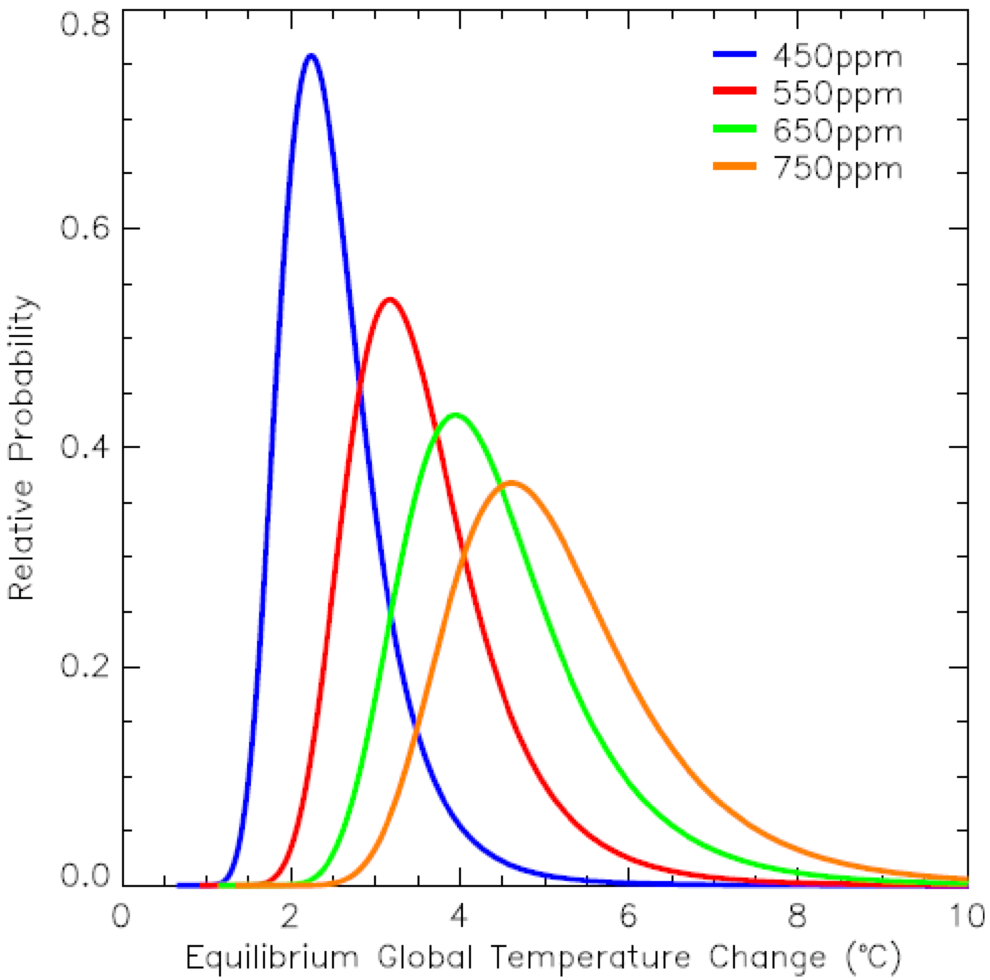
“Climate change is probably the greatest long-term challenge facing the human race.”

Tony Blair – Climate Change: The UK Programme 2006 (Defra)

Recent warming can be simulated when man-made factors are included



Global warming – the dangerous sting is in the risk tail

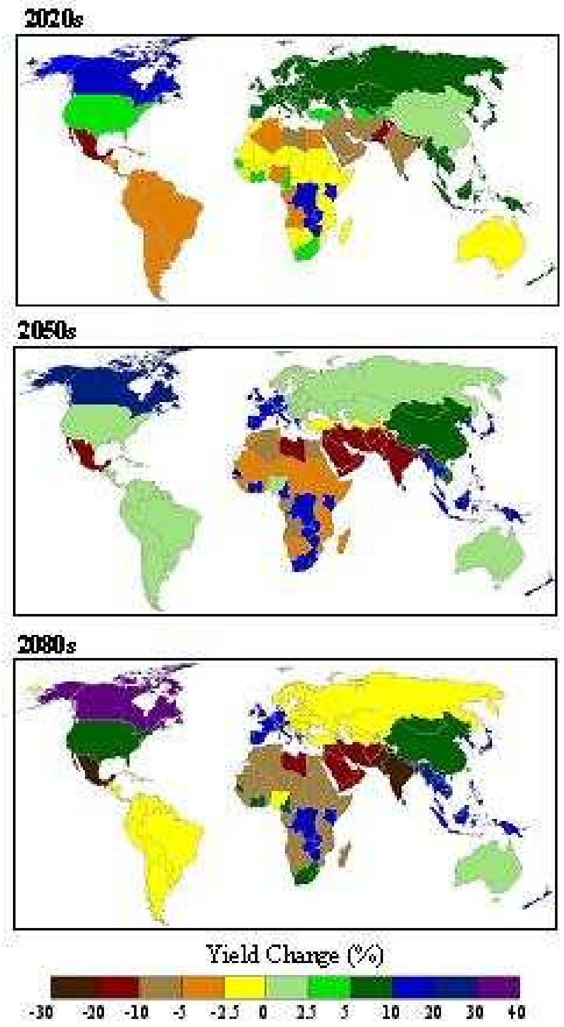


Source: Hadley Centre, cited by Sir David King

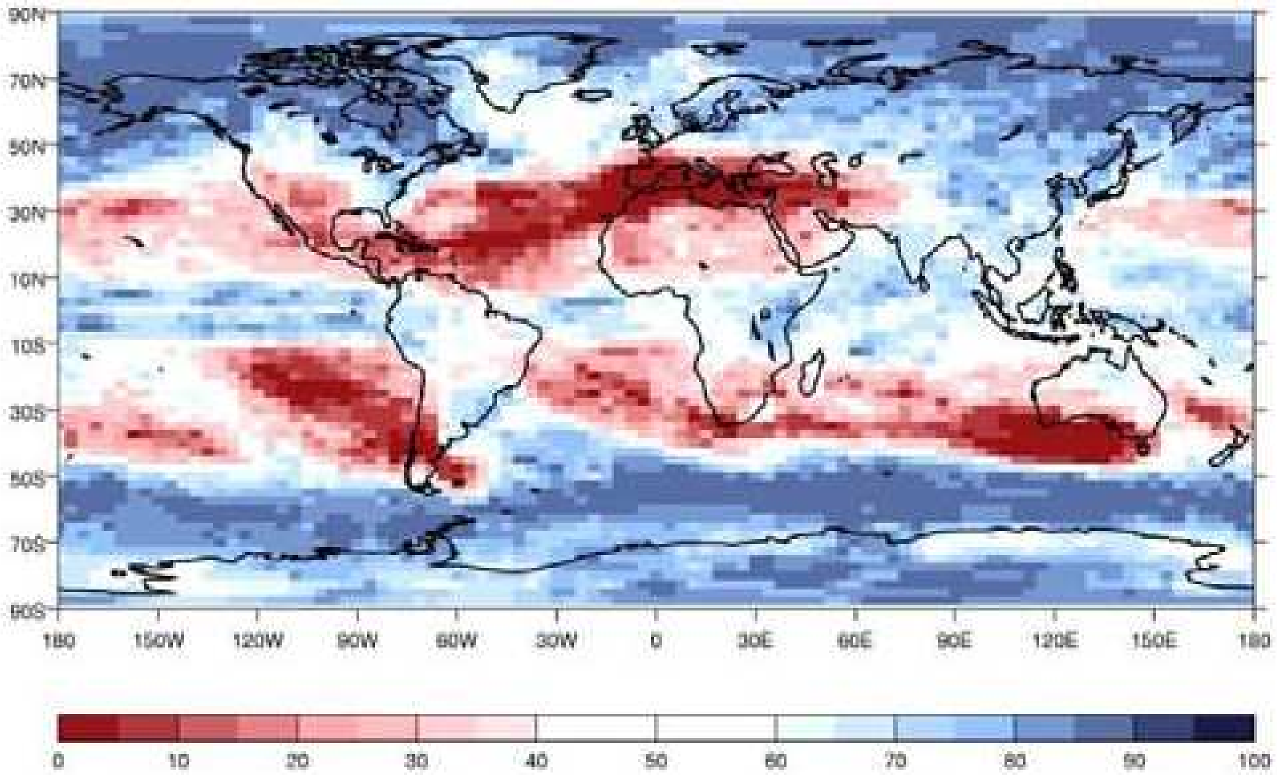
Murphy-Bokern Konzepte

Climate change and crop production

Models suggest that climate change effects on crop yield are positive or neutral at high latitudes, but negative at low latitudes



Consistency of future rainfall estimates

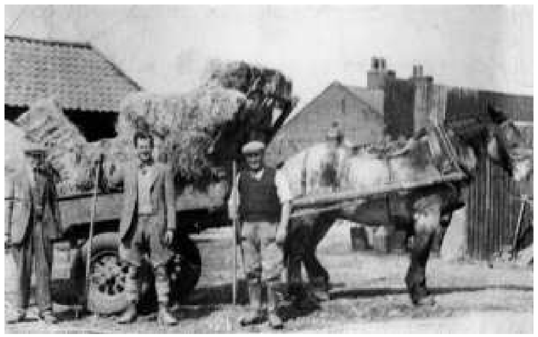


Map derived from the percentage of models (out of a total of 23) that predict that annual rainfall will increase by 2100 (for a warming of around 3.5℃ above pre-industrial). Blue shading indica tes that most models (>75%) show an increase in annual rainfall, while red shading indicates that most models show a decrease in rainfall. Lightly shaded areas are where models show inconsistent results. The figure shows only the direction of change and gives no information about its scale. In general, there is agreement between most of the models that high latitudes will see increases in rainfall, while much of the subtropics will see reductions in rainfall. Changes in rainfall in the tropics are still uncertain.

Source: *Climate Directorate of the National Centre for Atmospheric Science, University of Reading*

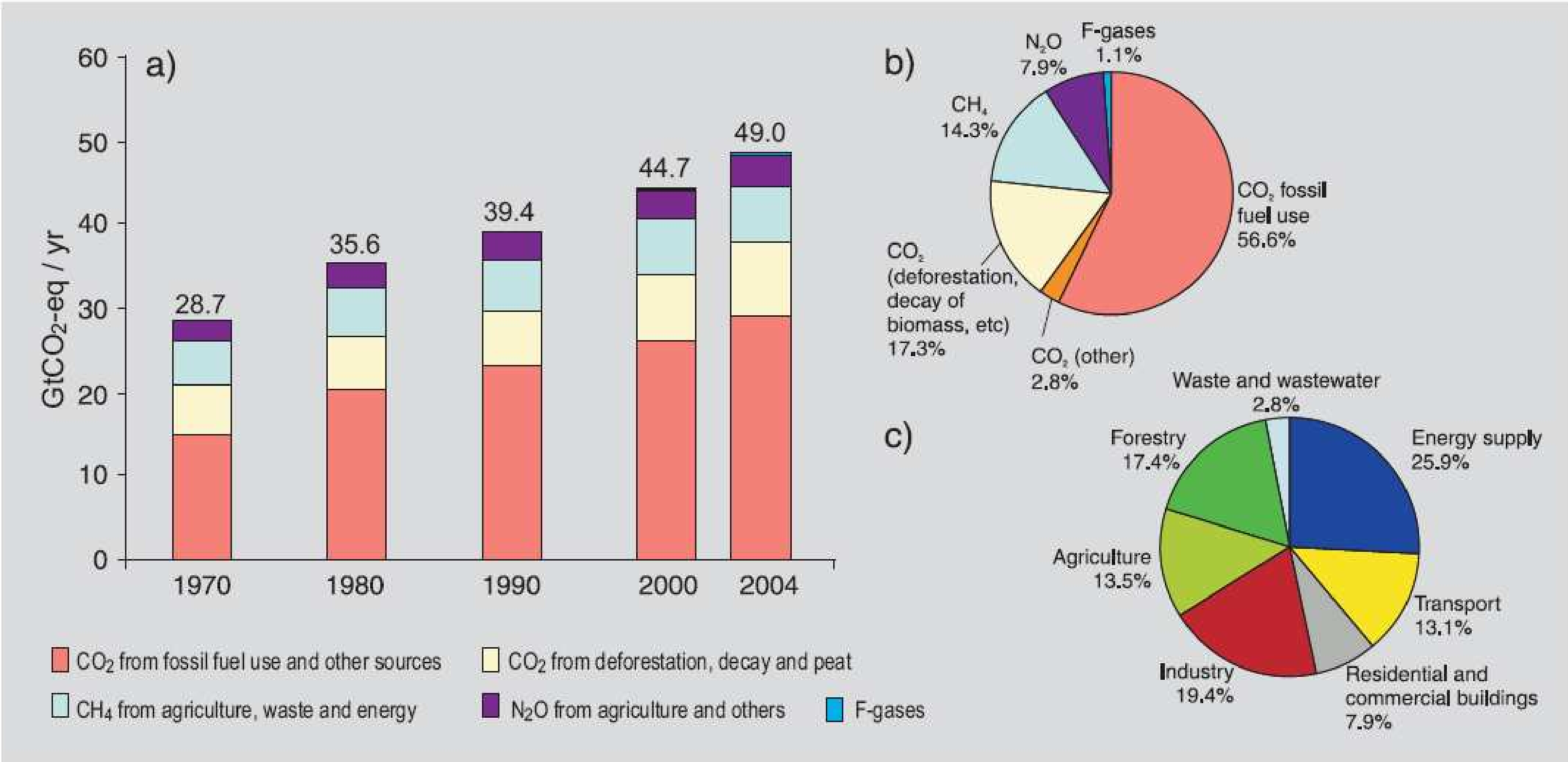
Adaptation planning is a natural part of farmers business and cropping plans

Provide farmers information at right scale and in right form and they will adapt as they always have



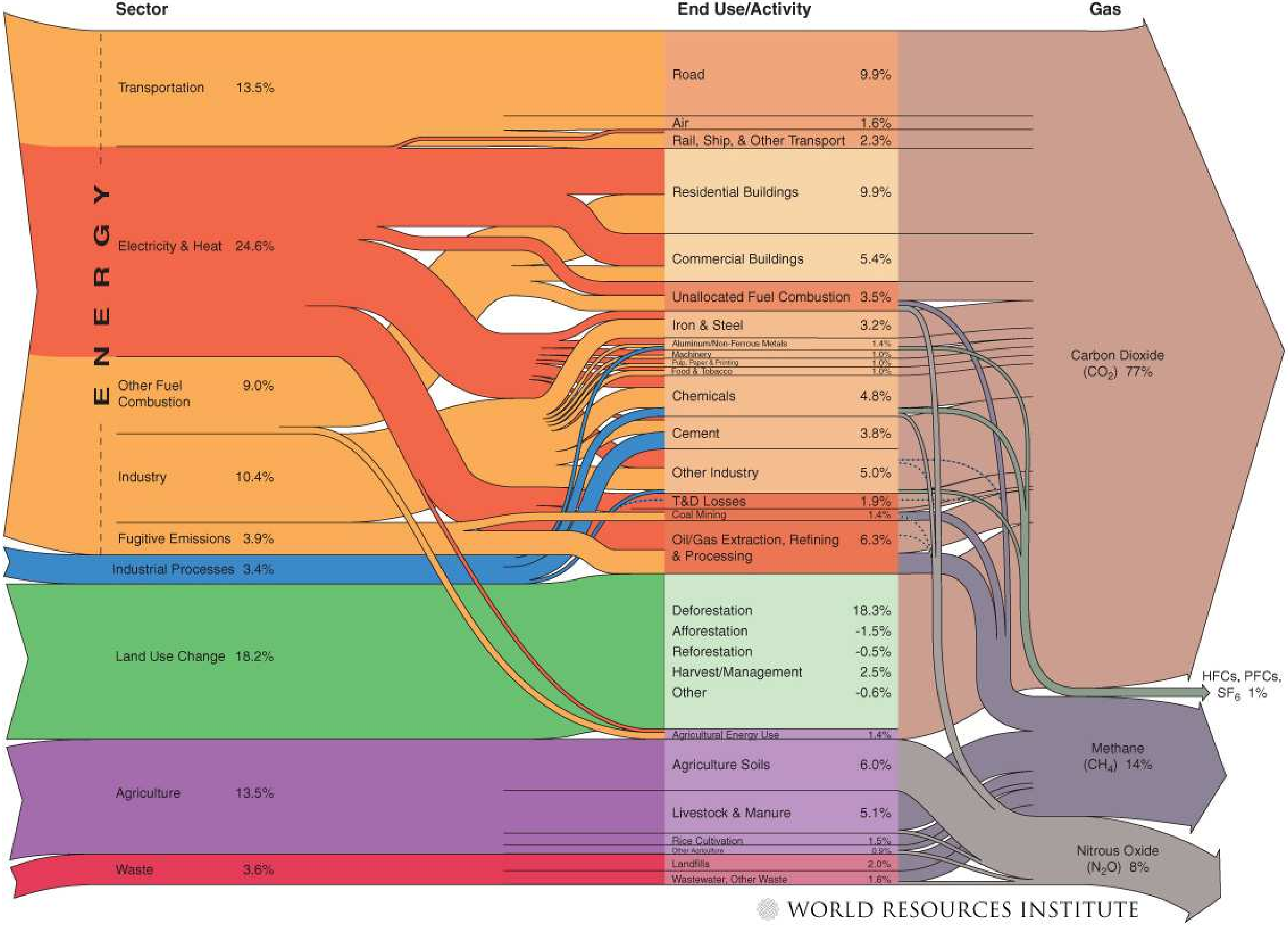
Murphy-Bokern Konzepte

Constraint 2
Mitigating global anthropogenic GHG emissions



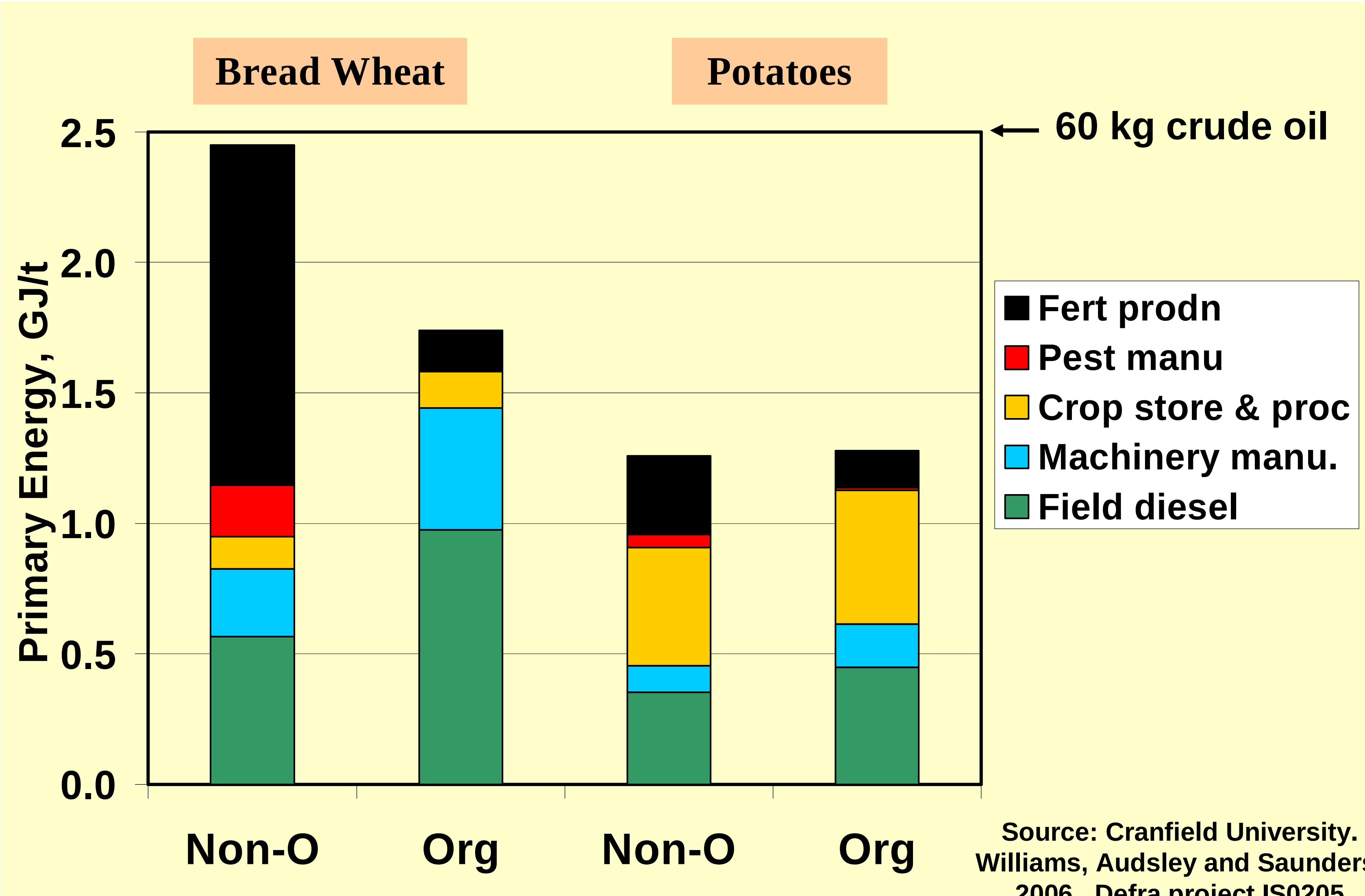
Source: IPCC Fourth Assessment Report

World GHG Emissions Flow Chart



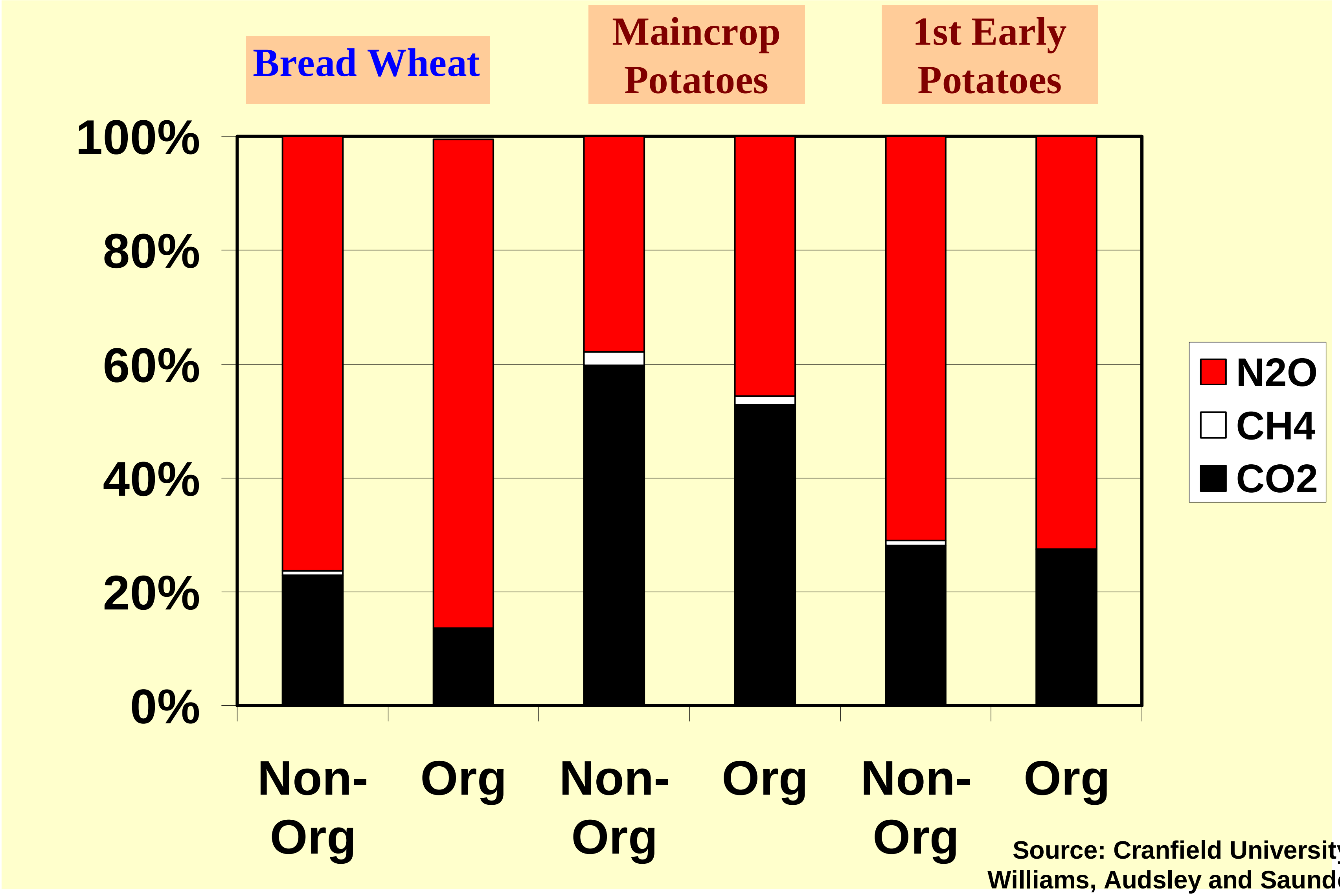
WORLD RESOURCES INSTITUTE

Distribution of primary energy use in bread wheat and potato production



Source: Cranfield University. Williams, Audsley and Saunders, 2006. Defra project IS0205

Distribution of GWP for three crops



Source: Cranfield University. Williams, Audsley and Saunders, 2006. Defra project IS0205

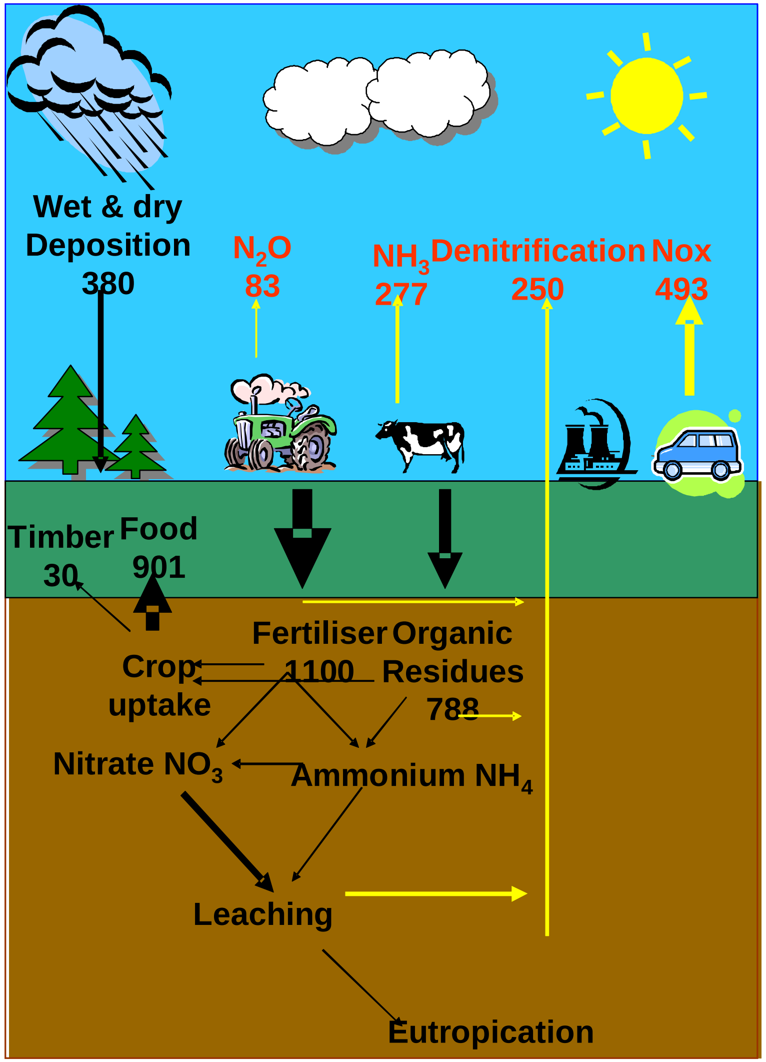
Main burdens in animal production (National Scale)

1 tonne of carcase meat, milk dry matter, 20,000 eggs

	Beef	Sheep Meat	Pig Meat	Poultry Meat	Eggs	Milk
Primary Enery, GJ	28	23	17	12	14	25
GWP100, t CO2 equiv.	16	17	6	5	6	11
EP, kg PO4 equiv.	160	200	100	49	77	64
AP, kg SO2 equiv.	470	380	390	170	310	160
ARU, kg antimony equiv.	36	27	35	30	38	28
Land use (grade 3a), ha	2.3	1.4	0.7	0.6	0.7	1.2
Crude Oil, kg	650	540	390	280	330	590

Source: Cranfield University.
Williams, Audsley and Saunders,
2006. Defra project IS0205

Food has a carbon-nitrogen footprint



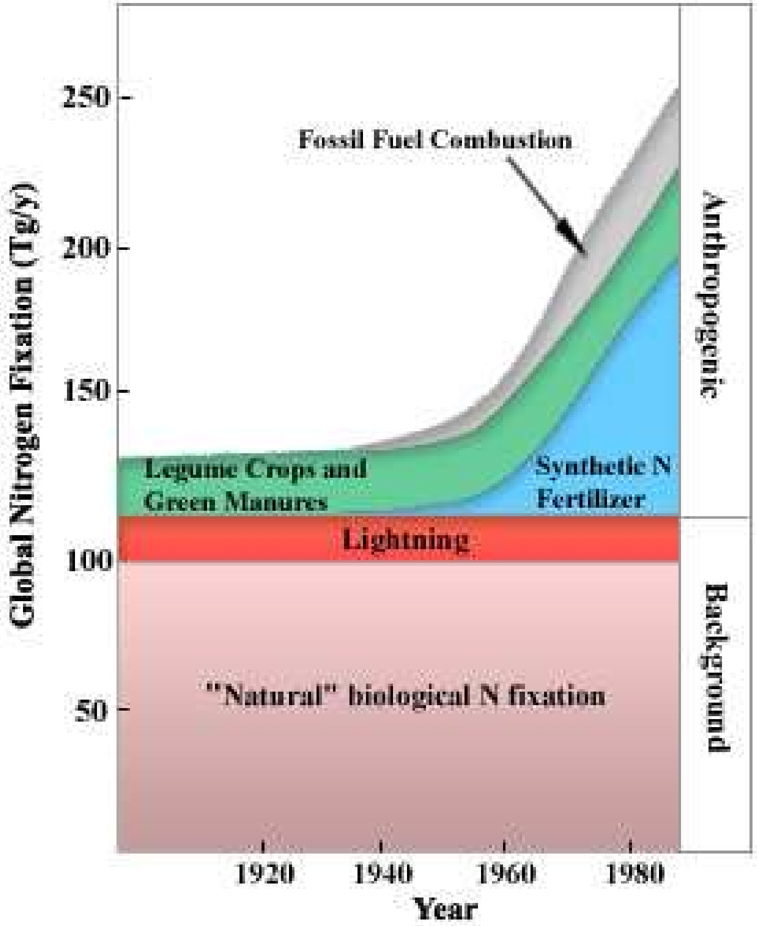
"… a carbon footprint inadequately describes agriculture; it has a *carbon-nitrogen footprint*…..The majority of environmental burdens arising from the production of agricultural food commodities arise either directly or indirectly from the nitrogen cycle and its modification….."

(Adrian Williams, Eric Audsley and Daniel Sandars of Cranfield University – Executive summary of the Defra Project Report IS0205)

Improving the nitrogen economy lies at the centre of agricultural mitigation

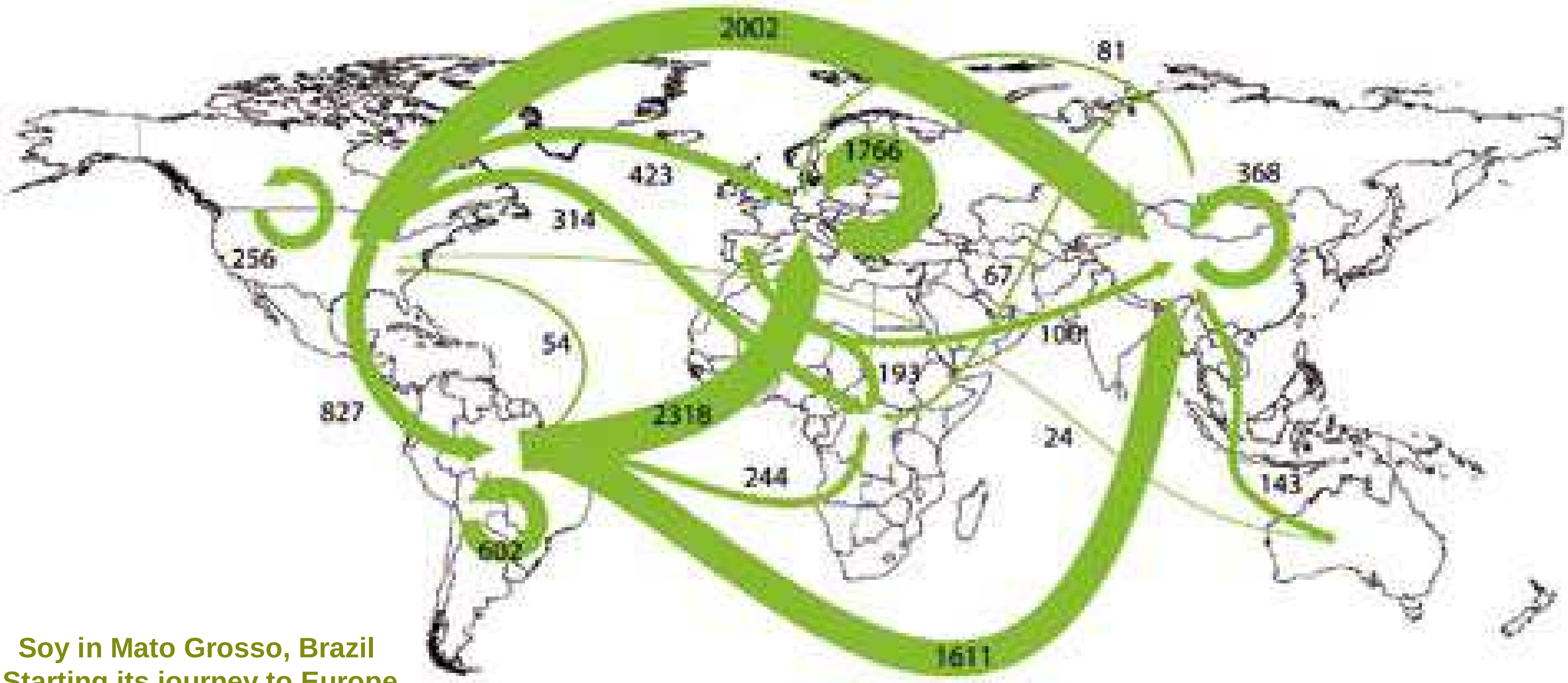
Murphy-Bokern Konzepte

Mankind has doubled nitrogen fixation – mostly since 1945



Recent increases in anthropogenic N fixation in relation to "natural" N fixation. Modified from Vitousek, P. M. and P. A. Matson (1993). Agriculture, the global nitrogen cycle, and trace gas flux. The Biogeochemistry of Global Change: Radiative Trace Gases. R. S. Oremland. New York, Chapman and Hall: 193-208.

Nitrogen contained in internationally traded crops



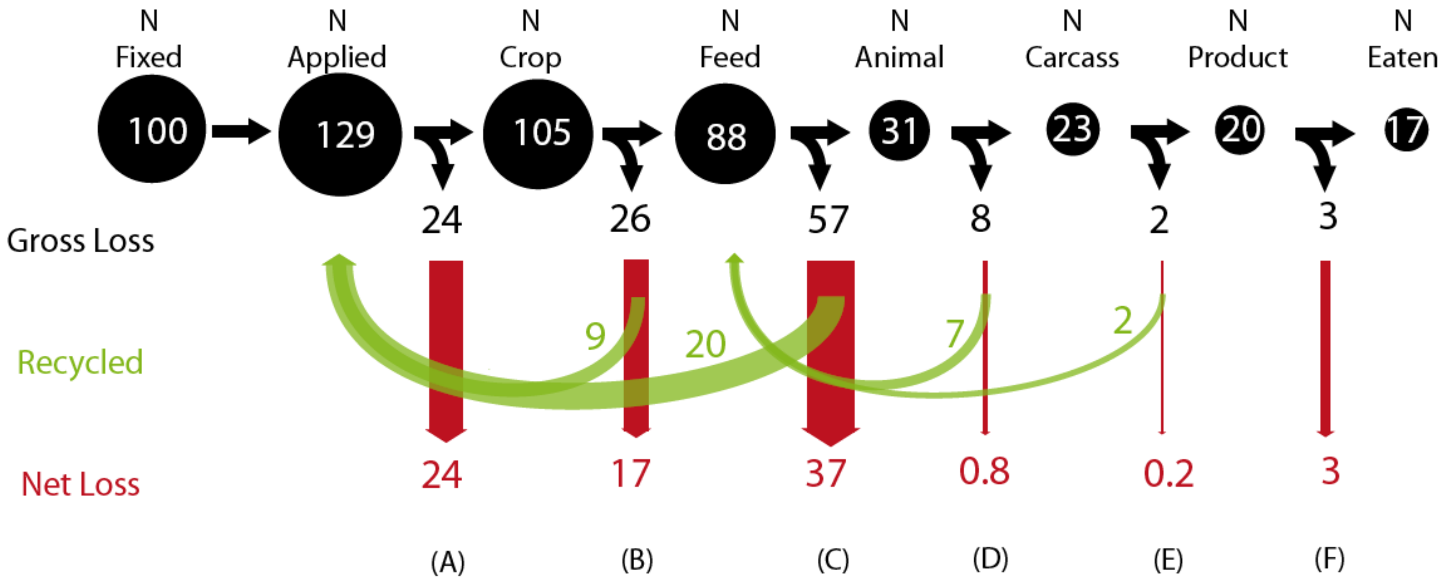
Soy in Mato Grosso, Brazil
Starting its journey to Europe

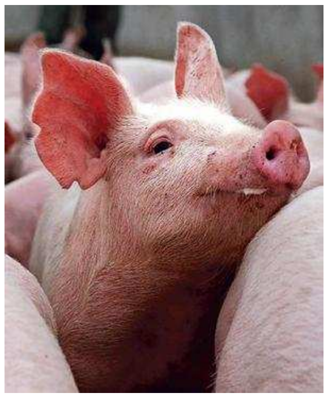
Source: Lalo de Almaida for the New York Times

2004 data in thousands of tons of N; minimum requirement for drawing a line is 20,000 tons N. The total amount of nitrogen transferred in the trade of crop commodities was 11.5 million tonnes in 2004. (From Braun, 2007).

Murphy-Bokern Konzepte

Fate of nitrogen entering the pigmeat production chain



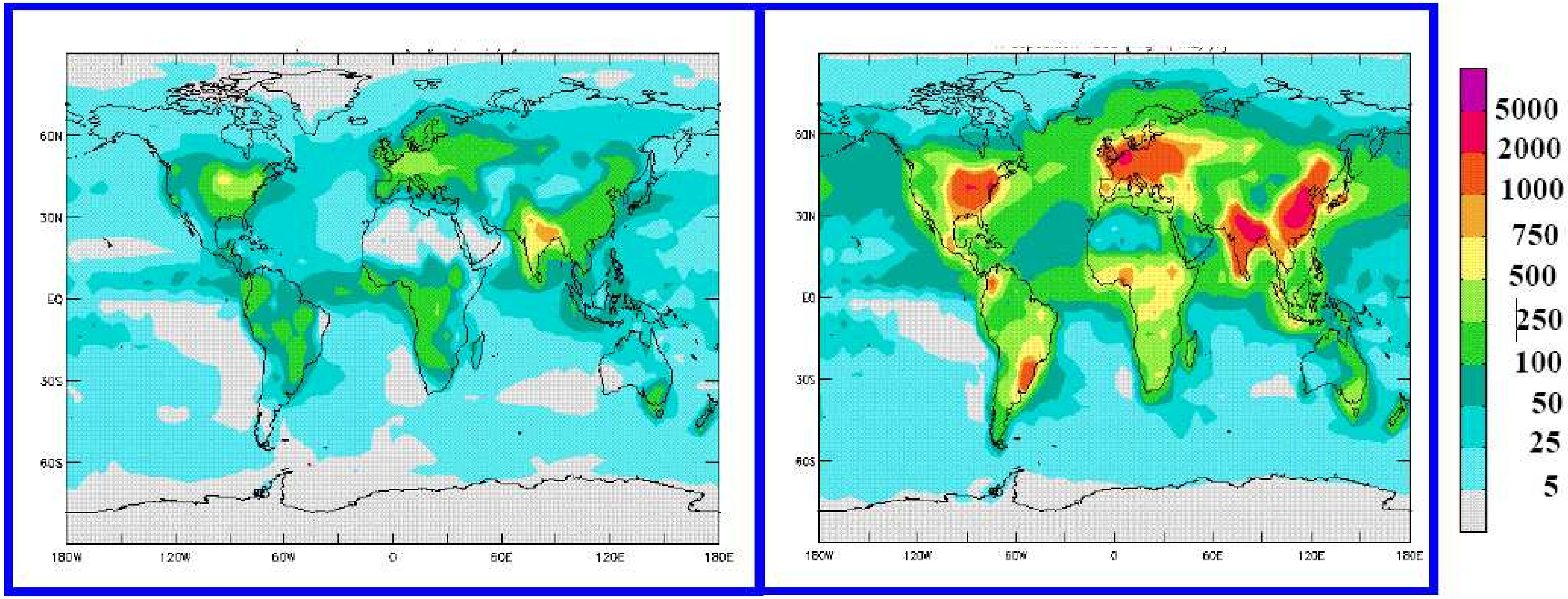


Source: Galloway et al. cited by Braun (2007).

Murphy-Bokern Konzepte

Nitrogen deposition

mg/m2/year



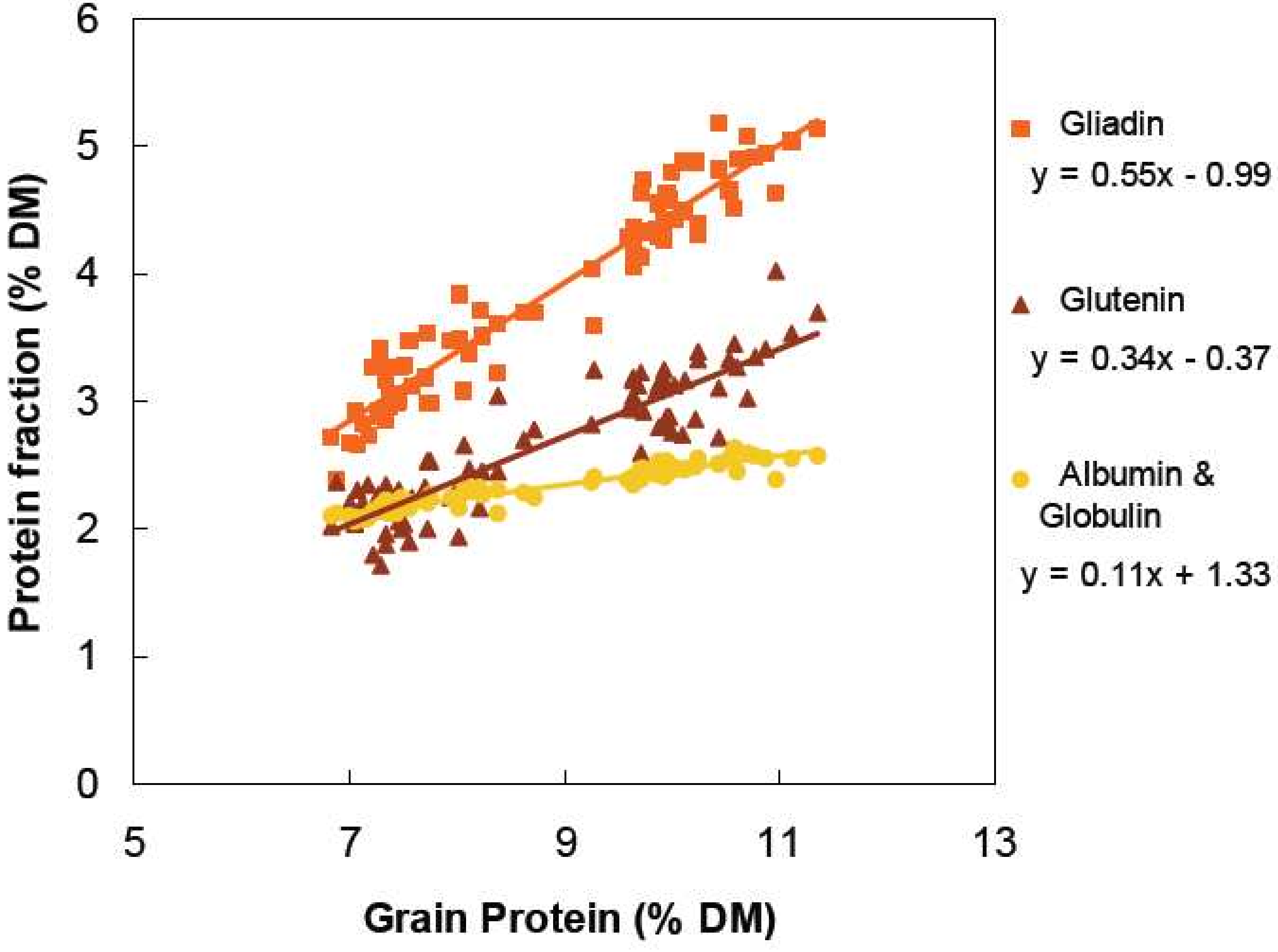
1890

1993

Source: Galloway and Cowling, 2002

Murphy-Bokern Konzepte

Increasing the nitrogen use efficiency of cereal and oilseed based food chains



Source: The Defra and SEERAD sponsored Green Grain Project

CIMMYT
International Maize and Wheat Improvement Center

Home Research

CIMMYT E-News,

Wild grasses lighten wheat's nitrogen footprint

Masahiro Kishii, CIMMYT wheat cytogeneticist, stands next to a plant (center) of *Leymus racemosus*, a wild relative of wheat that grows on sea shores and which, in addition to exuding nitrification inhibitors, carries tolerance to saline soils and resistance to fungal diseases of wheat. Directly to the right is a plant of the first filial generation of the cross between *L. racemosus* and wheat.

In work cited in Science *magazine, a research team from JIRCAS (Japan) and CIMMYT uses a grassy relative of wheat as a source of genes to inhibit soil nitrification and the associated release of nitrous oxide, a notorious greenhouse gas, from wheat cropping.*

Nitrogen, the major component of the air we breathe and the basic building block of plant and animal proteins, exists in the atmosphere as an inert gas. Plants, including cereal crops like wheat, do not use nitrogen in this form. They require the help of bacteria that fix the element in the soil or break down animal wastes and tissue, creating nitrogen-rich compounds. In modern agriculture, humans apply fertilizers containing those compounds to make crops grow better.

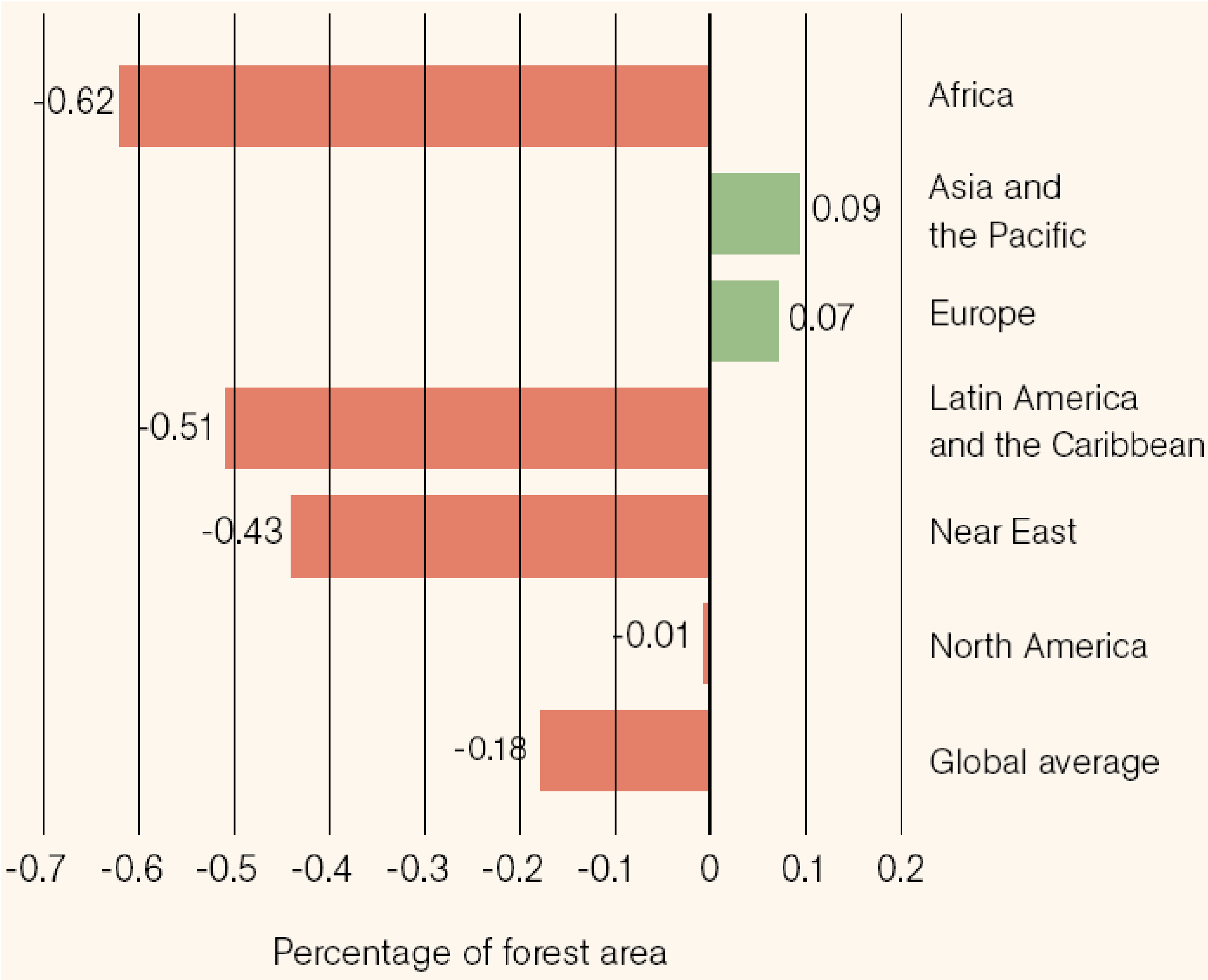
Reconnecting plant and livestock production
Closing the nitrogen cycle

Harvesting and milling rye for feeding pigs in Kroge-Ehrendorf, Germany

Murphy-Bokern Konzepte

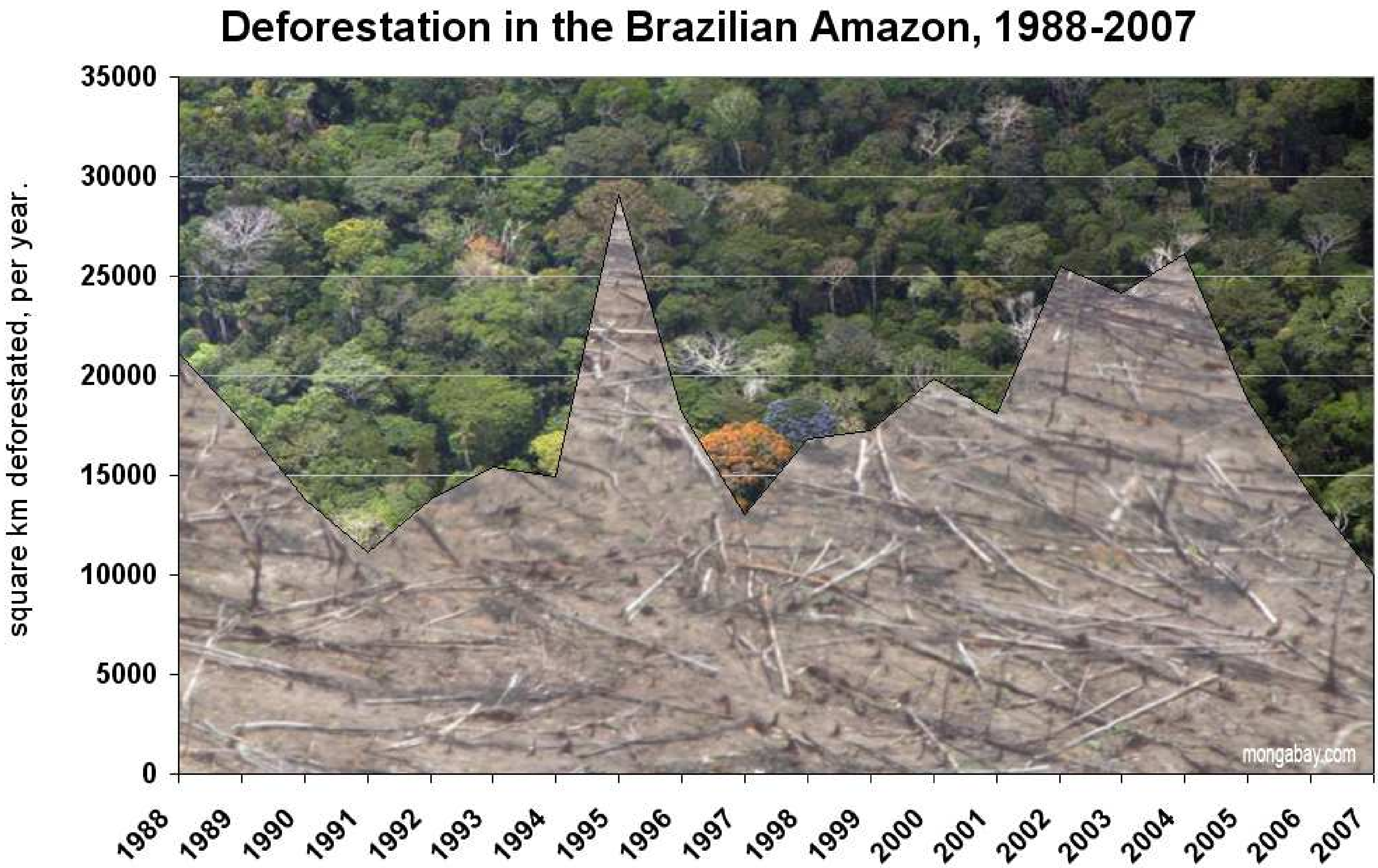
Constraint 3 Avoiding deforestation

Annual net change in forest area 2000-2007



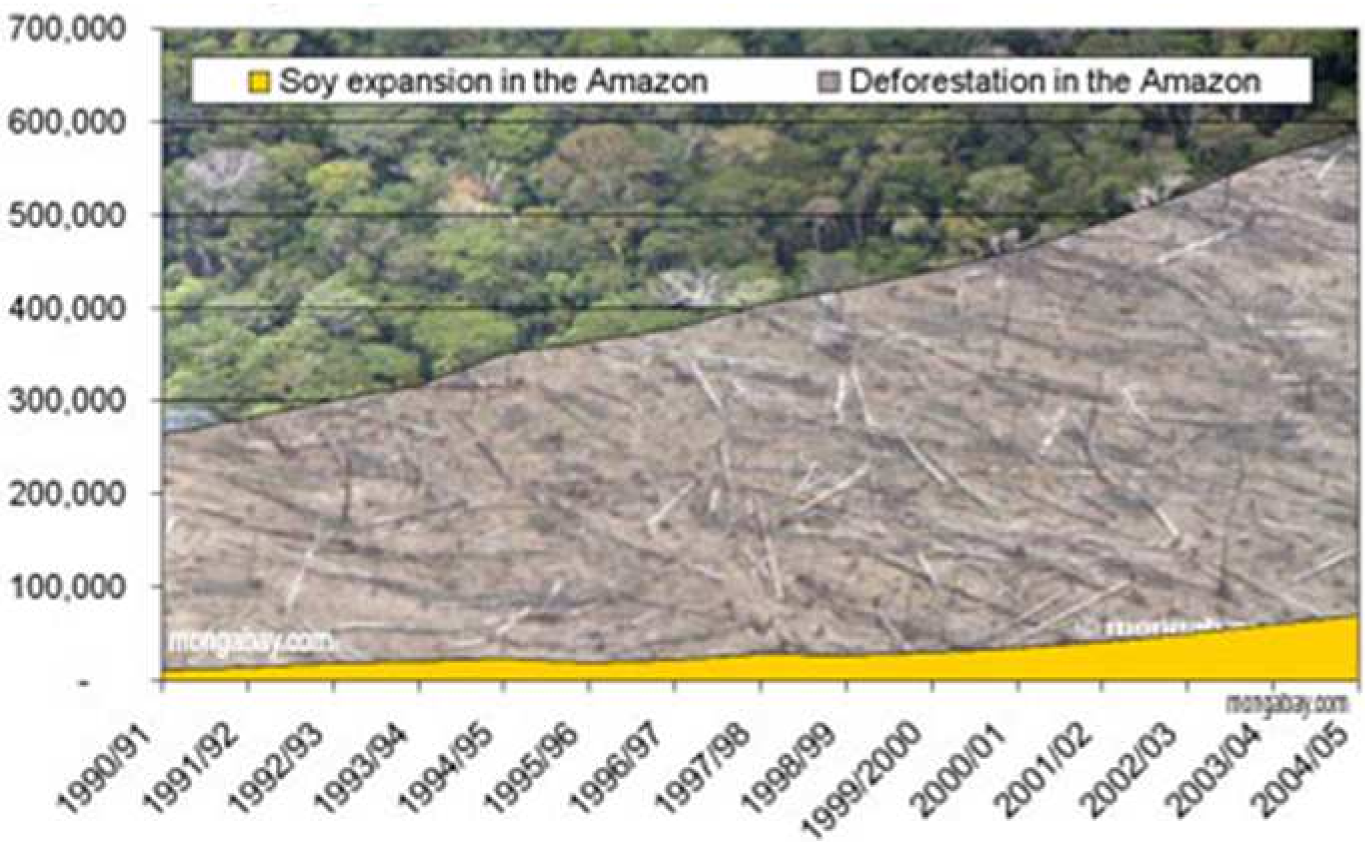
Source: FAO 2006, State of the world's forests

Murphy-Bokern Konzepte



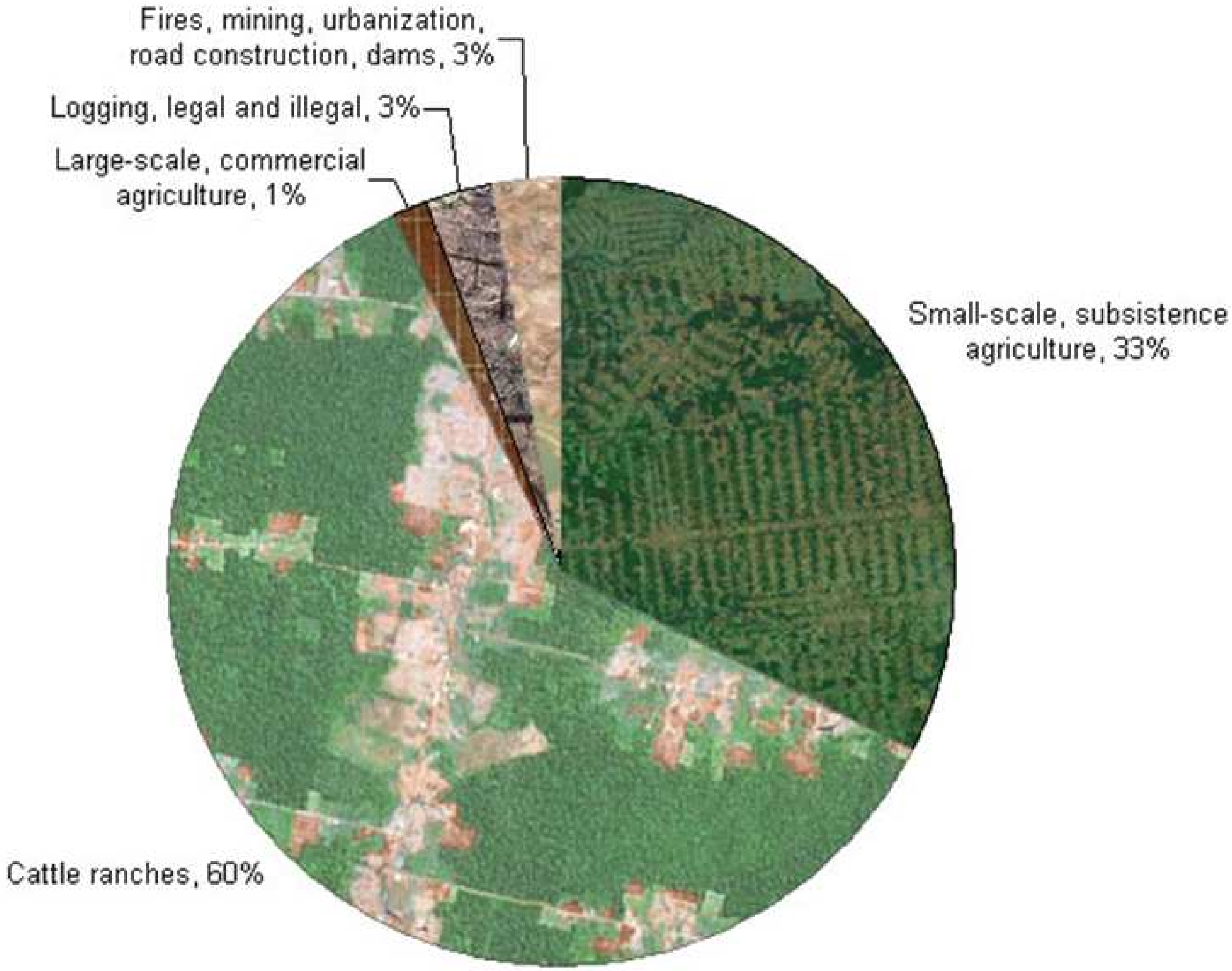
Source: Mongabay.com

Soy expansion in the Amazon in 2000-2005



Source: Mongabay.com

Use of land in the Amazon deforested in 2000-2005



Source: Mongabay.com

Source: Mongabay.com

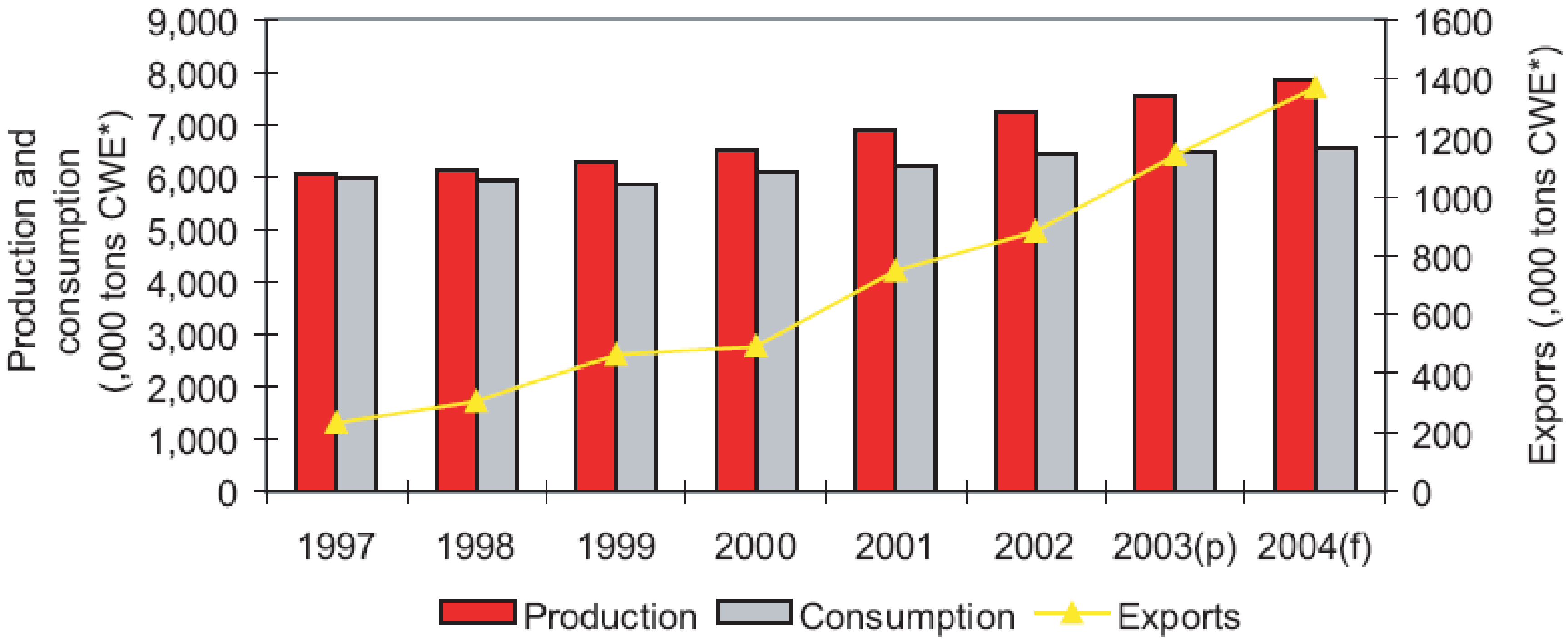
Hamburger Connection Fuels Amazon Destruction[1]

Cattle ranching and deforestation in Brazil's Amazon

CENTER FOR INTERNATIONAL FORESTRY RESEARCH
David Kaimowitz, Benoit Mertens, Sven Wunder and Pablo Pacheco

Murphy-Bokern Konzepte

Changes in Brazilian beef production and consumption between 1997 - 2004



Source: United States Department of Agriculture (USDA),

Murphy-Bokern Konzepte

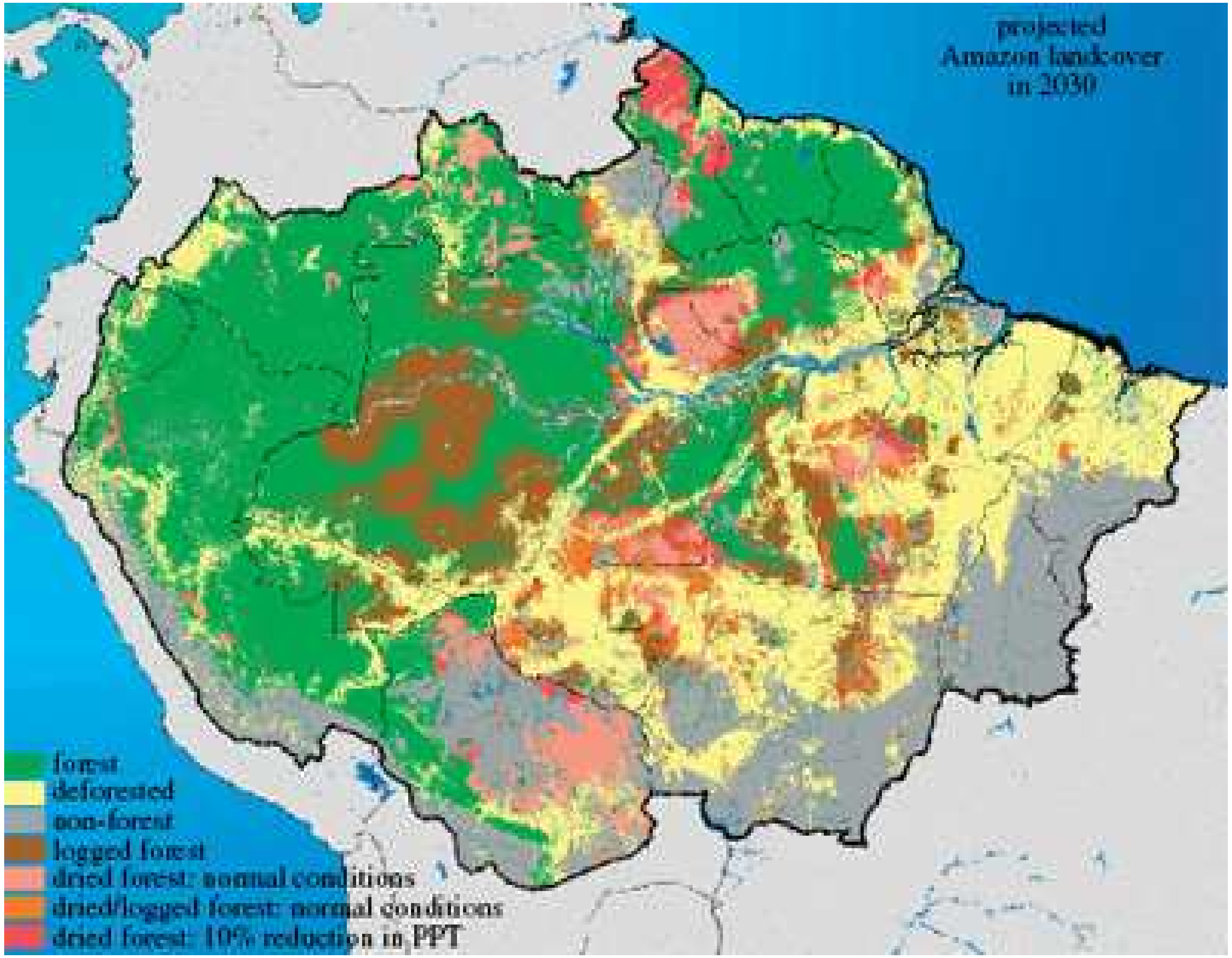
Commodity markets driving agriculture north

Credit Aliança da Terra

Source: Paula Fridman/Carbis, Business Week May 22, 2008

Murphy-Bokern Konzepte

Projected deforestation to 2030



The Brazilian Amazon in 2030, showing drought-damaged, logged, and cleared forests. This map assumes that deforestation rates of 1997-2003 continue into the future, and that the climatic conditions of the last 10 years are repeated into the future. From Soares-Filho et al. 2006, Nepstad et al. 2004, 2007, Nepstad and Stickler in press, Merry et al. in review. (See Supplemental Online Material for description of methods at http://whrc.org/Brazilcarbonsupplement

Rational economic behaviour is driving deforestation

Source: WWF

Murphy-Bokern Konzepte

Net present value of sustainably managed forest
0 – 350 USD/ha

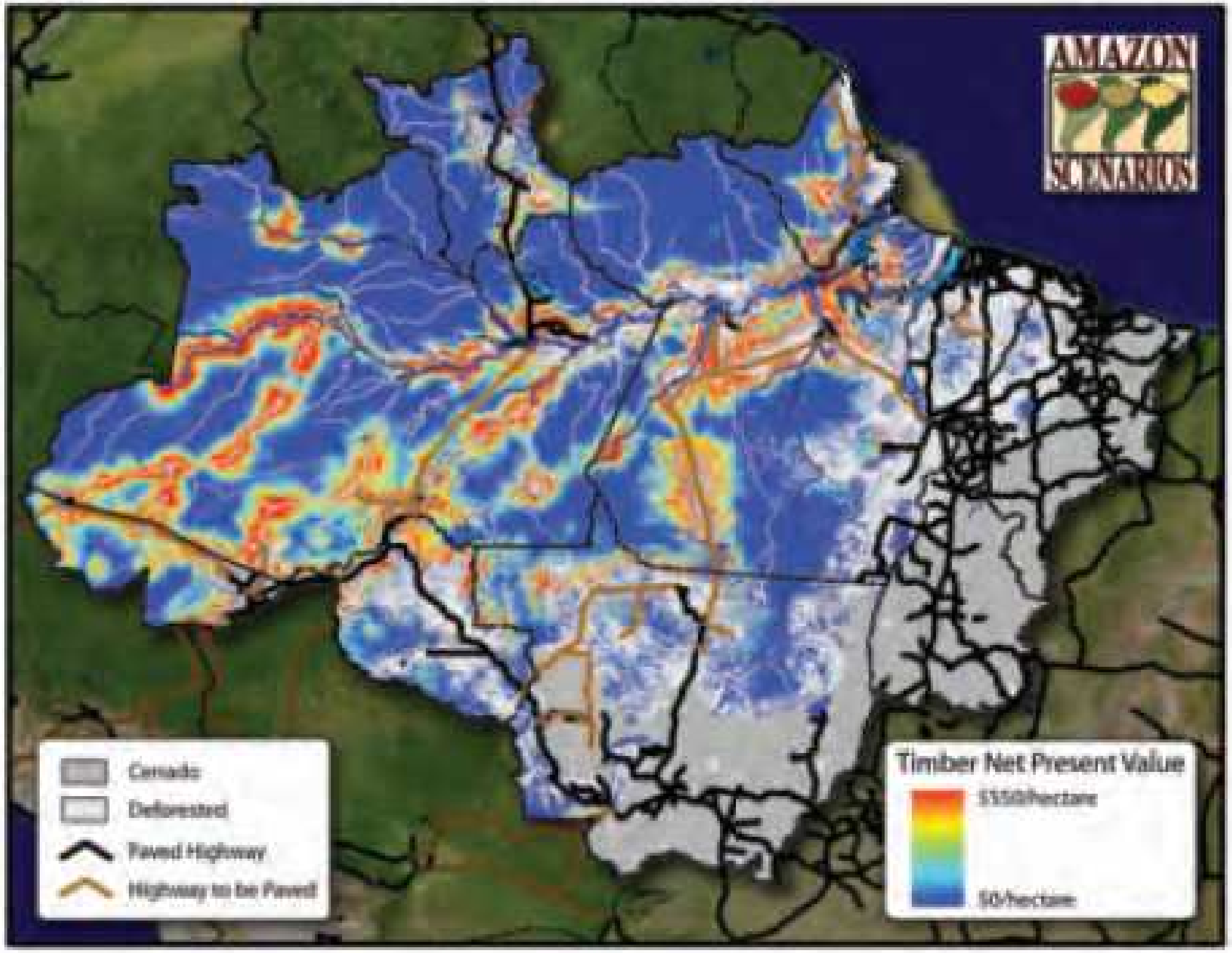


Figure 5. Potential net present value of sustainable timber production (2007–2037) for the forests of the Brazilian Amazon. Processing centers in this run of the timber rent model are restricted to annual harvests of 1/30th of the profitably harvestable timber stocks, thereby "forcing" the industry into sustainable, 30-year rotations. See http://.whrc.org/Brazilcarbonsupplement for model description.

Net present value of cattle pasture
0 – 1150 USD/ha

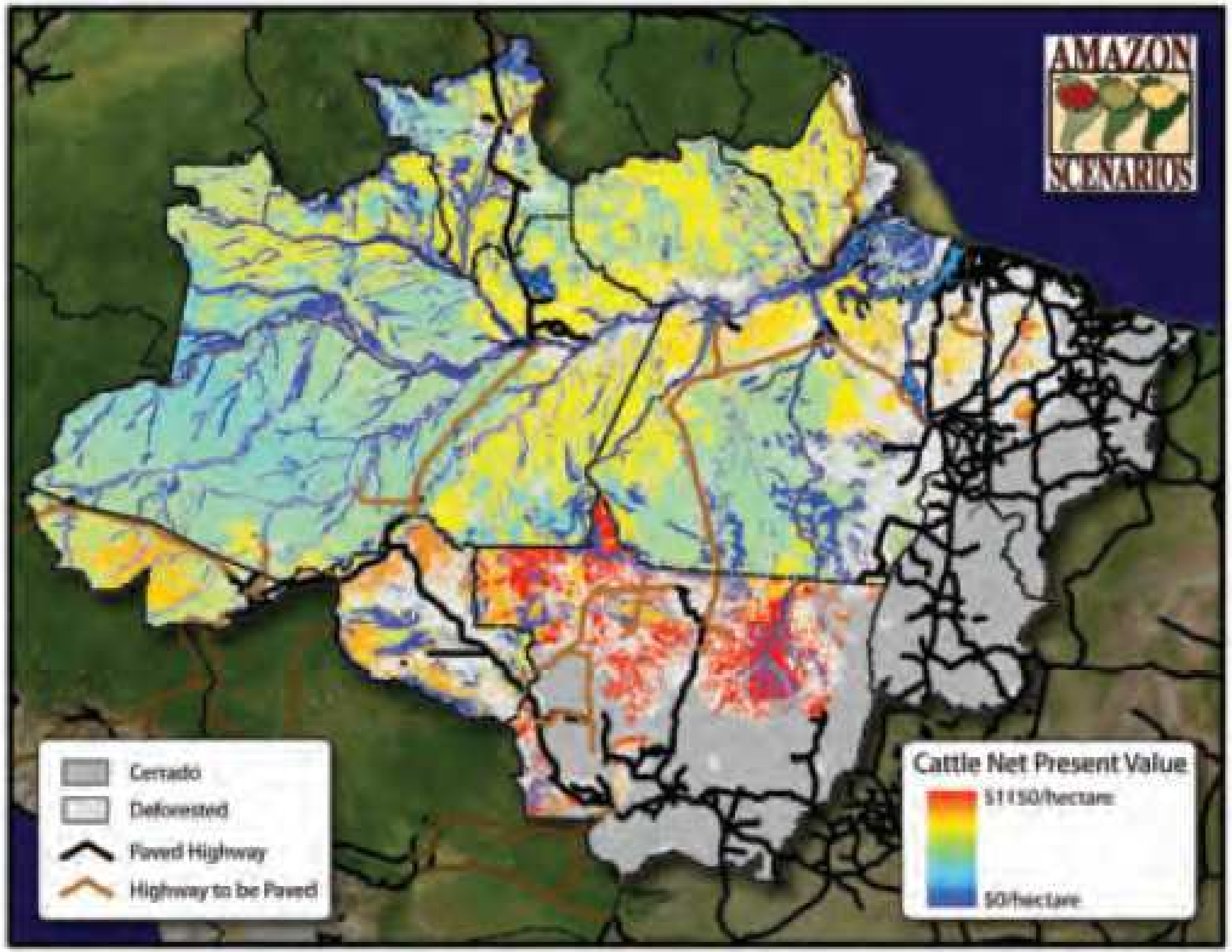


Figure 4. Potential net present value of cattle production (2007-2037) on the forested lands of the Brazilian Amazon. (http://whrc.org/Brazilcarbonsupplement).

Net present value of land for soy
0 – 12,000 USD/ha

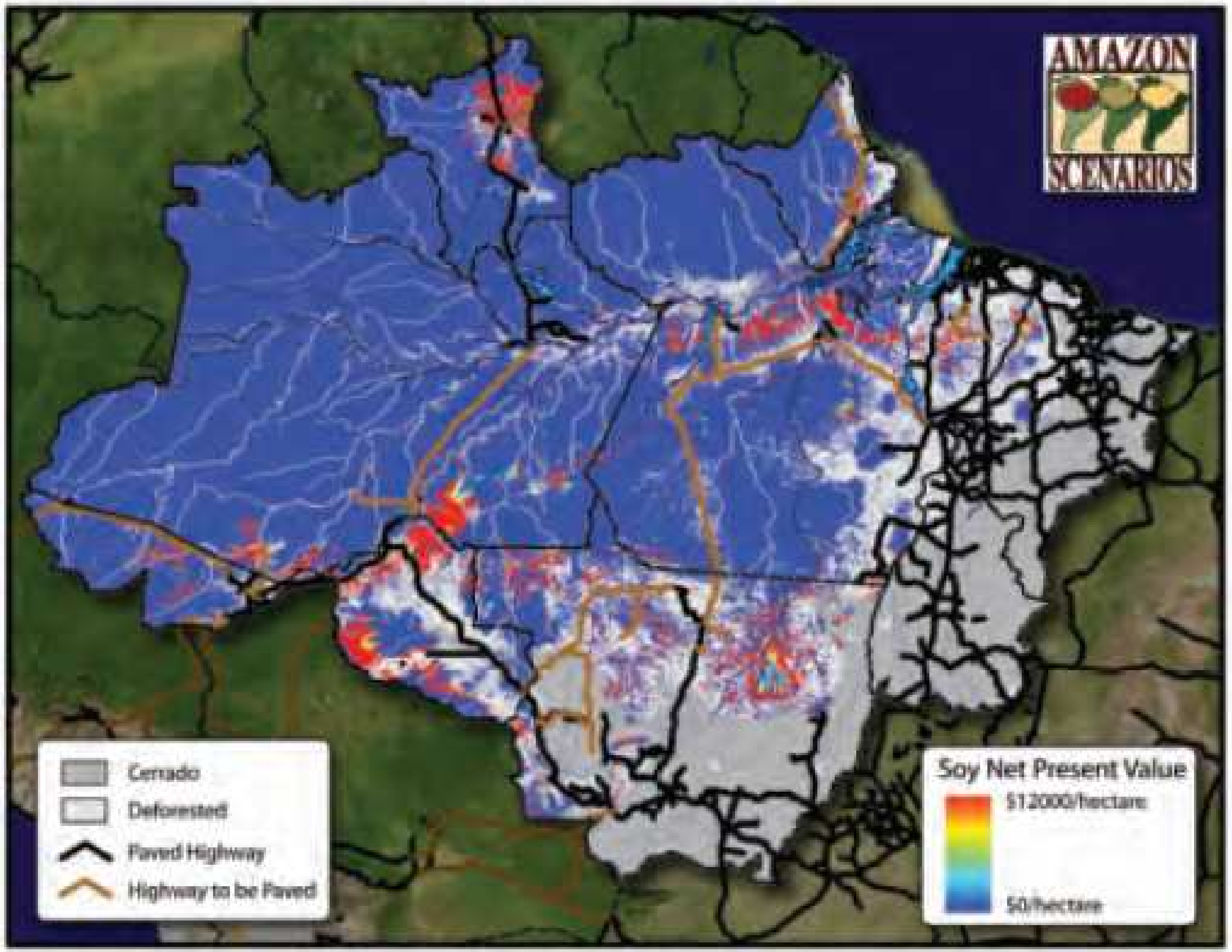


Figure 3. The potential net present value (2007 through 2037) of soy production on the forested lands of the Brazilian Amazon. (http://whrc.org/Brazilcarbonsupplement, Vera Diaz et al. 2007.)

Opportunity cost of carbon through land management
0 – 100 USD/t

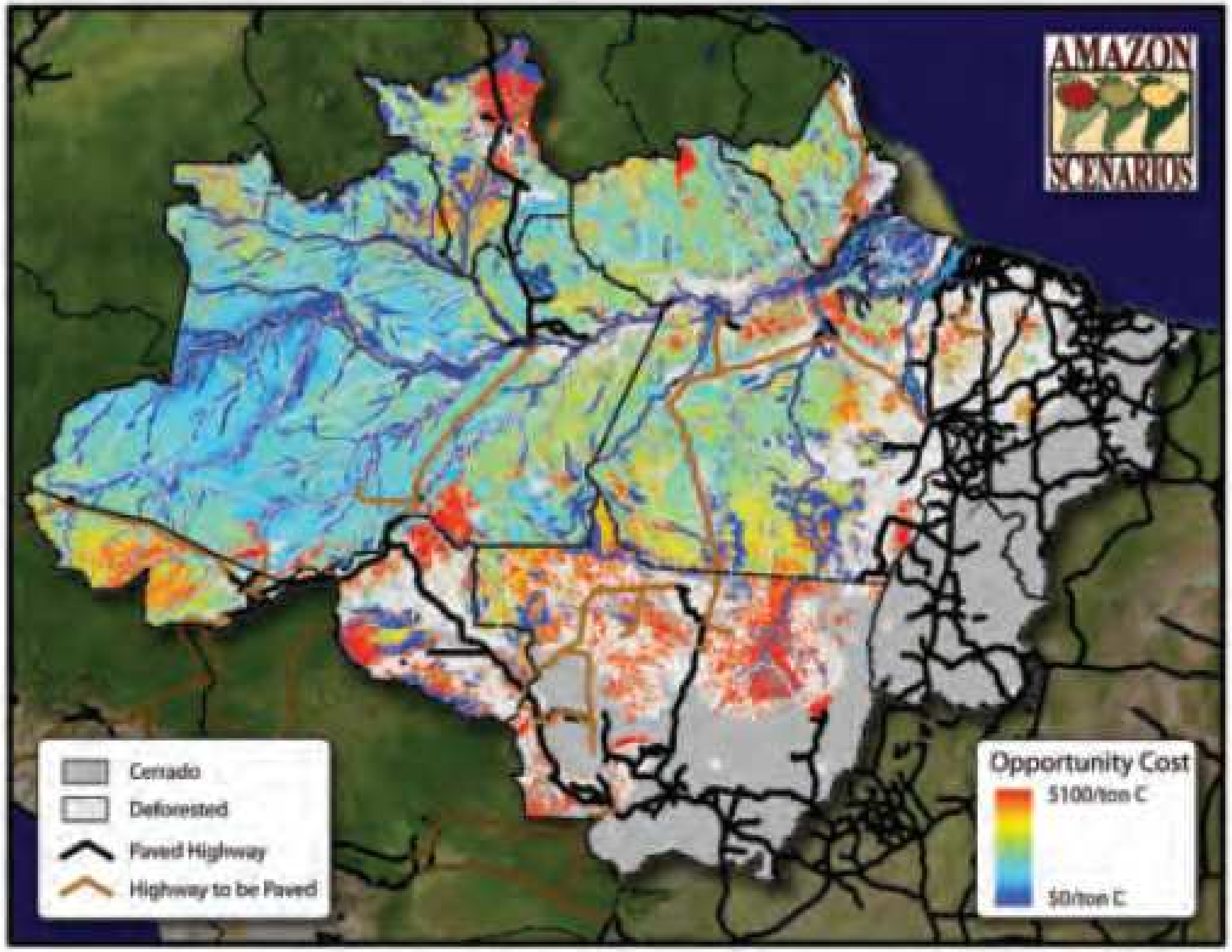


Figure 7. Net opportunity cost of forest protection in the Brazilian Amazon. Calculated as maximum net present value of soy or cattle production minus NPV of timber. The value was then divided by forest carbon stocks (Figure 6).

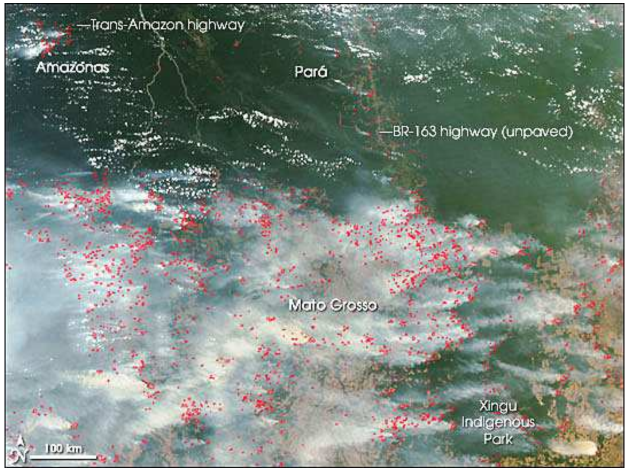
http://whrc.org/BaliReports/assets/WHRC_Amazon_REDD.pdf

Reducing deforestation – four market based approaches

Reduced emissions from deforestation and degradation REDD

Increase the value of forest

Sustainable forest management



Farm produce certification

Reduce the value of agricultural land at the forest frontier

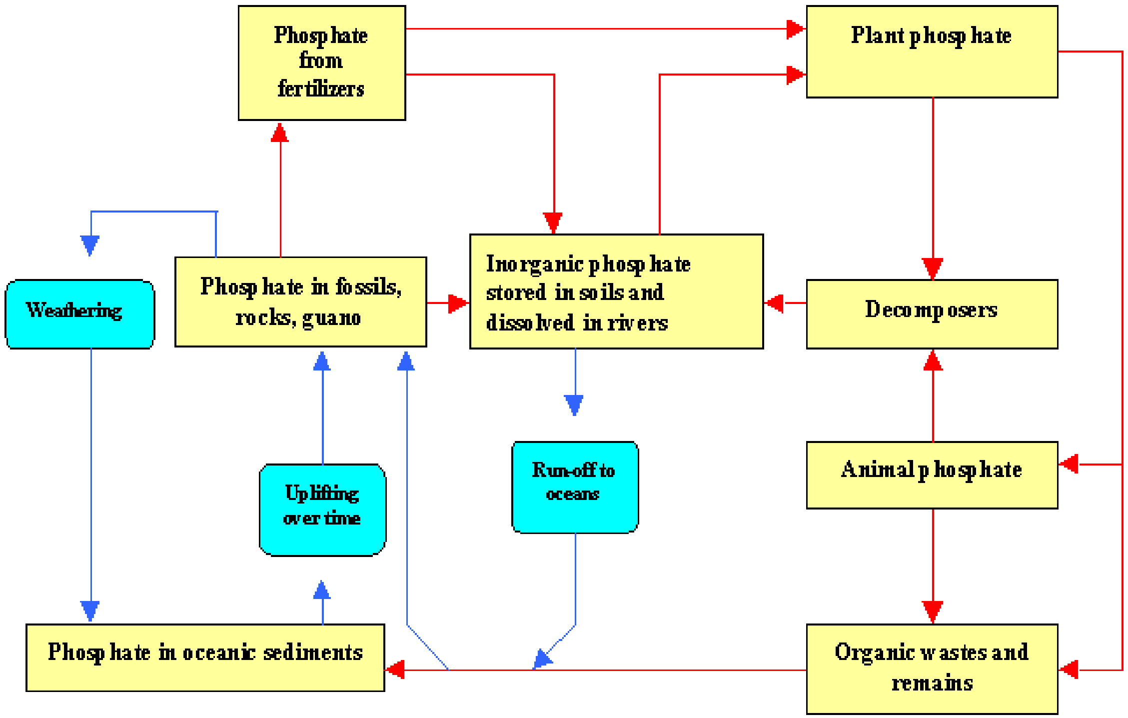
Increase crop performance in established areas

Murphy-Bokern Konzepte

Farm produce certification

Preferential access to premium European markets
UK retailers could pioneer new market relationships

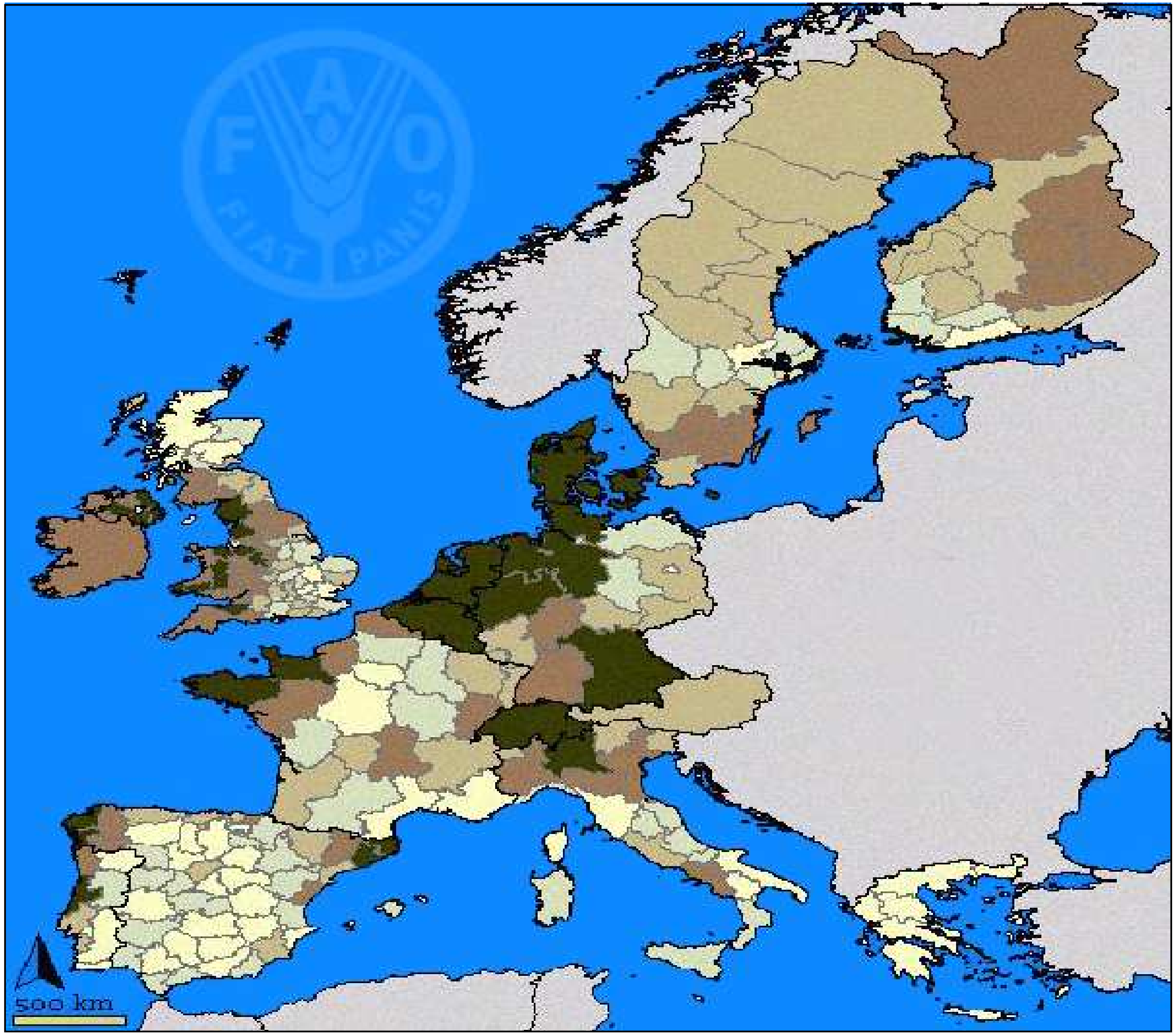
Constraint 4 Resources, e.g. phosphorus



Peak P: no substitute?

Like oil and other natural resources, the rate of production of economically available phosphate reserves will eventually peak, followed by a steep decline and subsequent increasing gap between demand and supply. An analysis based on industry data shows the global peak P is expected to occur around 2040. While oil can be substituted with other sources when its reserves peak (like wind, biomass or thermal energy), phosphorus has no substitute in food production and as an element cannot be manufactured or synthesized (Dana Cordell)

TOTAL LIVESTOCK BIO-MASS ON AGRICULTURAL LAND



Legend

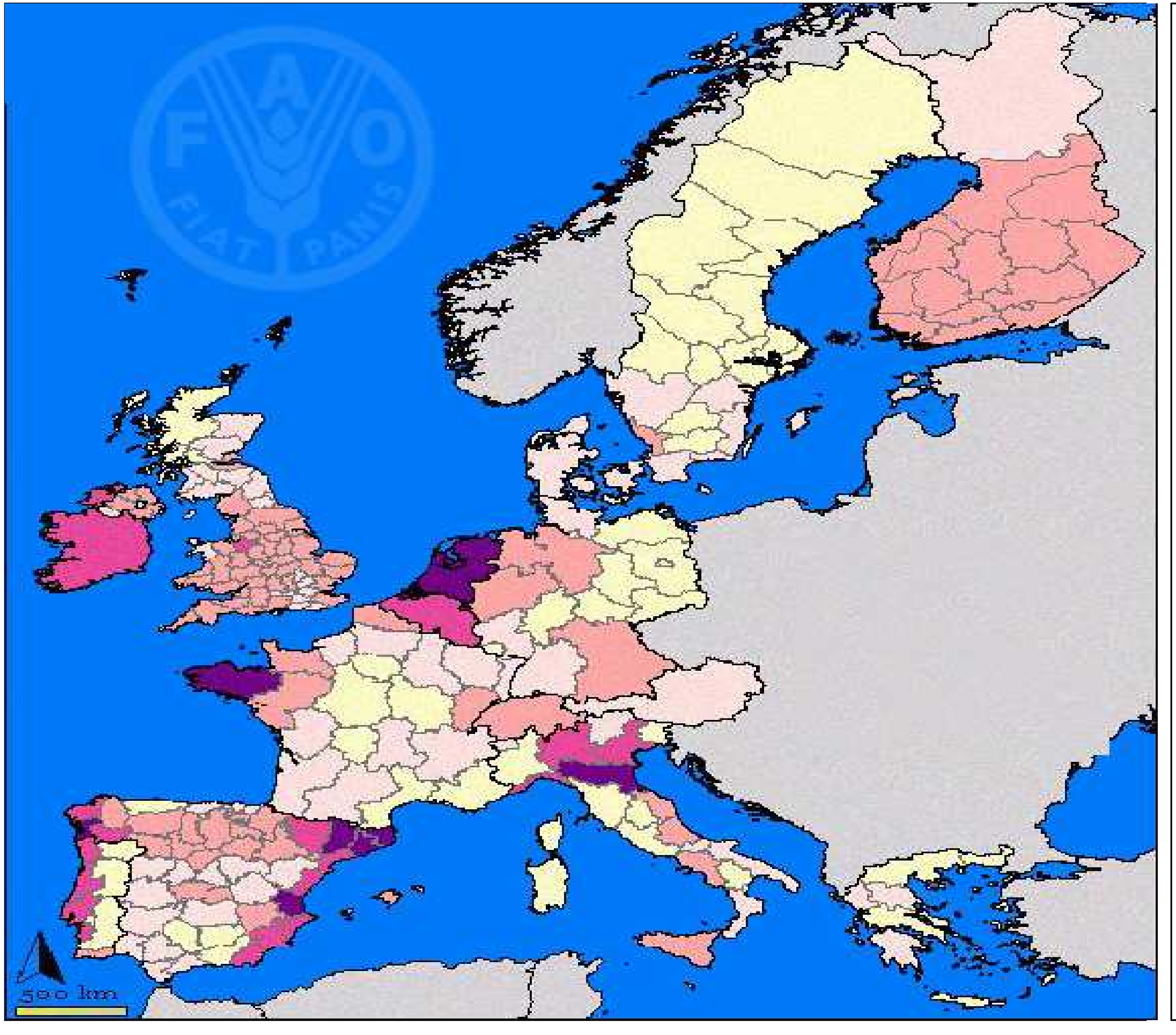
Kg/ ha

- 0 - 100
- 100 - 200
- 200 - 400
- 400 - 500
- > 500

Source : LEAD FAO
Year :2002
Map prepared by LEAD - FAO

Contact us:
lead@fao.org

PHOSPHATE BALANCE ON AGRICULTURAL LAND



Legend

Kg/ ha

- no overload
- 10 - 20
- 20 - 40
- 40 - 70
- > 70

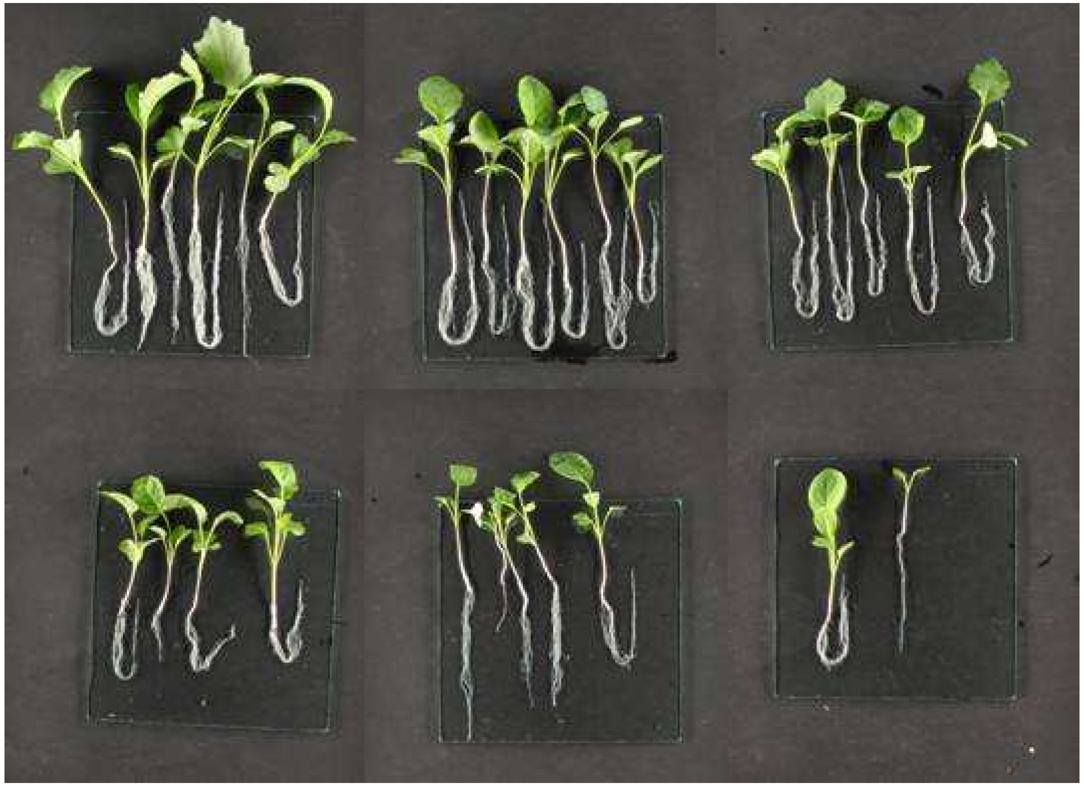
Source : LEAD FAO
Year :2002
Map prepared by LEAD - FAO

Contact us:
lead@fao.org

Breeding crops to perform with less phosphorus

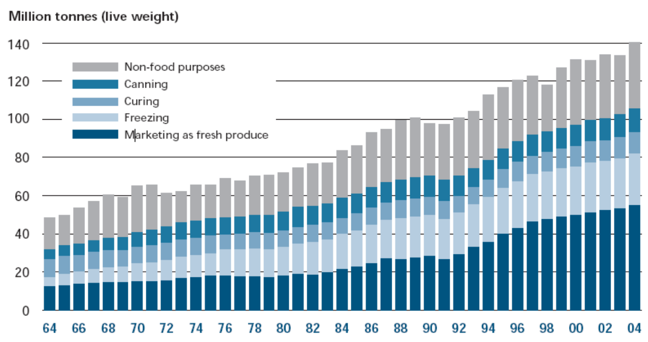
Brassica **with high PUE**
P-responsive
High internal P-use efficiency
Larger shoots
Longer roots
Greater root FW
No difference in root DW

Brassica **with low PUE**
Non P-responsive
Low internal P-use efficiency
Smaller shoots
Shorter roots
Less root FW
No difference in root DW



Constraint 4 Resources, e.g. example fish

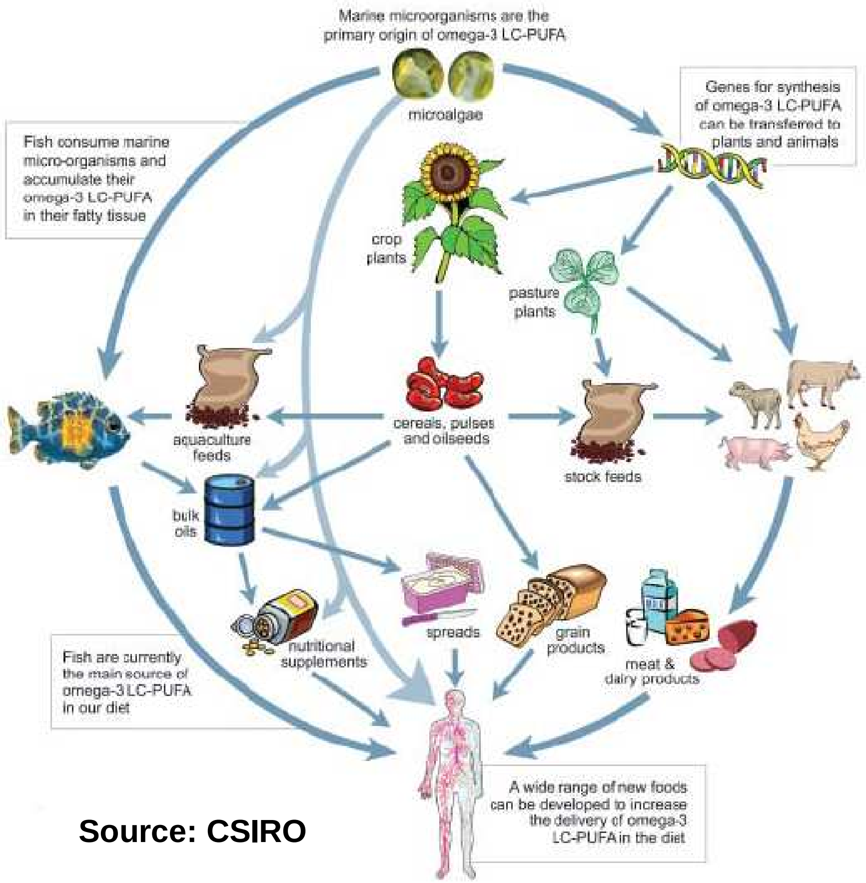
ROTHAMSTED RESEARCH



Increased plant based aquaculture → Reduced demand for wild fish

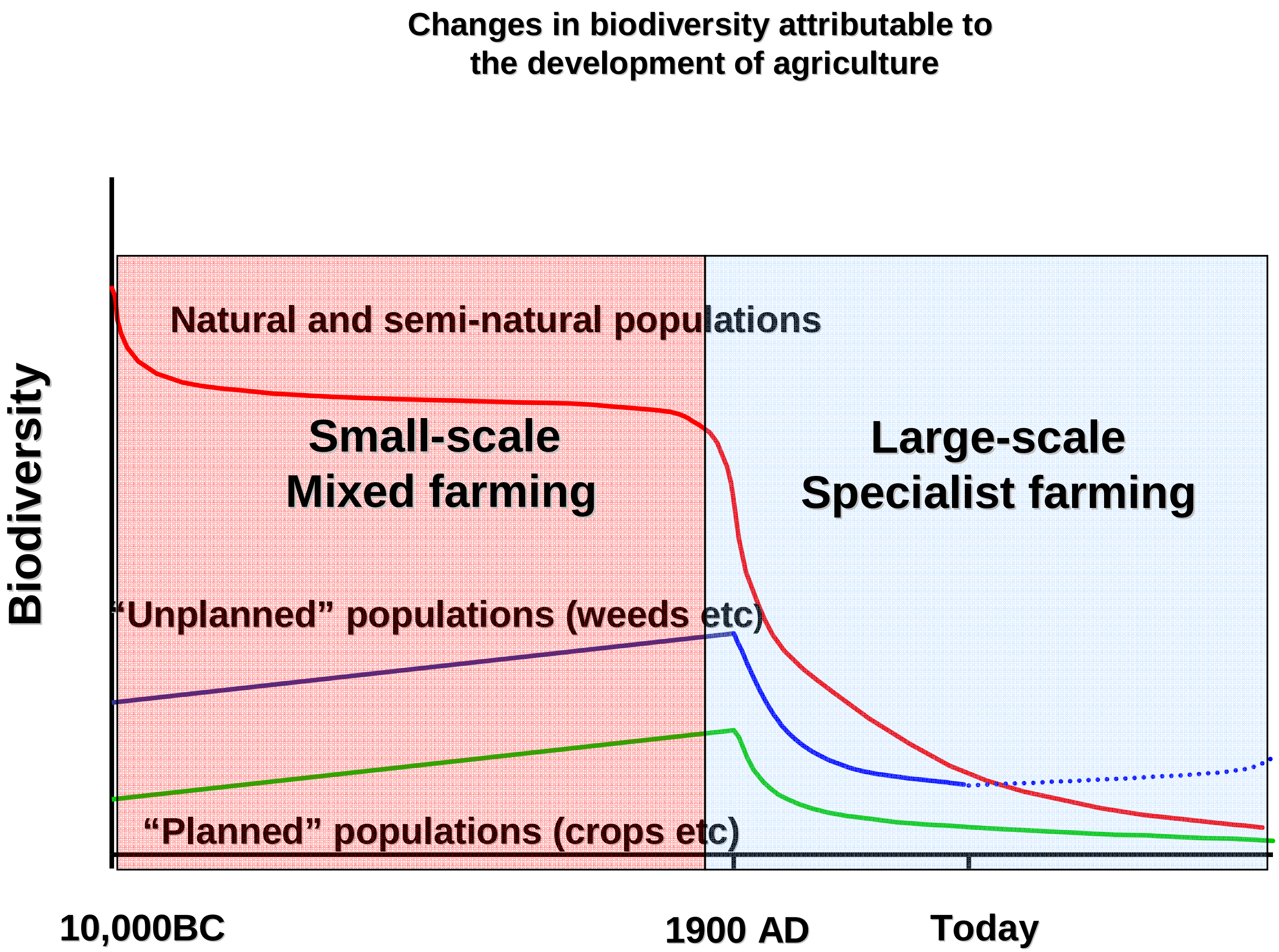
↓ ↓

Reduced industrial fishing → Recovery of wild fish stocks



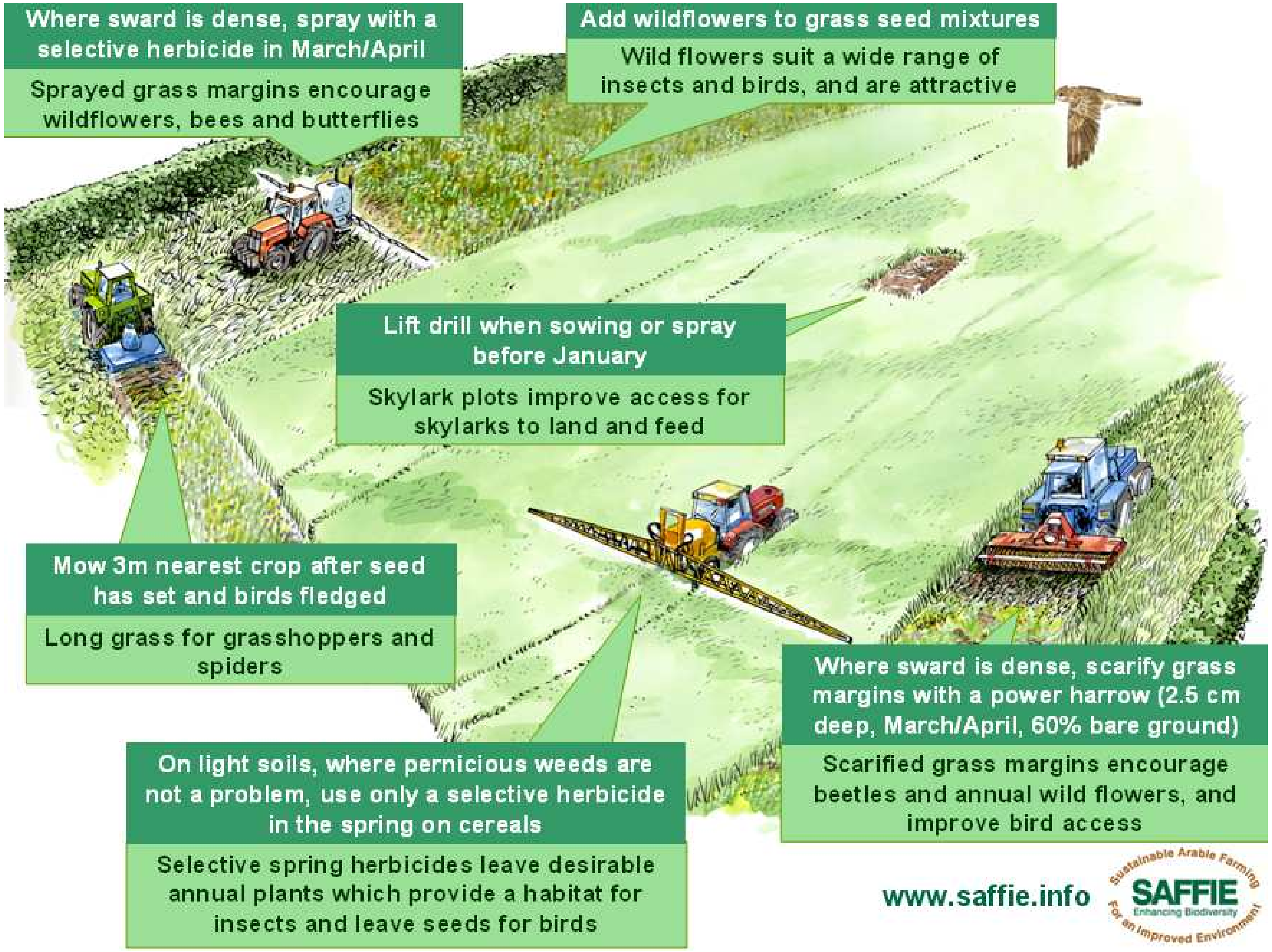
Source: CSIRO

Constraint 5 – leaving space and light for biodiversity



Redrawn by Chris Pollock from Edwards & Hilbeck, 2001

Strategic science based approaches to farmland habitat management



www.saffie.info

Sustainable Arable Farming For an Improved Environment SAFFIE Enhancing Biodiversity

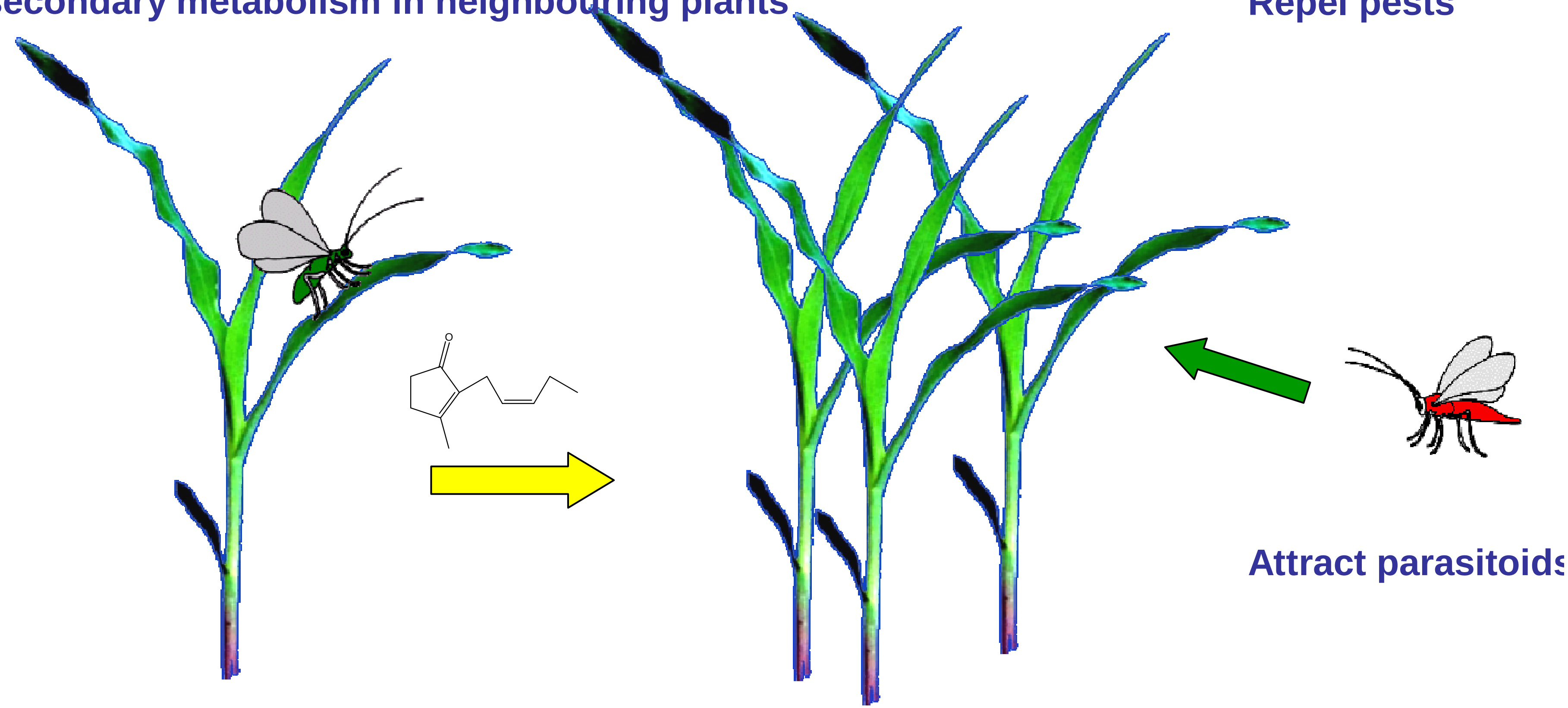
defra Department for Environment Food and Rural Affairs

SCOTTISH EXECUTIVE

NATURAL ENGLAND

Fostering and harnessing biodiversity in crop protection

Insects attacking plants cause release of signals e.g. *cis*-jasmone, which switch on plant defence secondary metabolism in neighbouring plants



In the field, a treatment of *cis*-jasmone on wheat, applied in May, gives a 50% reduction of aphid populations in June (e.g. Pickett and Poppy, *Trends in Plant Science* 2001)

Constraint 5 - Air quality - ozone

MIT: Human-generated ozone will damage crops

Could reduce production by more than 10 percent by 2100

Nancy Stauffer
MIT Energy Initiative

A novel MIT study concludes that increasing levels of ozone due to the growing use of fossil fuels will damage global vegetation, resulting in serious costs to the world's economy.

The analysis, reported in the November issue of Energy Policy, focused on how three environmental changes (increases in temperature, carbon dioxide and ozone) associated with human activity will affect crops, pastures and forests.

The research shows that increases in temperature and in carbon dioxide may actually benefit vegetation, especially in northern temperate regions. However, those benefits may be more than offset by the detrimental effects of increases in ozone, notably on crops. Ozone is a form of oxygen that is an atmospheric pollutant at ground level.

The economic cost of the damage will be moderated by changes in land use and by agricultural trade, with some regions more able to adapt than others. But the overall

which combines linked state-of-the-art economic, climate and agricultural computer models to project emissions of greenhouse gases and ozone precursors based on human activity and natural systems.

Expected and unexpected findings

Results for the impacts of climate change and rising carbon dioxide concentrations (assuming business as usual, with no emissions restrictions) brought few surprises. For example, the estimated carbon dioxide and temperature increases would benefit vegetation in much of the world.

The effects of ozone are decidedly different.

Without emissions restrictions, growing fuel combustion worldwide will push global average ozone up 50 percent by 2100. That increase will have a disproportionately large impact on vegetation because ozone concentrations in many locations will rise above the critical level where adverse effects are observed in plants and ecosystems.

Crops are hardest hit. Model predictions show that ozone levels tend to be

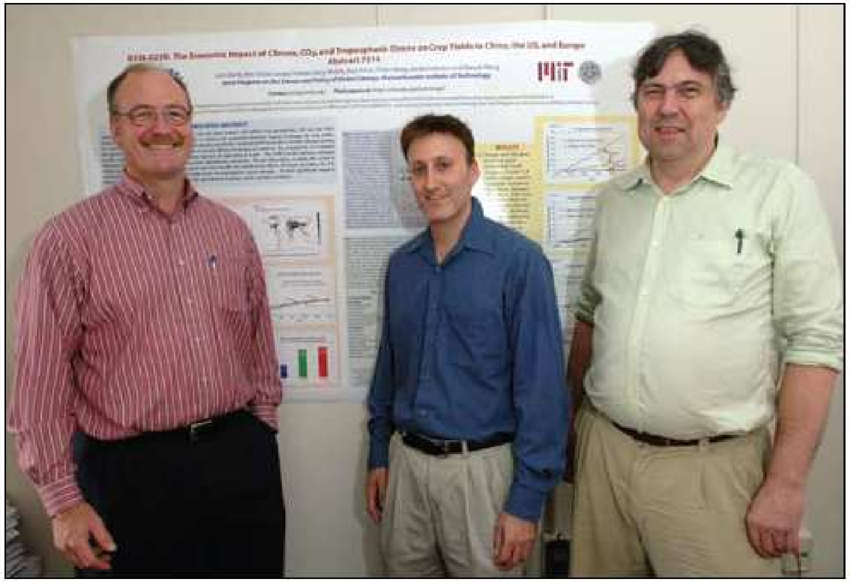


PHOTO / DONNA COVENEY

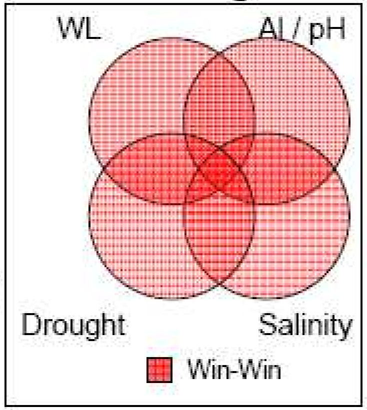
John Reilly, left, associate director of the MIT Joint Program on the Science and Policy of Global Change, Ben Felzer, center, and David Kicklighter, right, from the Marine Biological Laboratory Ecosystems Center at Woods Hole. Reilly leads a team that is showing the global economic effects of changes in crops, forests and pastures due to climate change.

Constraint 6 – Abiotic stress

Win-Win approach for tolerance to multiple abiotic stresses

There is no doubt that multiple abiotic stresses often occur in the same environment.

Therefore tolerance mechanisms to abiotic stresses that relate to multiple stresses (win-win) are the TOP PRIORITY for breeding.



For example, Al tolerance could contribute to:

- Tolerance to Al toxic soils
- Tolerance to drought in Al toxic soils
- Tolerance to increases in soil acidity
- Tolerance to waterlogging (in marginal Al tox soils)
- Tolerance to Al in highly alkaline soils

(Ma et al., 2003)

Al tolerance is much simpler to screen for than drought tolerance or waterlogging tolerance. This must be a top priority for breeding programs. (Current breeding programs indirectly select for this.)

Department of Agriculture and Food

GRDC Grains Research & Development Corporation

ACIAR

Australian Government Australian Research Council

MPB CRC

Source: ICARDA, CGIAR

An agricultural science based response needs:

Systems thinking

Multiply approaches – this and that

A focus on what really matters

Research

What really matters

“A focus on what matters may be a significant step forward for the UK food related impacts on the environment. This means avoiding being side-tracked by past and present emblematic issues and conflicts such as those around ‘organic’ food and farming, ‘food miles’, GMOs, large versus small scale farming, ‘industrial’ farming, ‘factory farming’ ‘chemical farming’ etc. What really matters is fostering sustainable consumption patterns, increasing the resource use efficiency of food production, increasing the efficiency of nutrient use in agricultural systems, improving farmland as a habitat, and reducing deforestation and other forms of land use change to agriculture”.

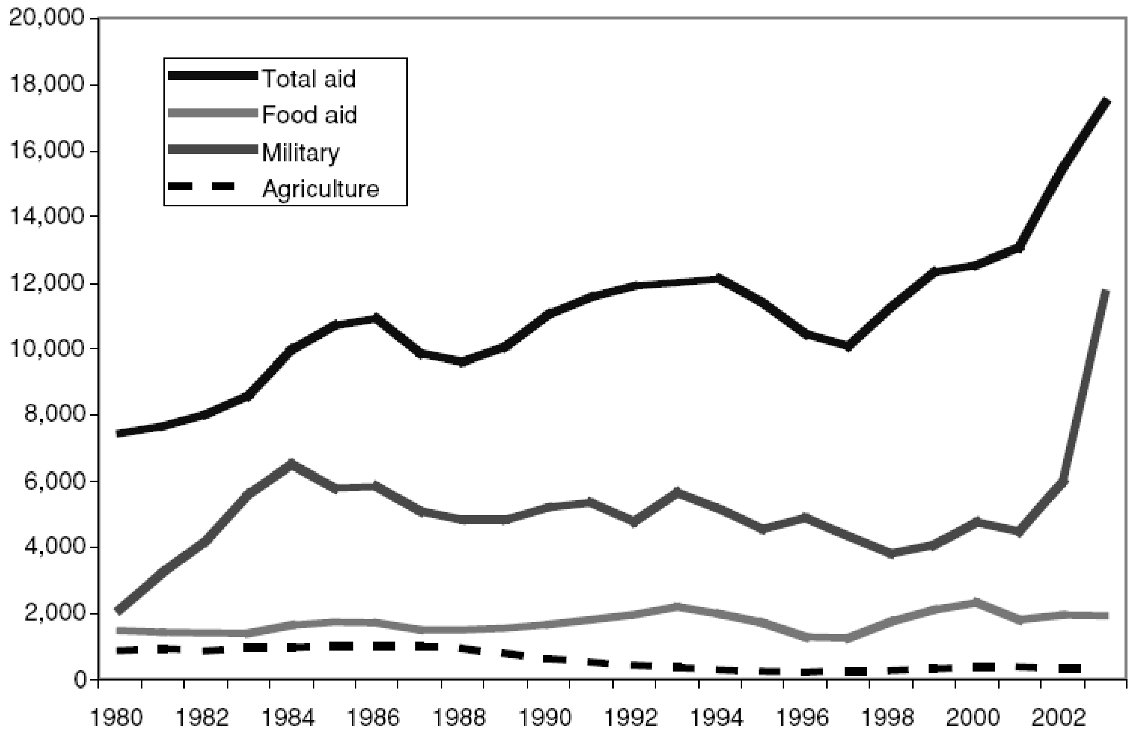
(Donal Murphy-Bokern)

Research

The CGIAR and the green revolution that it created have arguably been the most successful investments in development ever made. Countries that were involved with this revolution have crop values per acre roughly six times those who did not

Falcon and Naylor, 2005. Rethinking food security for the 21st century
American Journal of Agricultural Economics

US investment in aid



Falcon and Naylor, 2005. Rethinking food security for the 21st century
American Journal of Agricultural Economics

The knowledge and technologies required are by-and-large public goods

and

They will be deployed to deliver and protect public goods

- **Improved germplasm**
- **Novel selective crop protection technologies**
- **Water management**
- **Decision support systems**
- **Roadmaps to development and**
- **Toolkits to prioritise the management of land**

Murphy-Bokern Konzepte

A 'Marshall Plan' for world public agricultural research

Even with the best will in the world, the private sector cannot deliver this alone. A lot has changed since the first green revolution started but some things remain the same – public investment is needed to deliver the technologies for sustainable development in the way needed.

We new ways of working together – international public organisations generating public domain science and technology, and the private sector translating it into goods and services of local relevance.

Thoughts on the application of science and technology to meet future challenges

Acknowledgements

WWF UK for supporting some of the assessments reported here
Dr John Hammond, HRI Warwick
Prof. Johnathan Napier, Rothamsted Research
Dr Tony Hooper, Rothamsted Research
Dipl. Volksw. Anatoli Pauls, Nova Institut, Hürth, Germany

murphy-bokern.com