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# *Farming and wildlife: scaling, sparing, sharing*

Tim Benton

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# *Human Population growth*

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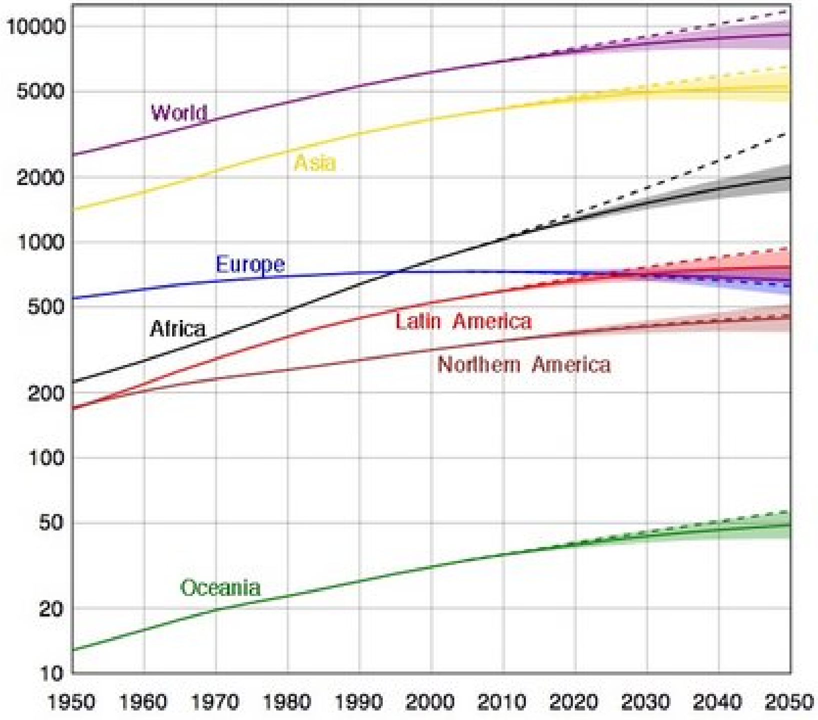
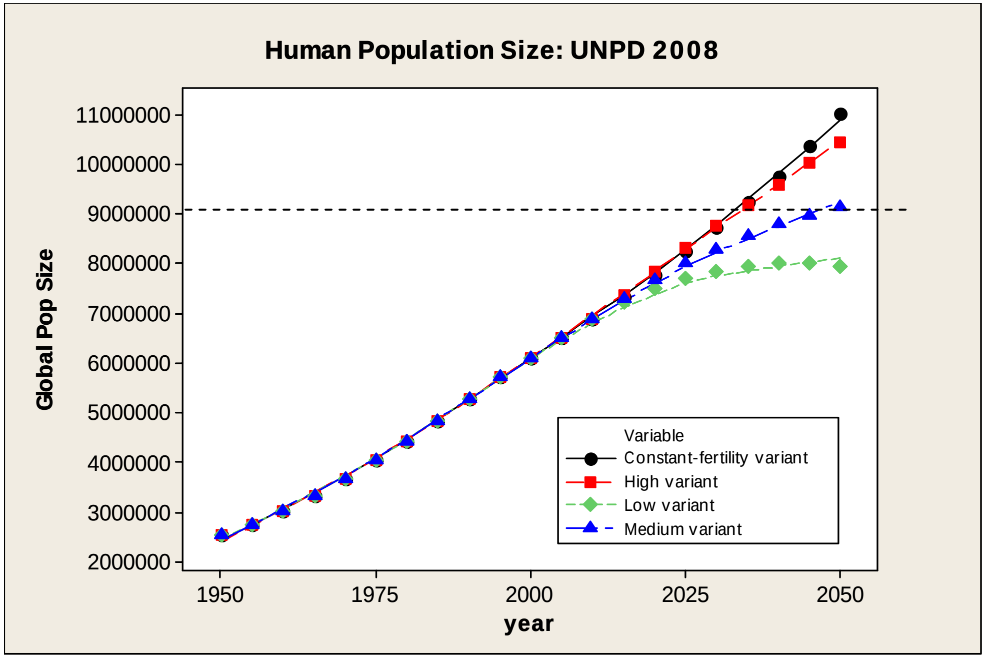



6.855 bn, July 2010
~9.15 bn by 2050
+35%



# *Global food: the big picture*

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- As countries develop, diet changes from crop to meat
  - e.g. China – demand increasing 2x faster than pop growth
  - A healthy vegetarian diet requires 0.2ha, a meat-based diet requires 1.4ha because a kg of meat requires 6 kg of grain to produce
- Projections suggest global demand will be for ~**2x** more food (but with big range)

## *Globally, we need about 2x the food, but:*

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- Biofuels will take land out of cropfood production
- Global warming will reduce yields (esp as water stress bites)
- Potential for yield loss as move to a “low carbon” economy

Putting these things together would suggest **>2x** area required….

# *Climate change: not just the mean*

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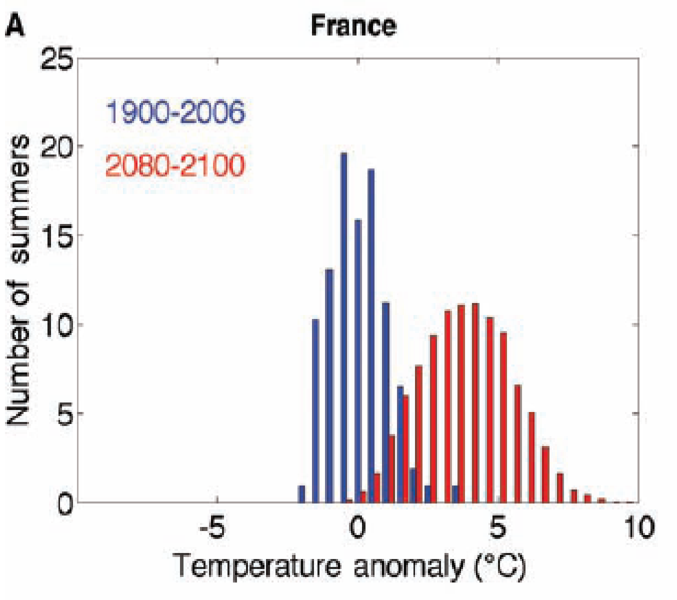
"The most intense seasonal temperature and the majority of fatalities were centered in France and northern Italy, where over **30,000** people perished from heat-related causes….Record high daytime and nighttime temperatures over most of the summer growing season reduced leaf and grain-filling development of key crops such as maize, fruit trees, and vineyards; accelerated crop ripening and maturity by 10 to 20 days; caused livestock to be stressed; and resulted in reduced soil moisture and increased water consumption in agriculture. Italy experienced a record drop in maize yields of **36%** from a year earlier, whereas in France maize and fodder production fell by **30**%, fruit harvests declined by **25**%, and wheat harvests (which had nearly reached maturity by the time the heat set in) declined by **21**%"




Battisti 2009 Science

# *Global farming*

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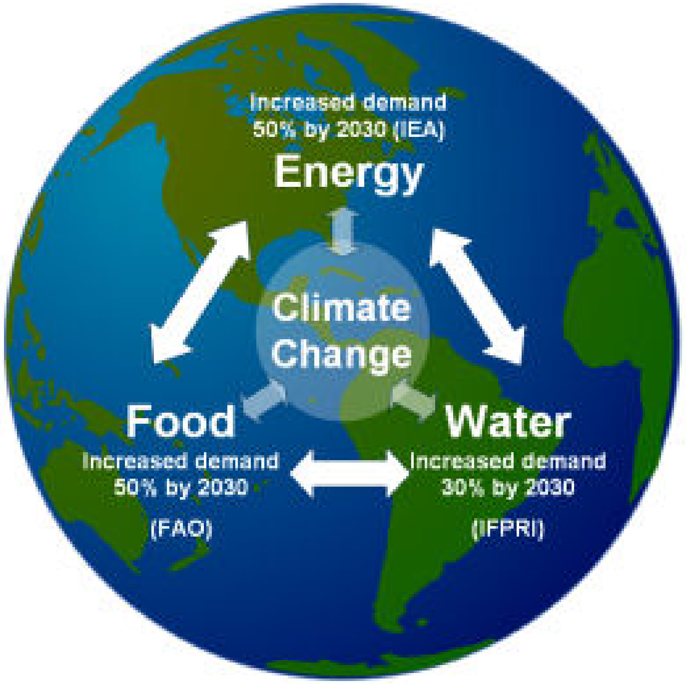
- Global land area is 13.4b ha
  - Current crop land is 1.53 b ha
  - Current pastureland is 3.44 b ha
- Land with potential for crops is estimated to be 3.32 b ha
  - i.e. potential for expansion of 2.16 x in crop area
- But this includes 0.77 b ha of forests, and land other land is not “prime”

# *The challenge*




- Increase food production
  - in the face of climate change
  - whilst reducing the carbon cost of farming
  - but not simply by farming at lower intensity and taking more land (because there isn't enough)
- Beddington's *Perfect Storm*

# *Ecosystem Services: biodiversity is important*

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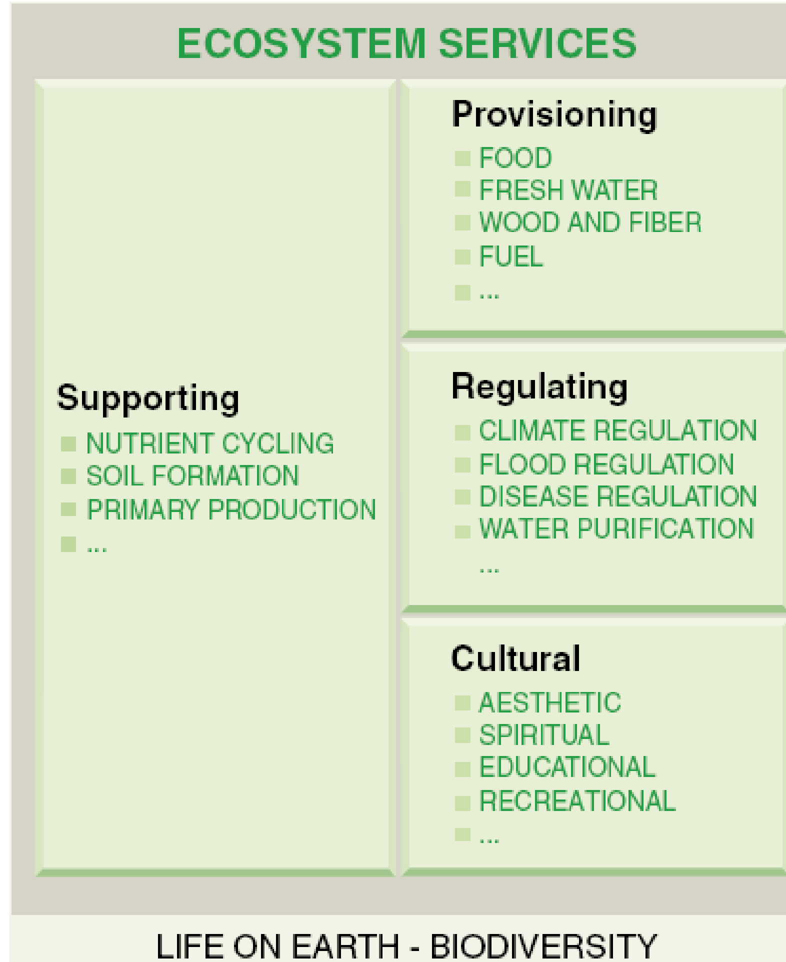
- Stewardship and nature
- Pollination
- Pest control
- Soil fertility
- Water
- Flood defences




Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Synthesis.* Island Press, Washington, DC.

# *Two key questions for conservation (for ES provision):*

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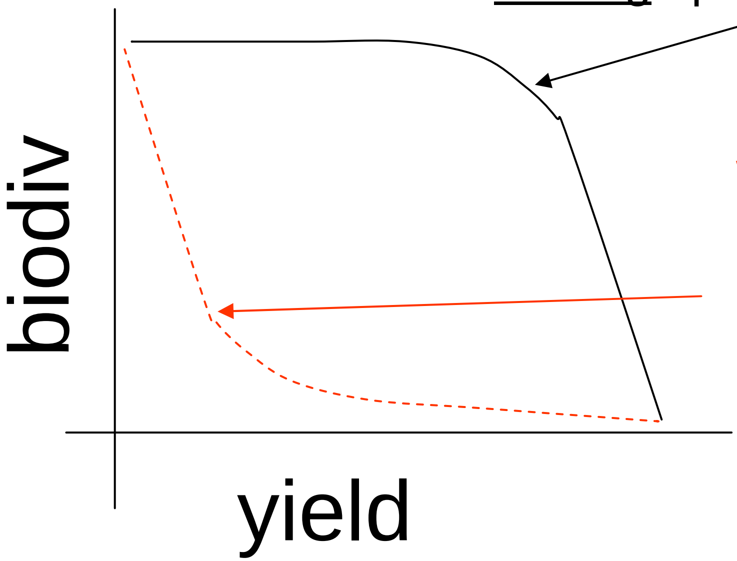
- Q1: is *land sparing* or *land sharing* optimal?

Small reduction in yield produces big wildlife benefit: land <u>sharing</u> optimal




wildlife benefit requires big yield reduction, much more land need to provide same food: land <u>sparing</u> optimal

Farming and the Fate of Wild Nature

Rhys E. Green,[1,2*] Stephen J. Cornell,[1,3] Jörn P. W. Scharlemann,[1,2] Andrew Balmford[1,4]

28 JANUARY 2005 VOL 307 SCIENCE

# *Q2 scale effects*

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- If land is managed for ES then *what is the appropriate scale* (within field, within farm, within landscape etc)?

# *Method: contrasting organic vs conventional farming*

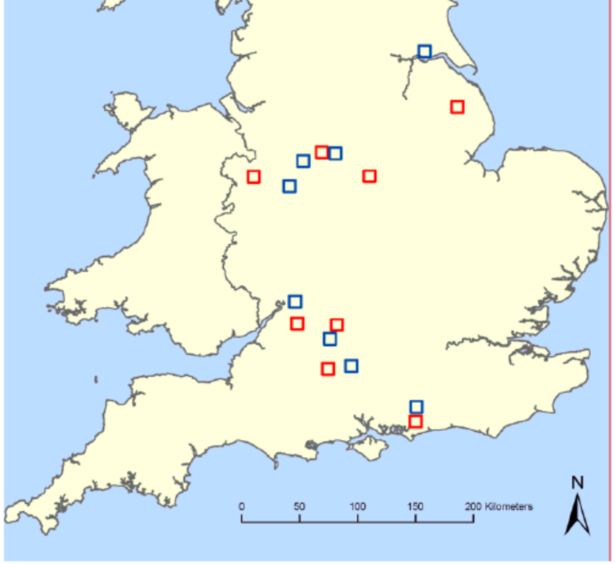


**Figure S1** Location of 16 paired coldspot (blue) and hotspot (red) landscapes in the Central South West and North Midlands of England (see Table 1 in main text for descriptions of farms and landscapes).

- Farms paired for 32 socio-environmental variables and selected randomly
- Paired focal farms (one O, one C) sat in landscapes that were highly intensive (“cold”) or had 10-20+% land farmed organically (“hot”)
- Sampling at *location* (margin, edge, centre), within *field* (crops or grass) within *farm* (organic or conventional) within *landscape* (hot or cold) within *region*

# *Description of results*

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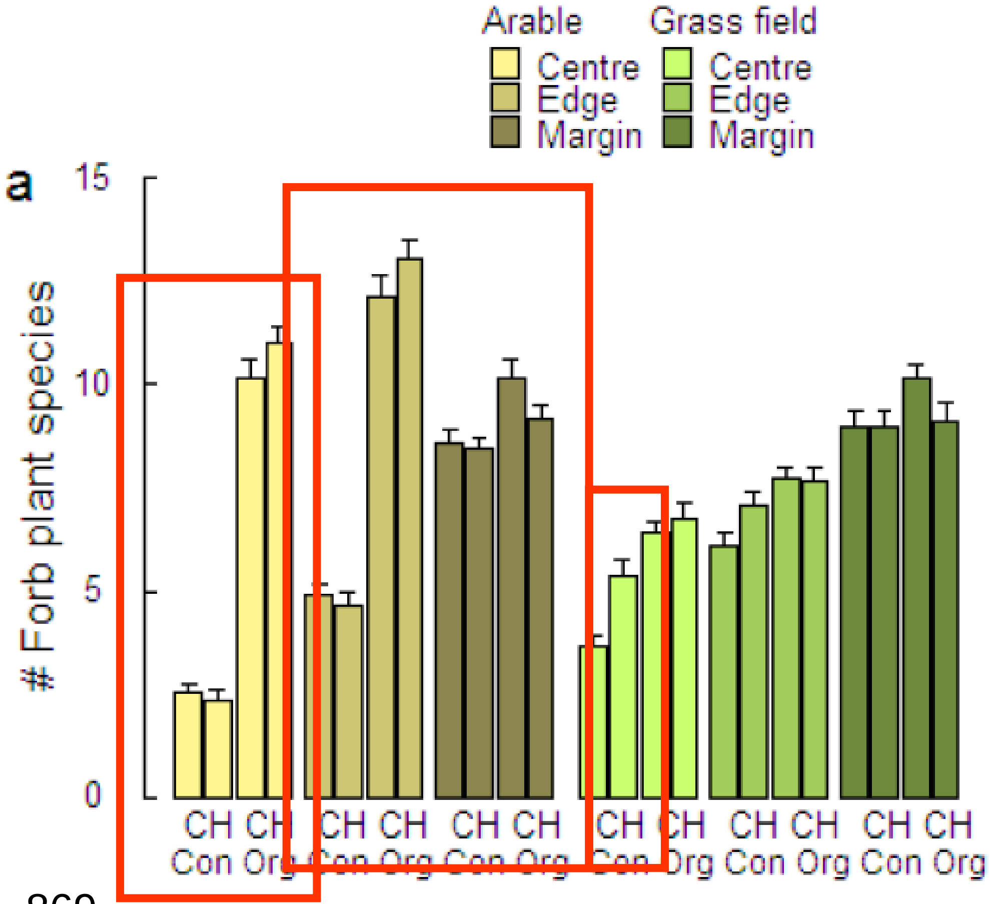
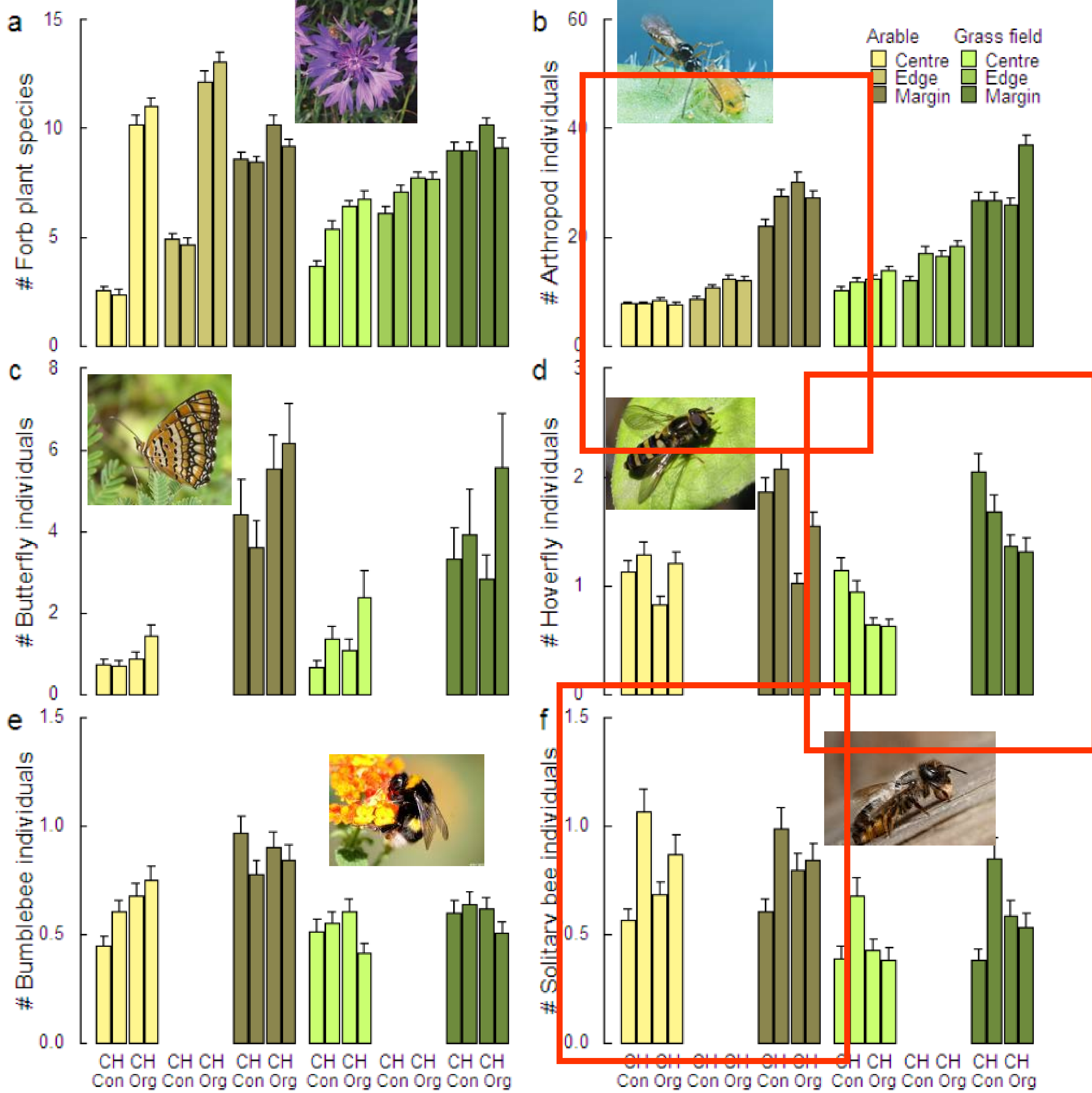
- Location, Management, Crop & Landscape all matter




Gabriel et al Ecology Letters, (2010) 13: 858–869


a
b
c
d
e
f
# Forb plant species
# Arthropod individuals
# Butterfly individuals
# Hoverfly individuals
# Bumblebee individuals
# Solitary bee individuals
Arable
Grass field
Centre
Edge
Margin
CH CH CH CH CH CH CH CH CH CH CH CH
Con Org Con Org Con Org Con Org Con Org Con Org

# *Farmland birds*

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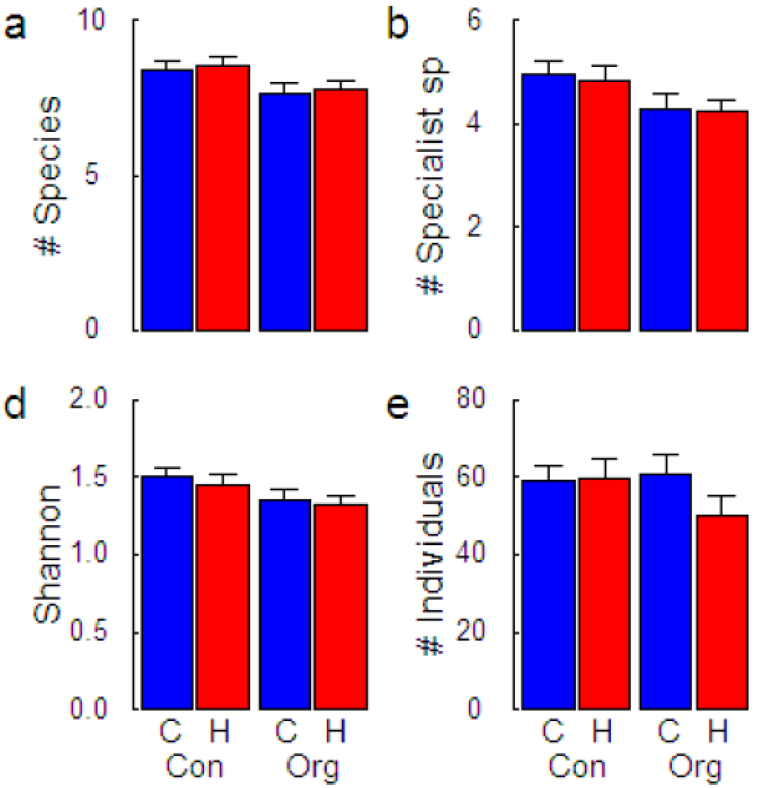


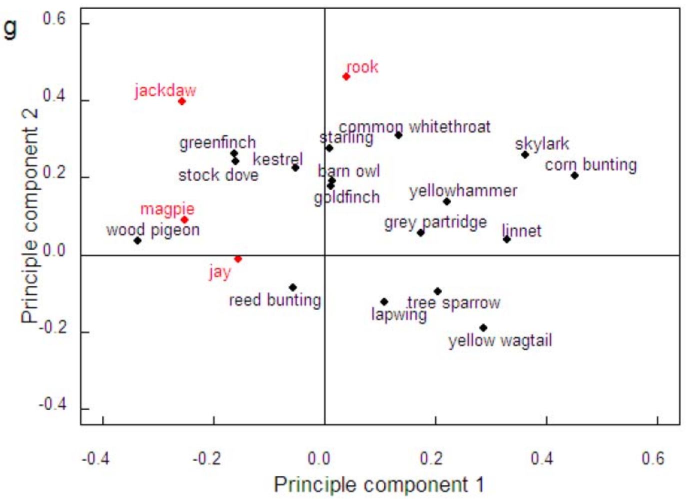

# Butterflies

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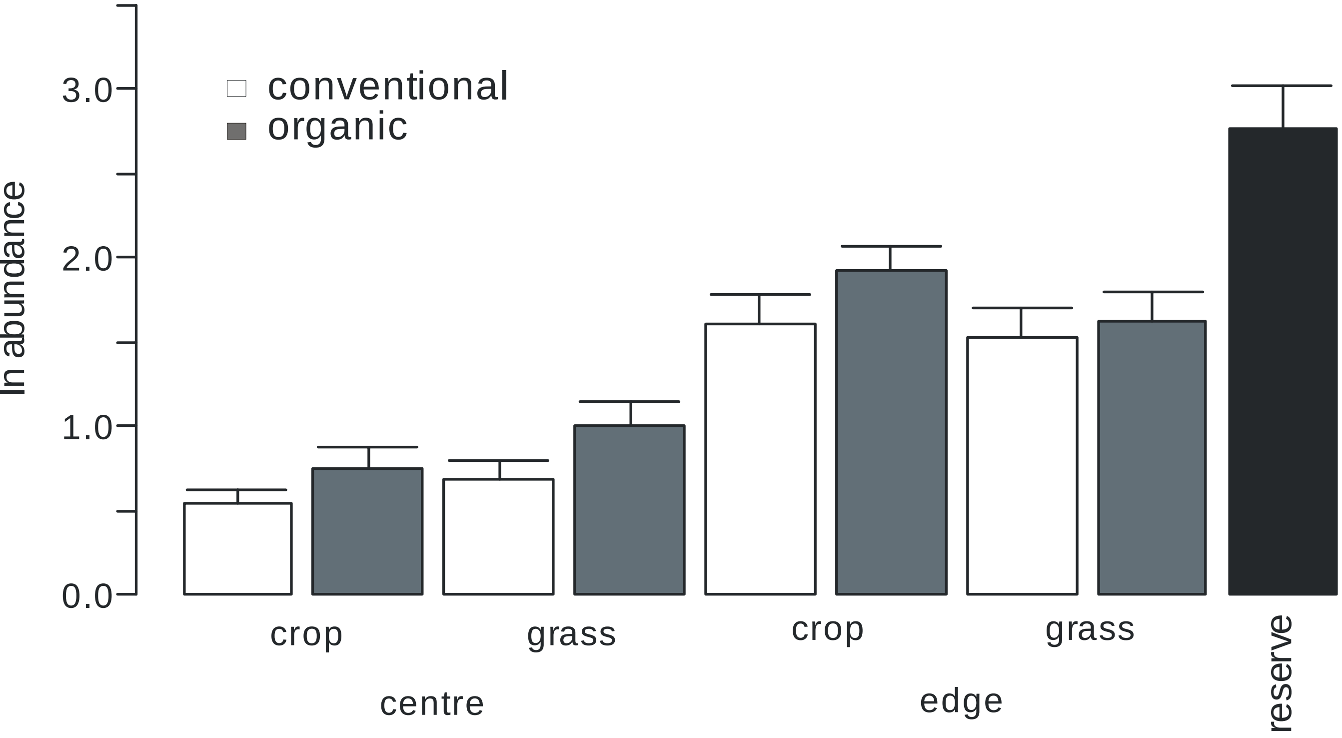


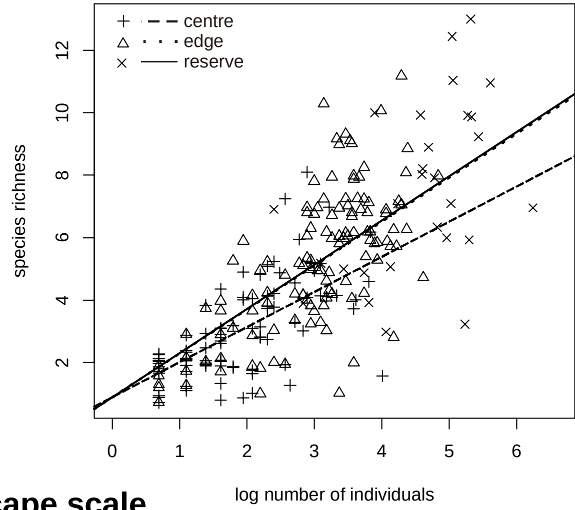


**Comparing organic farming and land sparing: maintaining yield and wildlife at a landscape scale.**
Jenny A. Hodgson*, William E. Kunin, Chris D. Thomas, Tim G. Benton & Doreen Gabriel. (in press)

# *Yields per field (wheat)*

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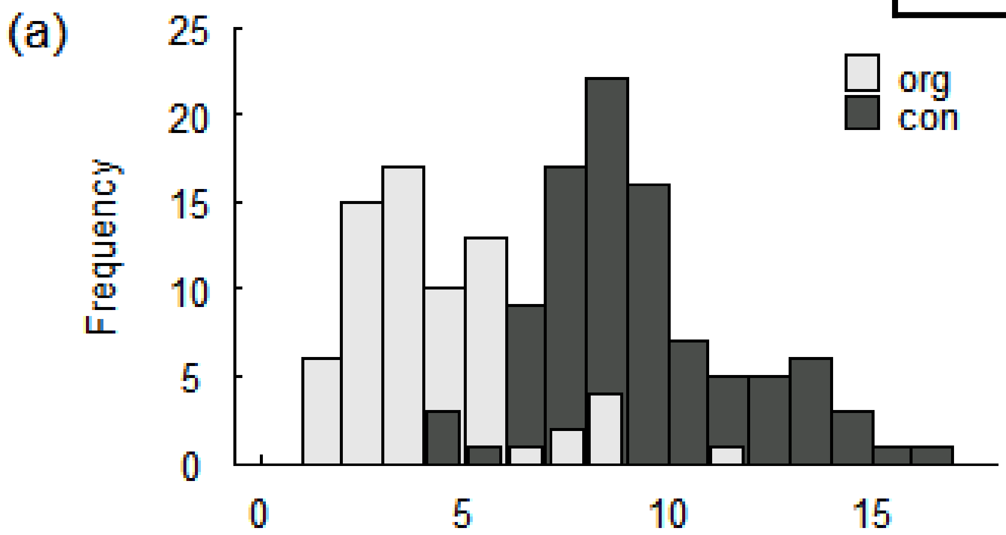
| | "cold" landscape | "hot" landscape |
|---|---|---|
| Conv | **9.3 ± 0.33 (9)** | 9.4 ± 0.39 (8.8) |
| Org | 4.2 ± 0.39 (3.8) | **4.3 ± 0.29 (4.3)** |




**The costs and benefits of farming in organic and conventional agriculture**
Doreen Gabriel, Steven M. Sait, William E. Kunin, Tim G. Benton
(under review)

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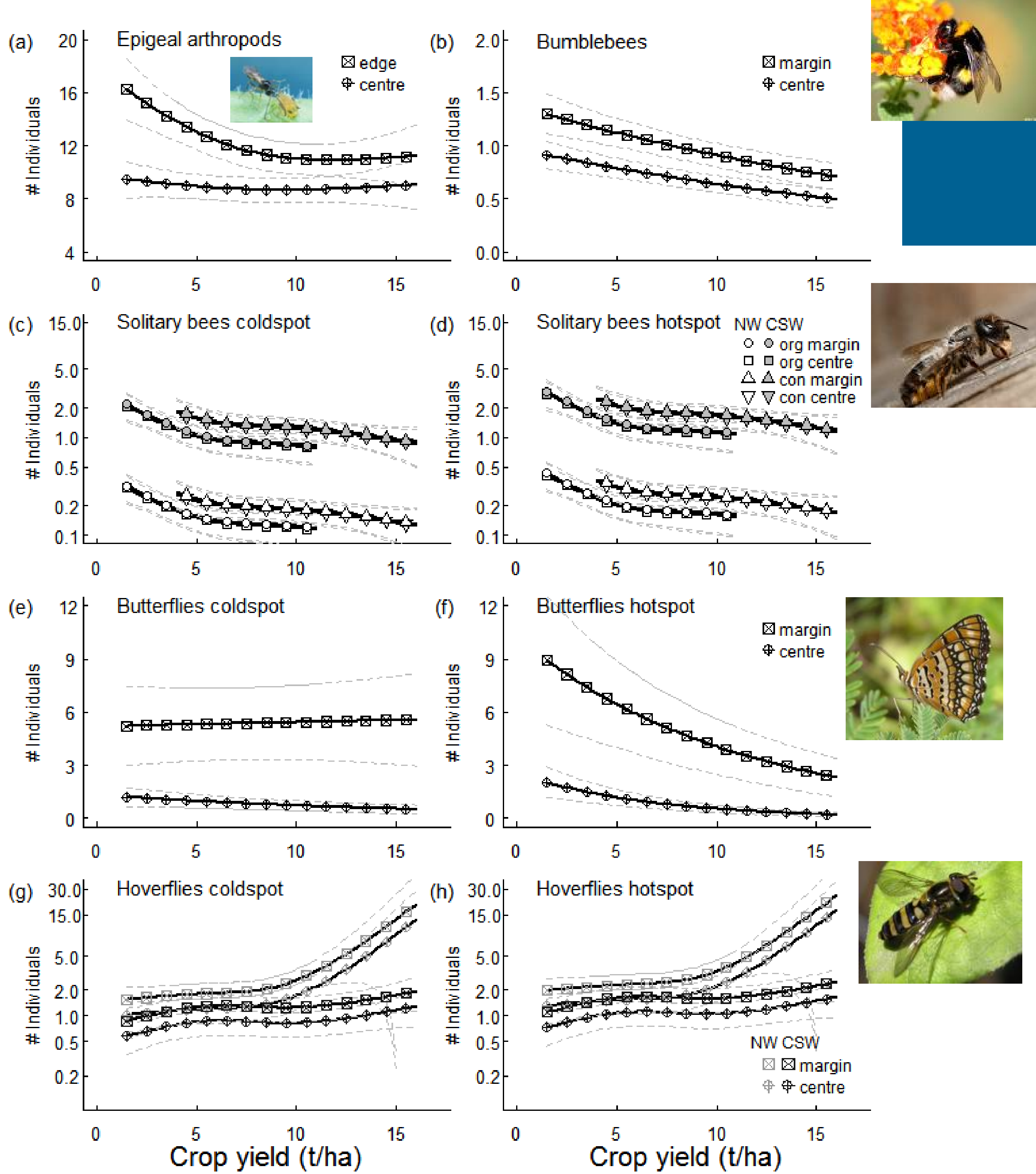


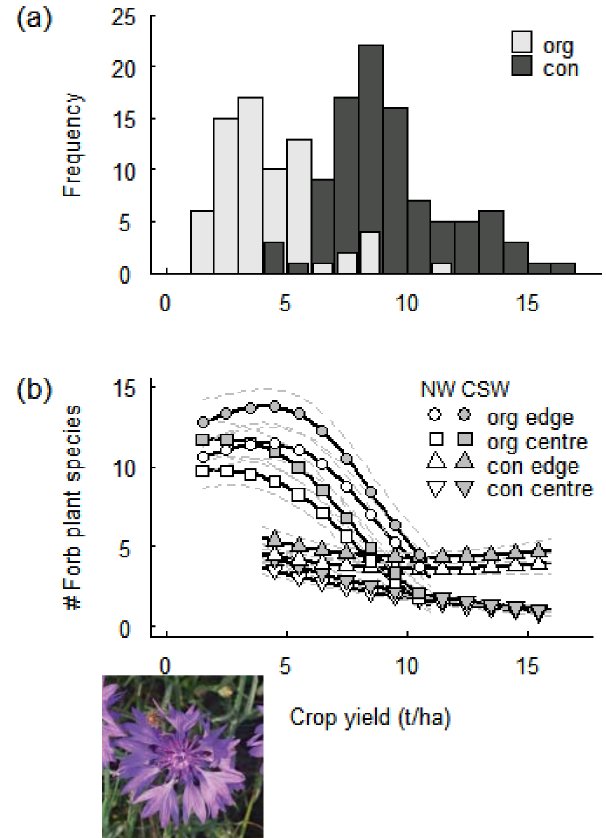

# *Interpreting the results*

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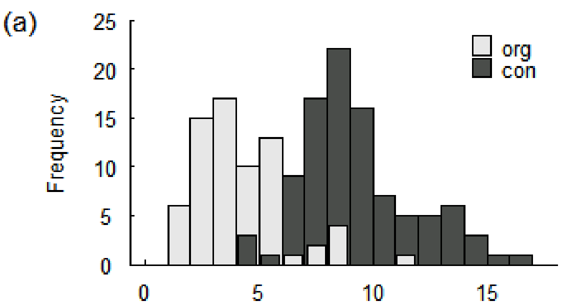
- Q1: land sparing vs land sharing

| worms | plants | arthropods | butterflies | hoverflies | bumbles | Solitary bees | birds |
|---|---|---|---|---|---|---|---|
| 23% | 59% | 17% | 40% | -34% | 2% | 2% | -10% |



# *Optimal average landscape design: spare or share?*

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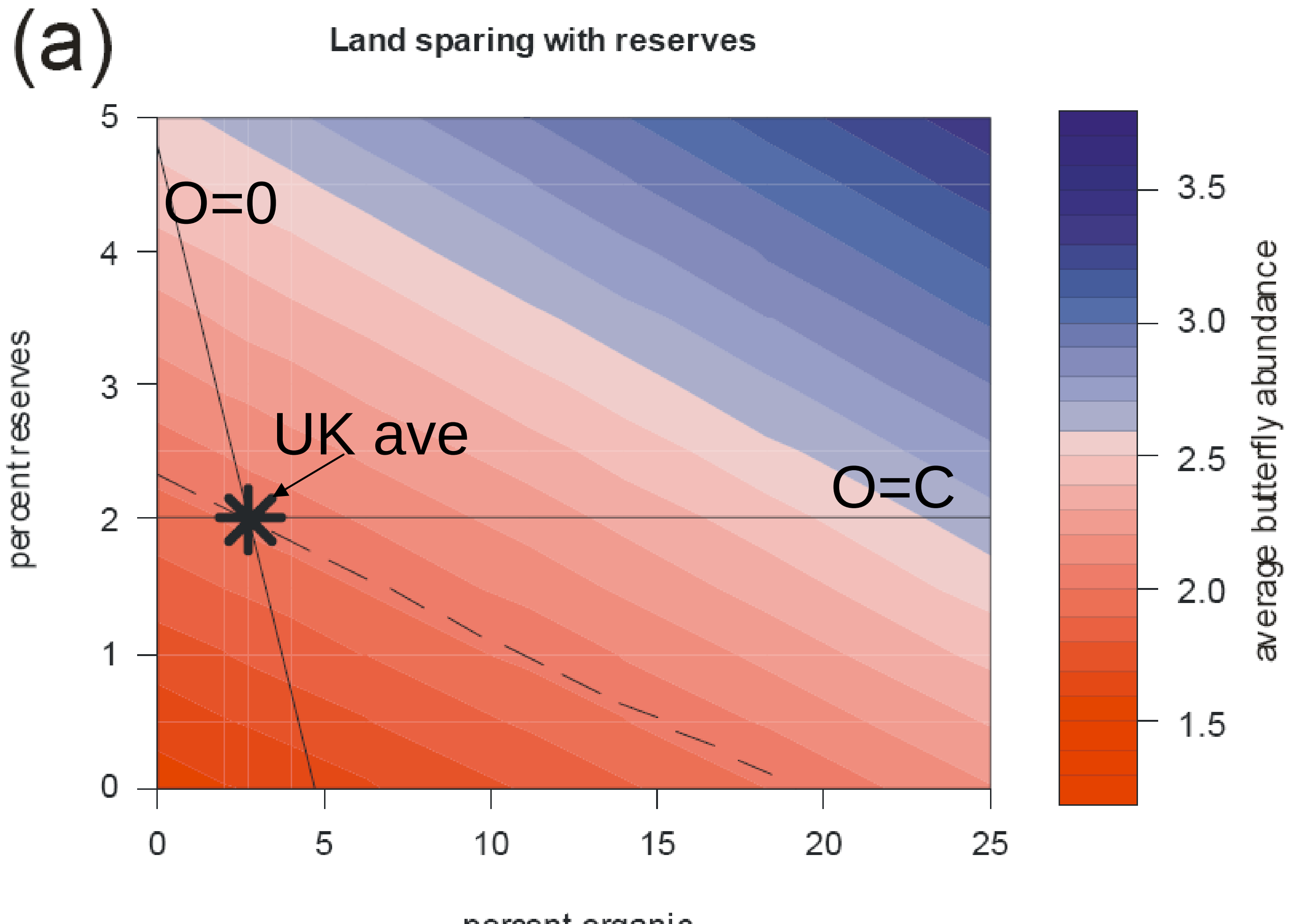
Critical threshold: only if O>87.5% C it is better to share rather than spare




**Comparing organic farming and land sparing: maintaining yield and wildlife at a landscape scale.**
Jenny A. Hodgson*, William E. Kunin, Chris D. Thomas, Tim G. Benton & Doreen Gabriel. (in press)

# *Land sparing*

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- Land exclusively managed for wildlife has most wildlife
- Yield loss in organic land is considerable and biodiversity gain isn’t always large
- Optimal way to maintain yield AND preserve wildlife is often by land sparing (“conventional” farming plus land for wildlife), rather than land sharing (as exemplified by organic farming)

# *Q2: scale issues*



- All spatial scales are important in influencing biodiversity:
  - Location in field
  - Field in farm
  - Farm in landscape
  - Landscape in region
- Different groups respond in different ways

# Statistical Conclusions

**Table 2. Sum of Akaike weight w+(J) across all models per species group.**

| | Plants | Earthworms | Epigeal Arthropods | Pollinators BF | Pollinators HF | Pollinators BB | Pollinators SB | Birds |
|---|---|---|---|---|---|---|---|---|
| | SPD | IND | IND | IND | IND | IND | IND | SPD |
| Region [R] | 1 | 0.60 | 1 | 1 | 1 | 0.57 | 1 | 0.97 |
| Hot/Coldspot [HC] | 1 | 0.39 | 0.61 | 0.85 | 0.38 | 0.5 | 1 | 0.97 |
| Management [M] | 1 | 0.60 | 0.93 | 0.99 | 1 | 0.46 | 1 | 0.99 |
| Crop type [CT] | 1 | NA | 1 | 1 | 0.98 | 1 | 1 | NA |
| Location [L] | 1 | 0.38 | 1 | 1 | 1 | 1 | 0.93 | NA |

| | Plants | Earthworms | Epigeal Arthropods | Butterflies | Pollinators HF | Pollinators BB | Pollinators SB | Birds |
|---|---|---|---|---|---|---|---|---|
| | SPD | IND | IND | IND | IND | IND | IND | SPD |
| (a) | | | | | | | | |
| Model $R^2$ fixed effect | 32.0 | 5.5 | 25.4 | 25.6 | 7.6 | 3.4 | 23.6 | 10.5 |
| Model $R^2$ fixed + random effect | 63.7 | 32.3 | 68.3 | 60.2 | 44.2 | 31.5 | 61.0 | 37.6 |
| (b) | | | | | | | | |
| Region [R] | 8.1 | 84.0 | 10.2 | 11.3 | 30.7 | 13.1 | 69.0 | 44.8 |
| Hot/Coldspot [HC] | 7.8 | 2.3 | 1.0 | 2.3 | 0.6 | 10.9 | 18.2 | 39.0 |
| Farm management [M] | 43.0 | 12.8 | 1.9 | 3.7 | 17.9 | 16.6 | 8.3 | 16.2 |
| Crop type [CT] | 17.7 | NA | 14.0 | 9.5 | 8.1 | 29.4 | 4.2 | NA |
| Location [L] | 23.4 | 0.9 | 72.8 | 73.2 | 42.6 | 30.0 | 0.3 | NA |

Hot/Org>Cold/Org=Hot/Con>Cold/Con

# *Biological conclusion*

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- When controlling properly for landscape: on average, wildlife effect of organic farms varies between groups and can be positive or negative.
- “best” overall effect on biodiv occurs when O farms grouped into “hotspot landscapes”

# *We know that organic farming is clumped*

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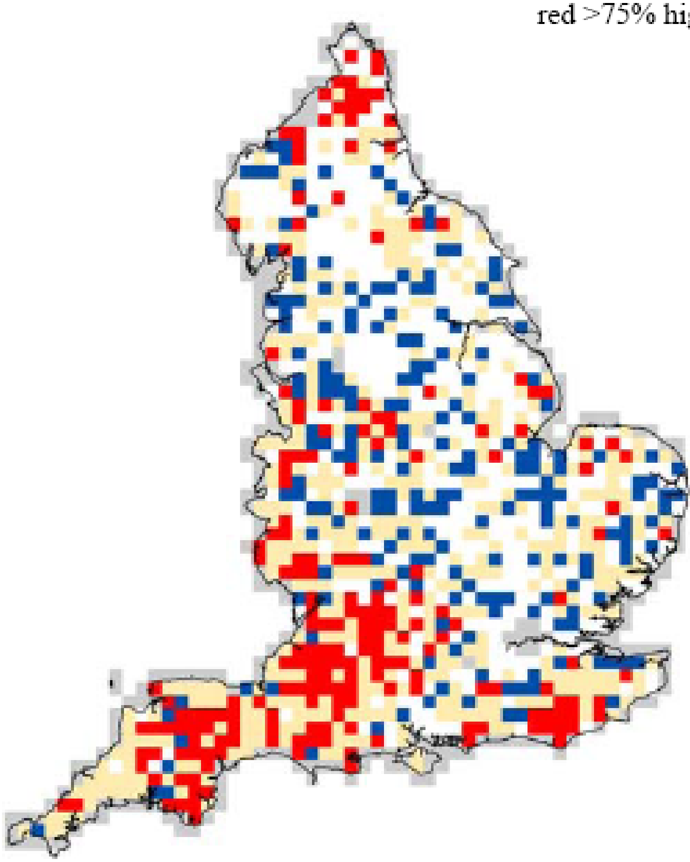
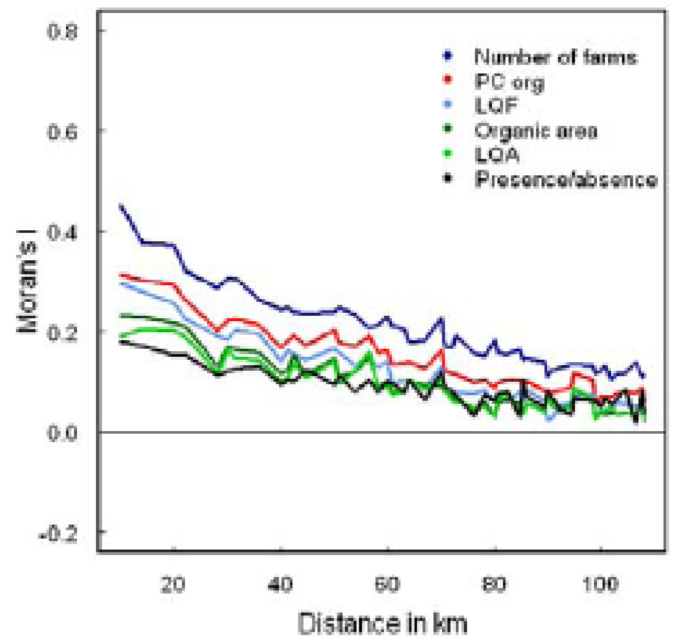
*Clumping arises via many factors: social and environmental*

(a) Map of organic farming hotspots (red) and coldspots (blue) in England. Hotspots and coldspots are defined as the extreme 25% of the principle component axis, which combined the four measures of organic farming (number of organic farms, organic area, LQF and LQA), white = no organic farms, blue = <25% lowest concentration, beige = 25-75% and red >75% highest concentration, grey = grid cells that were omitted from analysis (see






*Gabriel et al 2009 J appl Ecol*

# *Regional land sparing?*

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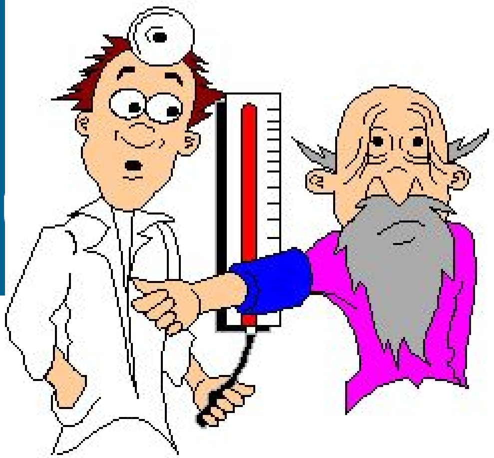
- Organic farms more likely in "non intensive landscapes" (farmers going for low-yield but premium)
- Organic farms in intensive landscapes lose much yield for small gain in biodiversity terms

grain yield winter cereal (t/ha)

| | "cold" landscape | "hot" landscape |
|---|---|---|
| Conv | **9.3 ± 0.33 (9)** | 9.4 ± 0.39 (8.8) |
| Org | 4.2 ± 0.39 (3.8) | **4.3 ± 0.29 (4.3)** |

- When land pressure increases perhaps most efficient to concentrate farming in "intensive landscapes" and "spare and share" in non-intensive landscapes?

# *Blood pressure mitigation*



- Land sparing requires land actively managed for wildlife
  - Blocks &/or networks of real conservation margins
- Move towards low-carbon economy may require more of ES
  - Spatial scale of 300m for natural enemies
- “intensive landscape” may be field centres managed non-organically and field edges as reserves

| system | farming (GJ ha$^{-1}$ y$^{-1}$) | output food[a] (GJ ha$^{-1}$ y$^{-1}$) | output fuel[a] (GJ ha$^{-1}$ y$^{-1}$) | output:input ratio for food |
|---|---|---|---|---|
| Conventional tillage (CT) | 7.1 | 72.7 (8.5) | 54.5 (2.1) | 10 |
| no till (NT) | 4.9 | 78.5 (3.4) | 57.3 (0.6) | 16 |
| Low Input with cover (LI) | 5.2 | 66.9 (3.2) | 53.2 (0.9) | 13 |
| Organic with cover (Org) | 4.8 | 53.1 (5.6) | 40.5 (1.2) | 11 |
| Alfalfa | 5.5 | 26.1 (3.2)[b] | 58.4 (5.1) | 5 |

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# Energy Efficiency of Conventional, Organic, and Alternative Cropping Systems for Food and Fuel at a Site in the U.S. Midwest

ILYA GELFAND,*,†,§
SIEGLINDE S. SNAPP,†,‡ AND
G. PHILIP ROBERTSON†,‡,§

**TABLE 1. Estimates of Energy Associated with Production of Agricultural Chemicals and Seeds and Energy Content of Grains**

| | MJ kg$^{-1}$ | source |
|---|---|---|
| agro-chemicals | | |
| N | 39.0 | (15,23) |
| P | 15.8 | (3) |
| K | 9.3 | (3) |
| boron | 4.7 | (4) |
| lime | 2.1 | (3) |
| herbicide | 288.0 | (3) |
| insecticide | 237.0 | (3) |
| Seed | | |
| wheat | 5.6 | (2) |
| soybean | 12.9 | (2) |
| corn | 53.4 | (2) |
| cover crop[a] | 87.1 | (2) |
| alfalfa | 133.1 | (2) |
| Grain Energy Content | | |
| wheat | 18.6 | (3) |
| soybean | 23.8 | (7) |
| corn | 15.5 | (15) |
| alfalfa meal | 16.2 | (24) |
| Biofuel Energy Content[b,c] | | |
| cellulosic biomass (ethanol) | 21.1 | (25) |
| soybean (biodiesel)[d] | 34.5 | (26) |

[a] Energy use associated with red clover seeds. [b] Lower heating value (LHV; MJL$^{-1}$). [c] Conversion efficiency of the biomass to biofuel is 30% (14) for cellulosic biomass and 15% for biodiesel (13). [d] Average of reported LHV for biodiesel (33.3–35.7 MJ L$^{-1}$).

**TABLE 2. Estimates of Energy Use Per Field Operations and Agricultural Machinery Maintenance[a]**

| field operation | L ha$^{-1}$ | MJ ha$^{-1}$ | source |
|---|---|---|---|
| Plowing[b] | | | |
| moldboard | 21.8 | 792.8 | (2) |
| chisel | 10.1 | 367.7 | (27) |
| soil finishing | 7.4 | 243.9 | (27) |
| fertilizer application | 9.8 | 357.5 | (2) |
| herbicide application | 1.8 | 65.2 | (27) |
| cultivation | 5.1 | 186.2 | (27) |
| rotary hoe | 2.6 | 93.1 | (27) |
| planting | 4.9 | 179.5 | (2) |
| Harvest | | | |
| baling (round) | 7.4 | 269.9 | (27) |
| mowing[c] | 1.3 | 48.8 | (27) |
| forage raking | 2.2 | 79.1 | (27) |
| alfalfa baling[c] | 1.2 | 48.8 | (28) |
| hay cut[d] | 4.1 | 119.4 | (29) |
| haylage[e] | 13.1 | 426.2 | (29) |
| soybean | 11.1 | 405.5 | (2) |
| wheat[f] | 11.1 | 405.5 | (2) |
| corn (grain) | 12.8 | 465.5 | (27) |
| forage | 17.4 | 633.0 | (27) |
| machinery | | 127.0 | (25) |

[a] Diesel energy content estimated to be 36.4 MJ L$^{-1}$ (30). [b] Moldboard plowing was conducted in the years 1989–1997, and chisel plowing in the years 1997–2007. [c] Fuel usage depend on crop yield; values are per Mg yield. [d] 12 ft pull type pickup heac mower-conditioner. [f] Wheat and operations were assumed to consume of energy.

The prospect of biofuel production on a large scale has focused attention on energy efficiencies associated with different agricultural systems and production goals. We used 17 years of detailed data on agricultural practices and yields to calculate an energy balance for different cropping systems under both food and fuel scenarios. We compared four grain and one forage systems in the U.S. Midwest: corn (*Zea mays*) - soybean (*Glycine max*) - wheat (*Triticum aestivum*) rotations managed with (1) conventional tillage, (2) no till, (3) low chemical input, and (4) biologically based (organic) practices, and (5) continuous alfalfa (*Medicago sativa*). We compared energy balances under two scenarios: all harvestable biomass used for food versus all harvestable biomass used for biofuel production. Among the annual grain crops, average energy costs of farming for the different systems ranged from 4.8 GJ ha$^{-1}$ y$^{-1}$ for the organic system to 7.1 GJ ha$^{-1}$ y$^{-1}$ for the conventional; the no-till system was also low at 4.9 GJ ha$^{-1}$ y$^{-1}$ and the low-chemical input system intermediate (5.2 GJ ha$^{-1}$ y$^{-1}$). For each system, the average energy output for food was always greater than that for fuel. Overall energy efficiencies ranged from output:input ratios of 10 to 16 for conventional and no-till food production and from 7 to 11 for conventional and no-till fuel production, respectively. Alfalfa for fuel production had an efficiency similar to that of no-till grain production for fuel. Our analysis points to a more energetically efficient use of cropland for food than for fuel production and large differences in efficiencies attributable to management, which suggests multiple opportunities for improvement.

# *Summary*

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- “extensification” (land sharing) is not likely to be the answer to joint problem of conservation and maximisation of yield
- Land sparing more likely:
  - At field level with proper marginal management
  - At landscape level with non-cropped areas creating network; requires coordination between farmers
  - At regional level when intensive farming less possible
- Future farming necessarily likely to become “greener” to raise efficiency, but we cannot lose sight of the need to maintain yields

# *Conclusion*

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- Food security is a societal problem and requires thinking in a different way and on different scales
  - Science alone will not solve
  - Interdisciplinary approach needed to avoid conflict between science domains
  - Yield needs to be optimised at a scale greater than “the field” (landscape, region, country….)