BIOENERGY AND BIODIVERSITY

David Howard
CEH Fellow, Director LEC Centre for Sustainable Energy, Lancaster
With support from friends and colleagues including Jeanette Whitaker, Rebecca Rowe, Lisa Norton and Bob Bunce at CEH

What am I talking about?
• Who am I?
• What do I mean?
• Why is it important?
• How much do we know?
• Where can we find the answers?
• Which issues are most important?

With thanks to Rudyard Kipling’s ‘Six honest serving men’
Who am I?

David C Howard BA PhD FRES

Yorkshireman
Studied biology
Lectured in zoology
Worked for a NERC research institute
Many roles including director of UKERC, governor of the Joule Centre, director of LEC’s Centre for Sustainable Energy

What is Bioenergy?

Wordcloud of internet definitions of ‘bioenergy’
Bioenergy terminology

- Bioenergy, biomass and biofuels
- Feedstock
- 1st, 2nd and 3rd generation fuels
- Bioethanol, biodiesel, biokerosene and biobutanol
- Conversion, decommissioning and reversion

Bioenergy statistics

Biomass 10% world energy supply
(58 EJ, traditional and modern)

Modern bioenergy
2% of world electricity generation
4% of world road transport fuel

UK
Bioenergy = 71% of renewable energy use (2015)
4.4% of UK electricity
3.3% road transport fuel
2.4% heat (84% of renewable heat)
What is biodiversity?

The variability among living organisms from all sources, including, 'inter alia', terrestrial, marine and aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems.

Species diversity

Genetic diversity

Biological diversity

Taxonomic diversity

All genes, species and ecosystems in a location

Species richness

Ecological diversity

Morphological diversity

Habitat diversity

Functional diversity

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**Why is bioenergy important?**

- Drive for alternative energy sources
  - Environmental protection
  - Security of supply
  - Economic success
  - Improve quality of life
- Bioenergy crops have a large spatial footprint
- Spatially variable and dynamic
- Government sees it as part of the solution
- Impacts largely unknown

**Where can we find answers?**

- Academic literature!
- Search Web of Science
  Terms: bioenergy & biodiversity
  Date: 1\textsuperscript{st} February 2017
  Papers: 435
- Information on
  - Who
  - Where
  - Funder
  - Topic, etc
Most cited

<table>
<thead>
<tr>
<th>Paper</th>
<th>Total</th>
<th>Average</th>
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<tr>
<td>Schroter, D.; Cramer, W.; Leemans, R.; et al. (2005) Ecosystem service supply and vulnerability to global change in Europe</td>
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<td>Power, A. G. (2003) Ecosystem services and agriculture: tradeoffs and synergies</td>
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<td>Gelland, I.; Sahagul, R.; Zhang, X. et al. (2013) Sustainable bioenergy production from marginal lands in the US Midwest</td>
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<td>Rowe, R. L.; Street, N. R.; Taylor, G. (2009) Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK</td>
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<td>Smith, P.; Haberl, H.; Popp, A. et al. (2013) How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals?</td>
<td>9440</td>
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</table>

What’s the relationship between bioenergy and biodiversity?

- Text mining in R
  - Simple examination
  - Standard analysis
  - Latent Dirichlet Allocation
Countryside Survey

- Monitoring the state and change of British environment
- Started in 1978
- Uses different approaches
- Includes repeated visits to the same sites
- Used to inform Government policy
Countryside Survey, field survey: sampling design

45 environmental strata - GB

Based on 40 underlying variables including; climate, location, topography, geology and human geography classified using ISA to give 32 land classes across Great Britain


Vegetation plots recorded in each CS square...
current status in 2007

Random area (X) plots (5)

Targeted Y plots (5+n)

Unenclosed plots (10)

Margin plots (<=15)

Linear plots
- Hedges (10,2)
- Streams (3,2)
- Roads (3,2)
- Boundaries (5)
- Arable (5)
**Land Cover Map**


http://www.ceh.ac.uk/services/land-cover-map-2015

**Biodiversity monitoring - field survey**

Widespread GB habitats, including farmland (arable and grassland) and upland habitats, woodland

Landscape features, e.g. Individual trees, hedgerows and ponds

Large plots in habitats covering large areas
Smaller plots in small patches of habitat and alongside linear features (e.g. Roads, hedges, stream sides)
Ponds and headwater streams

Interesting biodiversity/farmland facts from CS

- In 2007 CS captured 68% of UK plant species diversity (not designated as ‘rare’, ‘scarce’ or ‘alien’) (PLANTATT, Hill et al. 2004)

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<th>RANK</th>
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<th>1998</th>
<th>1990</th>
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<td>1</td>
</tr>
<tr>
<td>Holcus lanatus</td>
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<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Arrhenatherum elatius</td>
<td></td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Urtica dioica</td>
<td></td>
<td>4</td>
<td>6</td>
<td>11</td>
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<tr>
<td>Crataegus monogyna</td>
<td></td>
<td>5</td>
<td>8</td>
<td>9</td>
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<tr>
<td>Agrostis stolonifera</td>
<td></td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Rubus fruticosus</td>
<td></td>
<td>7</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Dactylis glomerata</td>
<td></td>
<td>8</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Agrostis capillaris</td>
<td></td>
<td>9</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Festuca rubra</td>
<td></td>
<td>10</td>
<td>9</td>
<td>7</td>
</tr>
</tbody>
</table>

2007 Headlines - Biodiversity of arable land

- The area of arable land decreased by 9.1% in the UK between 1998 and 2007, mostly through conversion to grassland.
- Between 1998 and 2007 plant species richness increased in arable land by 30% in Great Britain.
Validation
Estimates of area under different agricultural categories compared to MAFF June Census for 1978 (smallest sample)

Bioenergy studies

- Wood Energy (1986)
- Novel crops (1989)
- ExternE (1996)
- UKERC uses of bioenergy (2008)
- Towards integration of low carbon energy and biodiversity policies (2012)
- ELUM
Wood energy

- Model of potential energy from standards (SRF) and coppice (SRC) woodland
- Used Countryside Survey sample squares
- Assessed by foresters
- Filtered and compared with existing land use
- Weighted, using the ITE Land Classification to produce national estimates
- Scenarios developed for different barriers and drivers

Example scenarios

England

Farming  Conservation  Industry

Coppice woodland

- Visual interpretation by land class
- Interpretation of habitats that change
- Species or stock at risk

Artistic interpretation by Chris Benefield

Woody crops - emissions

- Cultivation and Harvest: 3.03 (2.5)
- Feedstock storage and drying: 1.52 (4.3)
- Emission from leaf litter: 1.34 (1.1)
- Transport: 1.30 (8.6)
- Soil Carbon: 2.59 (2.1)
- Total fuel use and machinery: 1.55 (2.3)
- Emission during storage: 23.84 (2.1)

Total wood crop production: 4.47 (11.7)

- Plant operation, maintenance, and construction: 10.48
- Gasification: 15.08
- Co-firing: 15.21
- Direct Firing: 20.48
- CHP (direct combustion): 6.45
- CHP Gasification: 8.65
Variability in bioenergy life-cycle assessment

Bioethanol GHG emissions

- Real
  - Fertiliser use
  - Crop yields
  - Feedstock drying method

- LCA methodology
  - System boundaries
  - Co-product credit method

- Uncertainty
  - \( \text{N}_2\text{O} \) emissions from field
  - Soil carbon stock change


Indirect Land Use Change (ILUC)

- Involves:
  - Displacement of activity (cascade)
  - Intensification to balance productivity
  - Integrated impacts with direct land use change

Simple concept – almost impossible to assess

DECC 2050 Pathways Calculator

http://2050-calculator-tool.decc.gov.uk/

LUC Model

LUC Cover type | Calculator | LCM2007 | Validation
---|---|---|---
Arable agriculture | 45,350 | 63,005 | 63,840
Grassland | 132,020 | 127,301 | 115,220
Woodland | 24,370 | 28,790 | 28,410
Settlement | 21,241 | 14,648 | 19,632
Other | 21,350 | 9,448 | 27,773
Total | 244,330 | 243,192 | 242,495

ERC SCIENCE OF THE ENVIRONMENT
LUC baseline

Production options
Constraints and production

How much is needed?

<table>
<thead>
<tr>
<th>Year</th>
<th>BAU</th>
<th>High Nuclear</th>
<th>High CCS</th>
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</thead>
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<tr>
<td>2007</td>
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<td>3,639</td>
<td>3,639</td>
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<tr>
<td>2010</td>
<td>1,120</td>
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<td>1,943</td>
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<td>2015</td>
<td>1,420</td>
<td>6,300</td>
<td>4,550</td>
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<tr>
<td>2020</td>
<td>1,720</td>
<td>10,082</td>
<td>7,082</td>
</tr>
<tr>
<td>2025</td>
<td>2,020</td>
<td>13,791</td>
<td>9,541</td>
</tr>
<tr>
<td>2030</td>
<td>2,320</td>
<td>19,760</td>
<td>11,930</td>
</tr>
<tr>
<td>2035</td>
<td>2,620</td>
<td>25,333</td>
<td>15,003</td>
</tr>
<tr>
<td>2040</td>
<td>2,920</td>
<td>30,843</td>
<td>18,013</td>
</tr>
<tr>
<td>2045</td>
<td>3,220</td>
<td>36,291</td>
<td>20,961</td>
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<tr>
<td>2050</td>
<td>3,520</td>
<td>41,680</td>
<td>23,850</td>
</tr>
</tbody>
</table>
But where?

(a) 9,482 km²
(b) 9,432 km²
(c) 9,765 km²
(d) 9,314 km²

Consequences....

Which habitat is used?

What the calculator calls grassland
Impact on species

- Biological Records Centre (National Biodiversity Network)
- 50 species examined

Most at risk?

Percentage occurrence of species in squares in different regions (UK, land available for bioenergy and land restricted).

Ratio represents available/restricted. Broad Habitats is association with habitat (see key at end of table). Status: a=archaeophyte, n=native, N=neophyte, c=critically endangered, e=endangered, v=vulnerable. Boxed species are grassland Broad Habitats.

<table>
<thead>
<tr>
<th>Species</th>
<th>UK</th>
<th>Available</th>
<th>Restricted</th>
<th>Risk Ratio</th>
<th>Broad Habitat</th>
<th>Status</th>
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</thead>
<tbody>
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<td>Alisma gramineum</td>
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<td>0.4</td>
<td>0.0</td>
<td>8.01</td>
<td>13</td>
<td>n,c</td>
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<td>0.2</td>
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<td>Crepis prostrata</td>
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<td>0.0</td>
<td>2.63</td>
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<td>0.2</td>
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<td>55.3</td>
<td>1.37</td>
<td>6</td>
<td>N</td>
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<tr>
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<td>30.5</td>
<td>1.33</td>
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<td>64.0</td>
<td>1.29</td>
<td>1</td>
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</table>

Key to Broad Habitats: 1=Broadleaved, mixed and yew woodland; 3=Boundary and linear features; 4=Arable and horticultural; 5=Improved grassland; 6=Neutral grassland; 7=Calcareous grassland; 8=Acid grassland; 9-Brook; 10=Dwarf shrub heath; 11=Feu, marsh and swamps; 12=Bog; 14=Rivers and streams; 15-Montane habitats; 16=Inland rock; 17=Built-up areas and gardens; 18=Supra-littoral rock; 21=Littoral sediment.
CEH Bioenergy and Land Use Research

Aim to reduce uncertainty in carbon savings from perennial bioenergy feedstocks in the UK

- Quantify the impact of direct land-use change to bioenergy on soil carbon and GHGs (CO₂, CH₄, and N₂O)
- Test land management and mitigation strategies
- Develop a knowledge exchange network to increase impact

Measurement Framework

18 Land use change scenarios for the UK

<table>
<thead>
<tr>
<th>Original land use</th>
<th>Bioenergy land use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arable</td>
<td>Wheat, sugar beet, OSR, SRC willow, SRF, Miscanthus</td>
</tr>
<tr>
<td>Grassland</td>
<td>Wheat, sugar beet, OSR, SRC willow, SRF, Miscanthus</td>
</tr>
<tr>
<td>Forestry</td>
<td>Wheat, sugar beet, OSR, SRC willow, SRF, Miscanthus</td>
</tr>
</tbody>
</table>

Measurements on commercial farms:
- Intensive soil C and GHG monitoring sites (4)
- Paired site soil carbon stock assessments (~70)
- Carbon isotope techniques to improve mechanistic understanding
Soil carbon stock assessment (0-30 and 0-100 cm depth)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Range (yrs)</th>
<th>Median (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short rotation forestry</td>
<td>4-24</td>
<td>16</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>1-10</td>
<td>7</td>
</tr>
<tr>
<td>SRC-Willow</td>
<td>4-23</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Lincolnshire – Miscanthus, SRC willow and arable

Eddy covariance
Net Ecosystem Exchange (NEE): balance between photosynthesis and plant and soil respiration

GHG emissions
Measurements of CO, CH₄, and N₂O

Soil carbon stock change
30 cm and 1 m depth sampling

Crop Range (yrs) Median (yrs)
Short rotation forestry 4-24 16
Miscanthus 1-10 7
SRC-Willow 4-23 6.5
Soil carbon stock change following LUC to bioenergy

Planting on **arable** land = soil carbon gain
Planting on **grassland** = soil carbon loss

![Graph showing soil carbon stock change](attachment://bioenergy.png)

Rowe et al. (2016) GCB Bioenergy

Vegetation

- **SRC**, change in *species composition*.
- **Miscanthus**, depend on crop patchiness, Dauber (2014) fields yielding > 9.8 odt ha\(^{-1}\) yr\(^{-1}\) had similar plant species richness arable fields.
- **SRF**, species dependant

![Ground Flora Species Richness](attachment://ground_flora.png)

![Fraction of total cover](attachment://total_cover.png)
Risks to vegetation

Plant species of concern that maybe negatively affected

- Rare arable plants
  - Cornflower, Corn buttercup, Pheasant’s eye, Venus's-looking-glass, Weasel's-snout, Shepherd's-needle
- Location and headland management may be crucial

![Image of plant species]

Plant Life, [http://www.plantlife.org.uk](http://www.plantlife.org.uk)

Invertebrates

- SRC, higher abundance and diversity of epigeal predatory invertebrates, but no impact on predation rates
- Miscanthus, Abundance of spider was found to be positively linked to patchiness but not ground beetles (Dauber 2014)

![Graph of invertebrate abundance]

D. melanogaster pupa C. Vomitoria pupa
Risks to invertebrates

Species of concern that maybe negatively affected

- Nectar and pollen feeding invertebrates
  - Spp. of Butterflies, hoverflies, bees.
  - SRC willow does produce catkins and stem feeding pest produce sugar dew
  - Headlands again essential

Mammals

Higher small mammal diversity, abundance and breeding in SRC willow compared to arable land

- S.J. Clapham (thesis) also reported higher small mammal abundance Miscanthus than in arable crops.
- All provide shelter for larger mammals
Birds

• SRC is associated with a high abundance and diversity of Bird spp.
  - Warblers, Reed Bunting, Snipe, Woodcock, Wren, Black Bird, Song Thrush.
• Young Miscanthus plantation are associated with higher abundance and diversity of bird spp. than arable fields, but benefits may diminish with crop age.
• SRF
  - Will depend on species selected and location, limited data.


Risks to birds

Bird species of concern that can be negatively affected

• Bird spp. associated with open farmland
  – Yellow wagtail, Grey Partridge, Stone Curlew, Lapwings, Skylarks, Raptors.
Summary

• It’s complicated!!!!
• Scale, location and intensity are fundamental
• Second generation bioenergy crops have potential to increase landscape biodiversity but are not a panacea.
• Objectives must be examined and trade-offs recognised

You niver get owt fer nowt!

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