Natural science and economics:
Partners for ecosystem service management

or Highway to Hell?

Ian Bateman
Royal Society Wolfson Professor,
H.M. Treasury Natural Capital Committee, Defra Science Advisory Council
True economists are not... Accountants
Accountants

Economists
Accountants

Prices

Economists

Values
Why the **Price** v. **Value** distinction matters

e.g. Riverside walks

| Price = 0 | The revenue which private firms would receive from providing riverside walks – hence they don’t |
| Value > 0 | The benefits to society |

Can we make decisions without values?
Two inescapable facts

1. Human wants (including those with the highest possible motivations such as improving society or even saving lives) exceed the resources available to satisfy them all;

2. Every time we decide to do one thing, we are making a decision not to do another. We are implicitly placing values on each option.

Valuation is unavoidable; it is the essence of decision making.

To pretend otherwise is irresponsible

Be explicit about the valuations inherent in decision making
Recognise the inevitable trade-offs which decisions imply.

And real-world trade-offs are many and complex...
Ecosystem Services: Conceptual Framework

Primary & intermediate ecosystem processes

- e.g. Nutrient cycling, water cycle, etc.

Final ecosystem services

- e.g. Trees, etc.
Ecosystem Services: Conceptual Framework

Primary & intermediate ecosystem processes
- e.g. Nutrient cycling, water cycle, etc.

Final ecosystem services
- e.g. Trees, etc.

Natural capital inputs

Other capital inputs
- e.g. Timber, etc.

Goods
Ecosystem Services: Conceptual Framework

- **Primary & intermediate ecosystem processes**
  - Solar & other physical inputs
  - Natural capital inputs
  - Natural capital inputs

- **Final ecosystem services**
  - Goods
  - Goods

- **Other capital inputs**

**Goods**
- e.g. Trees, etc.
- e.g. Timber, etc.

**Natural capital inputs**
- e.g. Nutrient cycling, water cycle, etc.

**Primary & intermediate ecosystem processes**

![The natural water cycle diagram]

![Image of trees]

![Image of timber]
Ecosystem Services: Conceptual Framework

<table>
<thead>
<tr>
<th>Solar &amp; other physical inputs</th>
<th>Natural capital inputs</th>
<th>Other capital inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary &amp; intermediate ecosystem processes</td>
<td>Final ecosystem services</td>
<td>Goods</td>
</tr>
</tbody>
</table>

- **Weathering**
  - Crops, livestock, fish
  - Food
- **Primary production**
  - Water availability
  - Drinking water
- **Decomposition**
  - Trees
  - Fibre
- **Soil formation**
  - Peat
  - Energy
- **Nutrient cycling**
  - Wild species diversity
  - Energy
- **Water cycling**
  - Waste breakdown
  - Pollution control
- **Climate regulation**
  - Detoxification
  - Equable climate
- **Pollination**
  - Purified water
  - Flood control
- **Evolutionary processes**
  - Local climate
  - Biodiversity
- **Ecological interactions**
  - Stabilising vegetation
  - Natural foods
  - Natural enemies
  - Recreation
  - Meaningful places
  - Good health
  - Wild species diversity
Ecosystem Services: Conceptual Framework

Solar & other physical inputs

Primary & intermediate ecosystem processes
- Weathering
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Other capital inputs

Final ecosystem services

Goods
- Food
- Drinking water
- Fibre
- Energy
- Equable climate
- Pollution control
- Flood control
- Biodiversity
- Natural foods
- Recreation
- Good health

Natural units
- Cultural
- Provisioning
- Regulating
- Supporting

How would YOU make decisions? (and not just for the environment – at the same time also allocate scarce resources for the health service, transport, employment and social security, etc., etc.)
- Need to make changes commensurate
- Need to know their relative importance (their value).

Money is a convenient common unit with comparability across sectors (the least worst common unit).
Highly diverse natural units (tonnes, mg/l, mm, visits, days, £). We need to make them commensurate and to know their relative importance (their value). Money is a convenient common unit with comparability across sectors which can be used for most goods.

Ecosystem Services: Conceptual Framework

Primary & intermediate ecosystem processes:
- Weathering
- Primary production
- Decomposition
- Soil formation
- Nutrient cycling
- Water cycling
- Climate regulation
- Pollination
- Evolutionary processes
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Final ecosystem services:
- Natural capital inputs
- Other capital inputs

Goods:
- Crops, livestock, fish
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- Local climate
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- Food
- Timber
- Water quality
- Energy
- Equable climate
- Pollution control
- Flood control
- Disease control
- Nature watching
- Recreation
- Good health

Measures of value:
- Monetary
- Other

Categories:
- Cultural
- Provisioning
- Regulating
- Supporting
Ecosystem Services: Conceptual Framework

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Goods:
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- Disease control
- Nature watching
- Recreation
- Good health

Measures of value:
- Monetary
  - £
- Other
  - ☺

Costs & Benefits

Wellbeing

Solar & other physical inputs

Natural capital

Other capital

Natural capital inputs

Other capital inputs

Ecosystem Services:
- Regulating
- Supporting
- Provisioning
- Cultural
Ecosystem Services: Conceptual Framework

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Measures of value
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Costs & Benefits

Wellbeing

Solar & other physical inputs

Converting forestry to farmland
Converting farmland to forestry

Natural capital
Other capital

Crops, livestock, fish
Water availability
Trees
Peat
Wild species diversity
Waste breakdown
Detoxification
Purified water
Local climate
Stabilising vegetation
Natural enemies
Meaningful places
Wild species diversity

Cultural
Provisioning
Regulating
Supporting

£

☺

&
Valuation methods

- Food production (agricultural, marine, other)
- Biodiversity: Use values (pollination, pest control, wildlife, sport)
- Biodiversity: Non-use values (existence values)
- Raw materials (timber, aggregates, other)
- Climate regulation (carbon storage, GHG)
- Water quantity and quality
- Flood prevention (inland and coastal)
- Pollution remediation
- Energy
- Amenity values (landscape, urban greenspace, climate amenity, etc)
- Recreation and tourism
- Environmental effects upon health

Valued via:
- Adjusted market prices
- Contribution to output
- Avoided costs
- Stated preferences
- Studies of behaviour

Two limitations:
1. The existence value of biodiversity
2. Changes not totals
Economic analysis: The value of changes

UK National Ecosystem Assessment

World Markets (WM)
Go With the Flow (GF)
Green & Pleasant Land (GPL)
Local Stewardship (LS)
National Security (NS)
Nature at Work (NW)
Integrating natural science and economics

- Recreation
- Biodiversity
- Land use change
- Farming
- Forestry
- GHG & climate change
- Water quality
- Nutrients

- CH₄
- N₂O
- CO₂
Integrated analysis: Drivers and their direct effect

Drivers:
e.g. market forces, climate change, policy, etc.

Recreation

Farming

Forestry

Biodiversity

GHG & climate change

Nutrients

Water quality

CH₄, N₂O, CO₂
Integrated analysis: Indirect effects

Drivers: e.g. market forces, climate change, policy, etc.

Recreation

Farming

Forestry

Biodiversity

GHG & climate change

Water quality

Nutrients

Drivers:

- N2O
- CO2
- GHG

Nutrients:

- Recent grass
- Permanent grass
- pasture
- Winter wheat
- Winter barley
- Spring grass
- Winter barley
- Potato
- Set aside
- Sugar beet
- Non-agricultural

Drivers:

- Market forces
- Climate change
- Policy

GHG cycle:

- CH4
- N2O
- CO2

Soil
Integrating natural science and economics

- Recreation
- Farming
- Biodiversity
- Forestry
- Land use change
- Nutrients
- GHG & climate change
- Water quality

- CH₄
- N₂O
- CO₂
The main drivers of agricultural land use

- Common Agricultural Policy
- Environmental Policy
- Intervention (historic)
- Output prices
- Input costs
- Technology
- Soils
- Temperature
- Rainfall

More than 40 years of spatially referenced data for all of GB
Empirical model of land use

Constrained optimization problem:

\[
\pi^L(p, w, z, L) = \max \{ \pi(p, w, z, L, s_1, \ldots, s_h) : \sum_{i=1}^{h} s_h = 1 \}
\]

Estimation profit function:

\[
\pi^L = \alpha_0 + \sum_{i=1}^{m+n-1} \alpha_i x_i + \frac{1}{2} \sum_{i=1}^{m+n-1} \sum_{j=1}^{m+n-1} \alpha_{ij} x_i x_j + \sum_{i=1}^{h-1} \beta_i s_i + \frac{1}{2} \sum_{i=1}^{h-1} \sum_{j=1}^{h-1} \beta_{ij} s_i s_j + \sum_{i=1}^{k+1} \gamma_i z_i^* +
\]

\[
+ \frac{1}{2} \sum_{i=1}^{k+1} \sum_{j=1}^{k+1} \gamma_{ij} z_i^* z_j^* + \sum_{i=1}^{m+n-1} \sum_{j=1}^{h-1} \delta_{ij} x_i s_j + \sum_{i=1}^{m+n-1} \sum_{j=1}^{k+1} \phi_{ij} x_i z_j^* + \sum_{i=1}^{h-1} \sum_{j=1}^{k+1} \phi_{ij} s_i z_j^*
\]

Example derived yield function:

\[
\frac{\partial \pi^L}{\partial x_i} = y_i^L = \alpha_i + \sum_{j=1}^{m+n-1} \alpha_{ij} x_j + \sum_{j=1}^{h-1} \delta_{ij} s_j + \sum_{j=1}^{k+1} \phi_{ij} z_j^*
\]

Optimal land allocation:

\[
s_i = \theta_i + \sum_{j=1}^{m+n-1} \theta_{ji} x_j + \sum_{j=1}^{k+1} \eta_{ji} z_j^* \]

for \( i = 1, \ldots, h-1 \)

Land use is driven by human behaviour

...but there are many long term influences and constraints upon that behaviour

e.g.: environmental characteristics of farms, prices; costs; policy; etc.

These dictate potential yields

The model estimates land use – which can be compared against actual observations to test model validity
Validation: Out-of-sample actual versus predicted tests

Cereals

Actual  Predicted

Temporary grassland

Actual  Predicted
Climate change impacts
UK Climate Impact Programme: Predictions

Rainfall: 2004 - 2040

Temperature: 2004 - 2040
Predicted climate change impacts on land use to 2060

Oilseed rape
(Δha/2km sq)

- < -30
- -30 to -12
- -12 to 12
- 12 to 30
- 30 to 70

Dairy
(Δcows/2km sq)

- < -100
- -100 to -20
- -20 to 20
- 20 to 80
- 80 to 200
All outdoor recreation: MENE data (n>40,000p.a.)
Baseline visit numbers and values

Estimated GB total recreational visits ('000 per annum)

Estimated GB value of recreational visits (£'000 per annum)
Scenario impacts on GHG values

Carbon storage in crops & trees

Carbon release from harvest & felling

Soil carbon changes

Machinery & fertiliser emissions

Livestock emissions

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Under gross</th>
<th>Under trees</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat</td>
<td>1300</td>
<td>420</td>
<td>-880</td>
</tr>
<tr>
<td>Humus grey</td>
<td>1800</td>
<td>2500</td>
<td>700</td>
</tr>
<tr>
<td>Phyllite</td>
<td>2000</td>
<td>2500</td>
<td>500</td>
</tr>
<tr>
<td>Brown calcareous</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Brown calcareous</td>
<td>100-400</td>
<td>190-450</td>
<td>90-50</td>
</tr>
<tr>
<td>Big boggy</td>
<td>120-400</td>
<td>190-450</td>
<td>70-50</td>
</tr>
</tbody>
</table>
Why ecosystem service valuation matters

**Best option**

**World Markets Scenario**
Increased intensification of natural resource use to maximise market values

*Market value gain*
+ £420 million per annum relative to the current baseline

**Nature at Work Scenario**
Sustainable use of natural resources to maximise net ecosystem service values

*Market value loss*
- £510 million per annum relative to the current baseline
Why ecosystem service valuation matters

Best option

World Markets Scenario
Increased intensification of natural resource use to maximise market values

Market value gain
+ £420 million per annum relative to the current baseline

Nature at Work Scenario

Why ecosystem service valuation matters
Why ecosystem service valuation matters

Net value loss
- £18,990 million per annum relative to the current baseline

Net value gain
+ £17,920 million per annum relative to the current baseline
Adjusting urban park values for income distribution

Recreational value (£ per household p.a.)

UK-NEA Scenarios

i  ii  iii  iv  v  vi

0

Losses Gains

Unweighted (conventional) values
Adjusting urban park values for income distribution

UK-NEA Scenarios

Recreational value (£ per household p.a.)

Losses Gains

0

Unweighted (conventional) values
Distributionally weighted values
Who pays? Who benefits? How much?

• Provision of urban parks (previous example):
  o Taxpayers fund the scheme
  o Poorer sections of society receive the benefits

• Countryside Stewardship:
  o Taxpayers fund the scheme
  o Benefits dispersed across society

• Fowey River Improvement Auction
  o Water company funds the scheme
  o Water company, farmers and society benefit (>cost)
Engaging business through game theory

- The Fowey supplies water for much of Cornwall
- Pesticide use by farms means water treatment costs are high
- Game theory design for competitive bidding process reveals that: compensation cost < treatment cost
- Net gains for water company, farmers & society
Who pays? Who benefits? How much?

- Provision of urban parks (previous example):
  - Taxpayers fund the scheme
  - Poorer sections of society receive the benefits

- Countryside Stewardship:
  - Taxpayers fund the scheme
  - Benefits dispersed across society

- Fowey River Improvement Auction
  - Water company funds the scheme
  - Water company, farmers and society benefit (>cost)

- Conservation grade palm oil
  - Consumers fund scheme
  - Consumers, farmers and society benefit (>cost)
Globally 1 in 4 terrestrial mammals are threatened with extinction (Schipper et al. 2008).

The main driver is loss of habitat to agriculture and plantations (Foley et al., 2005).

The most dramatic losses are within tropical forests: up to 12 million hectares lost per year (DeFries et al., 2002).
Four year field study with full plantation cooperation

Study site

- Concession divided into 400 sub-areas
- All financial data provided (inputs, outputs, prices, costs, etc.)
- Corresponding physical environment and meteorological data.
- More than 90 variables per sub-area per month from 2002 to 2006 = 2.5 million data records.
Mapping the opportunity cost of conservation (OCC)

OCC highest in existing oil palm plantation and near the mill.

Lowest in unplanted areas distant from the mill.
Modelling the effectiveness of conservation in oil palm plantations

- Over 1000km of transect line walks across all areas of the concession over a four year period.
- Animal sightings recorded using GPS
- Land use types and distances to different areas and features assessed using GIS
IUCN Red List mammals in Central Sumatran study area

- East Asian porcupine
- Smooth coated otter
- Pangolin
Long tailed macaque

Pig tailed macaque

Siamang

Agile gibbon

Long tailed macaque
Predicted probability of observing red list mammals

Effectiveness of conservation
Cost-effectiveness of conservation for red list mammals

Effectiveness of conservation

Costs of conservation

<table>
<thead>
<tr>
<th>Probability of sighting a Conservation Status 2 or 3 mammal</th>
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<tr>
<td></td>
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<tr>
<td>Quintile 1</td>
</tr>
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<td>Quintile 2</td>
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<tr>
<td>Quintile 3</td>
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<tr>
<td>Quintile 4</td>
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<tr>
<td>Quintile 5</td>
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</table>

Optimal sites for set-aside
- Small area (5000 ha)
- Medium area (11500 ha)
- Large area (21000 ha)
- No conservation
Does the Conservation Grade price premium cover conservation costs?

Change in profit across different levels of conservation

Provided certification specifies a minimum conservation area then an efficient win-win occurs

- 5,000 ha: Most red list species conserved
- 10,000 ha: All red list species conserved
- 20,000 ha: All red list species conserved

Change in profits (million IDR pa)

Size of conservation area
Summary

• The natural sciences are highly compatible with economic analysis

• They highlight the importance of natural resources in underpinning wellbeing; generating policy impact
Natural Environment White Paper

The Natural Choice: securing the value of nature

"mainstream the value of nature across our society"

Engaging the Business Sector

Policy impact

UK-NEA

Synthesis of the Key Findings

"Applying ecosystem service valuation across the UK"

Engaging the Treasury

Water White Paper

Water for Life

"A vision for future water management which values water as the precious and finite resource it is"

Uniting research and decision making

THE NATURAL CAPITAL COMMITTEE

VALUING NATURE NETWORK
Summary

• The natural sciences are highly compatible with economic analysis
• They highlight the importance of natural resources in underpinning wellbeing; generating policy impact
• Many (but not all) ecosystem services can now be valued
• Those that cannot be robustly valued can still be included within economic analyses
• Allows efficient targeting of limited resources in a time of financial austerity
• Better than the alternatives?
So how’s that “not valuing the environment” working out for you?
Challenges

• Major natural science research challenges have to be overcome to provide the knowledge for economic decision making – e.g.:
  o Systems modelling, dynamics and feedbacks;
  o The science of extreme events;
  o Thresholds;
  o Reversibility and irreversibility;
  o Resilience and sustaining natural capital stocks.

• Economic analysis highlights the value of that research and brings it into real-world decision making
Resilience and sustaining natural capital stocks

Stock level $(K)$

Level of depleting driver

$T$

Stock Threshold (not $K_0$)
Resilience and sustaining natural capital stocks

Stock level (K)
Level of depleting driver

Stock Threshold (not K₀)

Marginal Resilience Value (MRV)
MRV₀
MRV₁
MRV₂
MRV₃

K₃ᵋ K₂ᵋ K₁ K₀
Resilience and sustaining natural capital stocks

Uncertainty and risk aversion

Stock level ($K$)

Level of depleting driver

Stock Threshold (not $K_0$)

Marginal Resilience Value (MRV)

Risk aversion

MRV_3

MRV_2

MRV_1

MRV_0

$K^d_3$

$K^r_2$

$K^d_2$

$K_1$

$K_0$
Resilience and sustaining natural capital stocks

Uncertainty and risk aversion

Stock level (K)

Stock Threshold (not K_0)

Increased risk aversion

Marginal Resilience Value (MRV)

Level of depleting driver
Challenges

• Major natural science research challenges have to be overcome to provide the knowledge for economic decision making – e.g.:
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  o Thresholds;
  o Reversibility and irreversibility;
  o Resilience and sustaining natural capital stocks.

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• Major economic and social science research challenges – e.g.:
  o Imports/exports of (virtual) ecosystem services;
  o Development of decision tools;
  o Engagement with the business sector;
  o Public attitudes and social thresholds;
  o Co-delivery of ecosystem services and poverty alleviation.
Natural science and economics:

**Perfect** partners for ecosystem service management

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