Conserving Biodiversity across Biophysical and Land Use Gradients

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Human Expansion and Loss of Habitat

Increase in exurban development.
Brown 2005

How can we conserve biodiversity given more people and land consumption?
Need to Know:

- How native species are distributed spatially.
- Where humans are relative to biodiversity.
- How people influence native species?

Relationship between mammal species richness and human population density for Mexico. From Vazquez and Gaston 2005.
Promising Approaches: Satellite Data

The NASA Earth Observing System is a $7.3 billion program planning satellite-based earth monitoring for 15 years, and is the heart of global change science for the United States.
Promising Approaches: Species Energy Theory

Biodiversity is often strongly correlated with energy.

Energy
Heat – e.g., temperature, potential evapotranspiration

Ecological productivity – e.g., NPP

Why?

Abundant food resources or warmer thermal conditions allow higher survival and reproduction of individuals within a population, and larger population sizes reduce the chance of species extinctions (Wright 1983).

“Measures of energy (heat, primary productivity)...[and water balance]...explain spatial variation in richness better than other... variables in 82 of 85 cases”, Hawkins et al. 2003.
Conceptual Model

Biophysical Potential
(i.e. Energy, Habitat structure)

Current Biodiversity Value

Conservation Priority/Strategies

Human Land Use
(Land use, Home density)
The marriage of species energy theory and satellite data provides an important new framework for organizing conservation along biophysical and human gradients.
Questions

• How well do MODIS vegetation products account for bird species richness across North America?
  • Best predictor?
  • Shape of relationship?
  • Spatial distribution of energy/bird relationship?

• How are humans distributed relative to ecosystem energy and how does this influence species richness?

• How should conservation be tailored to biophysical and human gradients?
• Survey unit is a roadside route
  • 39.4 km in length
  • 50 stops at 0.8 km intervals
  • Birds tallied within 0.4 km
  • 3 minute sampling period

• One survey per year since 1966

• Water birds, hawks, owls,
  • and nonnative species excluded
  in this analysis
# Predictor Data

| MODIS Vegetation Products | Gross primary productivity  
|                          | Net primary productivity  
|                          | Enhanced vegetation index  
|                          | Normalized difference vegetation index  
|                          | Leaf area index  
| Other Data               | Land cover (MODIS)  
|                          | Human density (US and Canadian censuses)  |
### BBS Issues: Sampling Biases

<table>
<thead>
<tr>
<th>Issue</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Road-side survey.</td>
<td>• Uniqueness of data set outweighs bias</td>
</tr>
<tr>
<td>• Nonrandom habitats?</td>
<td></td>
</tr>
<tr>
<td>• Road-side bird species?</td>
<td></td>
</tr>
<tr>
<td>• Species detectability.</td>
<td>• Mark recapture statistical methods</td>
</tr>
<tr>
<td>• New observers tend to miss species.</td>
<td></td>
</tr>
<tr>
<td>• Ability to detect a bird</td>
<td></td>
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<tr>
<td>• differs among species</td>
<td></td>
</tr>
<tr>
<td>• and habitats.</td>
<td></td>
</tr>
<tr>
<td>• Representation of species richness.</td>
<td>• Average annual for 2000-2004</td>
</tr>
<tr>
<td>• Average annual or cumulative</td>
<td></td>
</tr>
<tr>
<td>• Land use effects.</td>
<td>• Omit routes &gt;30% human agriculture, mosaic, urban for biophysical analyses</td>
</tr>
<tr>
<td>• Humans may alter natural biodiversity</td>
<td></td>
</tr>
</tbody>
</table>
• Patterns of association evaluated with regression techniques.

• Model selection based on AIC (distance between specified model and reality).

• Coefficient of determination for amount of variance explained.

• Bird species richness transformed (log+1) to improve normality.

• Mixed models will be used to control for spatial and temporal autocorrelations, but not done yet.
Landbird Species Richness
Landbird Species Richness

Areas High in Richness

Landbird richness/6 yr average:
- 6 - 26.25
- 26.25 - 37.333
- 37.333 - 46.8
- 46.8 - 55.8
- 55.8 - 79.8

400 0 400 Kilometers
Summary of Results

- **GPP was strongest predictor (.50).**
  - Annual predictors were stronger than breeding season (GPP=.40) predictors.
  - Observed richness (GPP=.62) was stronger than estimated richness.

### MODIS Products and Bird Diversity

<table>
<thead>
<tr>
<th></th>
<th>R²</th>
<th>adj R²</th>
<th>AIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPP</td>
<td>0.4952</td>
<td>0.4936</td>
<td>-6518.4</td>
</tr>
<tr>
<td>NPP</td>
<td>0.4677</td>
<td>0.4671</td>
<td>-6435.9</td>
</tr>
<tr>
<td>EVI</td>
<td>0.4118</td>
<td>0.4111</td>
<td>-6288.2</td>
</tr>
<tr>
<td>NDVI</td>
<td>0.4588</td>
<td>0.4581</td>
<td>-6418.1</td>
</tr>
</tbody>
</table>

N=1617

*Rural routes only*
MODIS Products and Bird Diversity

The relationship is unimodal.
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Ecoregions lie on different portions of the unimodal relationship.
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Ecoregions lie on different portions of the unimodal relationship.
Biophysical Correlates with Human Density

Human density is also correlated with GPP.
Human Density and Biodiversity

Birds are correlated with human density.
Human Density and Biodiversity

Birds are correlated with human density.

Is there a human effect on birds beyond GPP?
Human Density and Biodiversity

Low population routes

For lower population routes (yellow in these graphics) human population density contributes little to the best model.

Human density has little effect on birds at lower human densities.
Human Density and Biodiversity

High population routes

For higher population routes, above the 1.75 threshold, human population density explains more variation than GPP.

Humans may reduce birds at higher human densities.
Conservation Implications

- The conservation implications of species energy theory are not yet well developed in the literature.
- The key strategies of conservation biology are currently applied without regard to biophysical gradients.
- Species energy theory may offer an organizing framework.
Managing along Biophysical Gradients

- Strong energy control
  - Low successional control
  - Lower human density

- Weak energy control
  - High succession control
  - Higher human density

- Energy depresses diversity
  - High successional control
  - Lower human density
High-Energy Ecoregions: Pacific Northwest

<table>
<thead>
<tr>
<th>Conservation Category</th>
<th>Management strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation Zones</td>
<td>Protect low energy places</td>
</tr>
<tr>
<td>Disturbance</td>
<td>Use disturbance to break competitive dominance</td>
</tr>
<tr>
<td></td>
<td>Use shifting mosaic harvest pattern</td>
</tr>
<tr>
<td></td>
<td>Maintain structural complexity</td>
</tr>
<tr>
<td>Landscape Pattern</td>
<td>Manage for patch size and edge</td>
</tr>
<tr>
<td>Sensitive Species</td>
<td>Forest interior species</td>
</tr>
<tr>
<td></td>
<td>Open canopy species</td>
</tr>
<tr>
<td>Protected Area Size</td>
<td>Smaller</td>
</tr>
<tr>
<td>Land Use</td>
<td>Allow more random placement</td>
</tr>
</tbody>
</table>

- **81-100% predicted maximum richness**
- **70-80% predicted maximum richness**
- **Unclassified**
# Low-Energy Ecoregions: Greater Yellowstone

<table>
<thead>
<tr>
<th>Conservation Category</th>
<th>Management strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation Zones</td>
<td>Protect high energy places</td>
</tr>
<tr>
<td>Disturbance</td>
<td>Use fire, flooding, logging judiciously in hotspots</td>
</tr>
<tr>
<td>Landscape Pattern</td>
<td>Maintain connectivity due to migrations</td>
</tr>
<tr>
<td>Sensitive Species</td>
<td>Many species with large home ranges and low population sizes due to energy limitations</td>
</tr>
<tr>
<td>Protected Area Size</td>
<td>Large</td>
</tr>
</tbody>
</table>
| Land Use              | Low overall  
  | Focused on hot spots  
  | Plan development outside of hotspots |

- **Energy Richness**
  - National Park Service
  - Other federal lands
  - County boundaries
  - Biodiversity hotspots
  - Biodiversity modeling mask
  - Homes
## Mid-Energy Ecoregions: Appalachians

### Conservation Category

<table>
<thead>
<tr>
<th>Conservation Category</th>
<th>Management strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation Zones</td>
<td>Protect more natural areas</td>
</tr>
<tr>
<td>Disturbance</td>
<td>Similar to “Descending”</td>
</tr>
<tr>
<td>Landscape Pattern</td>
<td>Similar to “Descending”</td>
</tr>
<tr>
<td>Sensitive Species</td>
<td>Synanthropic species will dominate natives</td>
</tr>
<tr>
<td>Exotics</td>
<td>High exotics likely due to productivity and high land use</td>
</tr>
<tr>
<td>Protected Area Size</td>
<td>Smaller</td>
</tr>
</tbody>
</table>
| Land Use              | Focus away from remaining natural areas  
                        | Emphasize “backyard” conservation  
                        | Apply restoration |
Conclusions

• Biophysical factors such as energy set a natural potential for biodiversity.

• Land use may modify biodiversity from this potential.

• The “hump-shaped” energy curve leads to the need to tailor conservation to the three zone of species/energy curve.
Broader Applications?

Where are the zones of energy and human density on other continents?

This study.

Balmford et al. 2001

Vertebrates and NPP

Humans and NPP

GPP/richness

Bird richness

Gross Primary Production (x1000)

0 5000 10000 15000 20000 25000

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

0 1000 2000 3000 4000 5000

This study.
Acknowledgements

NASA EOS Program

NASA Land Cover Land Use Change Program
Publications

Land Use Change Around Nature Reserves: Implications for Sustaining Biodiversity

In Press. Ecological Applications

Ecological mechanisms linking nature reserves to surrounding lands: A conceptual framework for assessing implications of land use change.
  A. Hansen and R. DeFries.
Sustaining regional biodiversity in the Mayan Forest.
Regional land use effects on panda populations and other species in the Wolong Reserve, China.
  J. Jiu.
Effects of alternative future growth scenarios on biodiversity in Greater Yellowstone
Towards regional management of nature reserves and surrounding lands
Next Steps

• Include sensitive species in the analyses

• Map for North America zones of energy and land use and recommend conservation strategies

• Test these hypotheses for other taxa and for other continents