What Is Scaling?

- **Scaling = Scale Transfer (or Scale Transformation)**
- **Scaling is the translation (or extrapolation) of information from one scale to another in time and/or space**

  - **Scaling up (or upscaling):**
    Finer/Smaller --> Coarser/Broader Scales

  - **Scaling down (or downscaling):**
    Coarser/Broader --> Finer/Smaller Scales
Why Is Scaling Necessary?

1). Most ecological studies, be they observational, experimental and theoretical, have been done at small scales.

2). Most environmental and resource management problems need to be dealt with at larger scales.

3). Understanding how nature works requires consideration of pattern and process at different scales and their hierarchical linkages.
Why Is Scaling in Ecology Complex?

1). Spatial heterogeneity
   • Climatic/meteorological conditions
   • Topographic/soils
   • Vegetation
   • Land use change
   • Disturbances (natural and anthropogenic)

2). Different controls and processes at different scales
   • Same factors/processes, but different degrees of dominance
   • New dominant factors/processes emerge as scale changes

3). Nonlinear relationships and feedbacks
   • Nonlinear relationships and feedbacks in physical processes
   • Nonlinear interactions and feedbacks among biological components
   • Nonlinear interactions between biological and physical components
   • Emergent properties
   • Threshold phenomena
Top 10 Research Topics in Landscape Ecology  
(Wu and Hobbs 2002)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ecological flows in landscape mosaics</td>
</tr>
<tr>
<td>2</td>
<td>Causes, processes, and consequences of land use and land cover change</td>
</tr>
<tr>
<td>3</td>
<td>Nonlinear dynamics and landscape complexity</td>
</tr>
<tr>
<td>4</td>
<td>Scaling</td>
</tr>
<tr>
<td>5</td>
<td>Methodological development</td>
</tr>
<tr>
<td>6</td>
<td>Relating landscape metrics to ecological processes</td>
</tr>
<tr>
<td>7</td>
<td>Integrating humans and their activities into landscape ecology</td>
</tr>
<tr>
<td>8</td>
<td>Optimization of landscape pattern</td>
</tr>
<tr>
<td>9</td>
<td>Landscape conservation and sustainability</td>
</tr>
<tr>
<td>10</td>
<td>Data acquisition and accuracy assessment</td>
</tr>
</tbody>
</table>
### 3 Basic Types of Scaling Operations

Adapted from Bierkens et al. (2000)

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changing Extent</td>
<td>“Extrapolation”</td>
</tr>
<tr>
<td>Changing Grain</td>
<td>Coarse-graining, Fine-graining</td>
</tr>
<tr>
<td>Changing Coverage</td>
<td>Interpolation, Sampling</td>
</tr>
<tr>
<td>Example of Combinations</td>
<td>Interpolation, Coarse-graining</td>
</tr>
</tbody>
</table>
Combinations of Basic Scaling Operations

**Basic operations**
1-E: Change extent only (extrapolation & singling out)
2-G: Change grain only (coarse- & fine-graining)
3-C: Change coverage only (interpolation & sampling)

**Combinations**
4-EG: Change extent and grain
5-EC: Change extent and coverage
6-GC: Change grain and coverage
7-EGC: Change extent, grain, and coverage
Two General Types of Scaling Approaches

(Bloschl and Sivapalan 1995, Bierkens et al. 2000)

1. Dynamic Model-Based Scaling Approaches
   - Deterministic & stochastic models
   - Upscaling & downscaling of
     - State variables
     - Model parameters
     - Input variables
     - Model conceptualizations

2. Similarity-Based Scaling Approaches
   - Based on the concepts of similarity or similitude
   - Simple scaling relationships
   - Examples:
     - Dimensional analysis,
     - Similarity (or similitude) analysis
     - Functional normalization
     - Fractal and multifractal analysis
     - Allometric scaling
Two-Step Scaling Procedure

(Bloschl and Sivapalan 1995)

Upscaling: “Point” value ---> Distributing (interpolation) ---> Aggregating
Downscaling: Disaggregating ---> Singling out ---> “Point” value
Upscaling Methods

(1) Simple extrapolation by lumping

(2) Spatially explicit summation or averaging (direct extrapolation)

(3) Mathematical expectation (Monte Carlo simulation)

(4) Explicit integration

(5) Spatially interactive aggregation

(6) Spatial allometric scaling

(7) Hierarchical modeling
A General Framework for Spatial Scaling

A Hierarchical Scaling Ladder Approach

(Wu 1999, Can. J. Rem. Sens.)

(1) Simple extrapolation by lumping
(2) Spatially explicit summation or averaging (direct extrapolation)
(3) Mathematical expectation (Monte Carlo simulation)
(4) Explicit integration
(5) Spatially interactive aggregation
(6) Spatial allometric scaling
Some General Guidelines for Scaling

• The most effective scaling strategies are those that integrate bottom-up and top-down approaches through combining field observations, experimentation, with mathematical modeling.

• The relationships between pattern and process, be they physical, biological, or social, are multifaceted and scale-dependent. *Only when pattern and process operate at similar time scales within the same geographic region, can they possibly have interactive relationships.*
Some General Guidelines For Scaling

• The feasibility and accuracy of scaling across scales depend greatly on properly identifying scaling thresholds.

• Selecting appropriate methods for scaling

• Scaling with known uncertainty
Concluding Remarks

- **Scaling** is ubiquitous in ecological studies and inevitable for understanding pattern and process on broad scales.

- **Translating information across multiple scale domains requires that scaling domains and thresholds be identified.**

- **Scaling across large heterogeneous landscapes often requires a hierarchical, pluralistic scaling strategy.**

- **An important step toward developing a science of scaling is to derive empirical ecological scalograms over a wide range of scales.**
Concluding Remarks

- Universality is “pretty”, but more of a fantasy in ecology;

- Pluralism is “messy”, but more germane to the reality.
The End

Heterogeneity, nonlinearity, and feedbacks?!