Landscape Ecology: An Overview

August 5, 2007

Ming Xu
Rutgers University
What Is Ecology?

• The word *ECOLOGY* was coined by Ernst Haeckel in 1869. It is derived from the Greek *oikos*, meaning "household", "home," or "place to live" and *logos*, "the study of."

• Haeckel’s definition: "...the investigation of the total relationships of the animal both to its inorganic and its organic environment...“
What Is Ecology? Other definitions I:

- "...scientific natural history." (Elton 1927)
- "...the scientific study of the distribution and abundance of animals." (Andrewartha 1961)
- "...the study of the structure and function of nature" (Odum 1971)
- "...the study of the adaptations of organisms to their environment" (Emlen 1973)
- "...the scientific study of the relationships between organisms and their environments" (McNaughton and Wolfe 1979)
What Is Ecology? Other definitions II:

"...the scientific study of the interactions that determine the distribution and abundance of organisms." (Krebs 1985)

• "...the study of the principles which govern temporal and spatial patterns for assemblages of organisms" (Fenchel 1987)

• "...the study of the relationships between organisms and the totality of the physical and biological factors affecting them or influenced by them" (Pianka 1988)
Generally, these definitions convey the notion that:

• The environment influences organisms
• AND, organisms influence the environment

The fact that we are breathing oxygen (generated mostly by the process of photosynthesis) is a rather striking example of the power of organisms to influence the environment.
So, broadly defined

Ecology is the study of interactions among organisms and their environment.

- Ecology has often assumed a non-spatial, homogeneous environment.
- The environment is extremely spatial (Everything has to be somewhere!).
- Interaction strength varies with distance.
What do ecologists study? 

How do ecologists study things?

- Experimental papers submitted to the journal *Ecology* between 1980-86
- >50% of studies used experimental plots <1m in diameter!
- >95% used plots <100m in diameter!
What is Landscape Ecology?

- .....focuses on (1) the spatial relationships among landscape elements, (2) the flows of energy, mineral nutrients, and species among the elements, and (3) the ecological dynamics of the landscape mosaic through time (Forman 1983)
What is Landscape Ecology?

• ....focuses explicitly upon spatial patterns. Specifically, landscape ecology considers the development and dynamics of spatial heterogeneity, spatial and temporal interactions and exchanges across heterogeneous landscapes, influence of spatial heterogeneity on biotic and abiotic processes, and management of spatial heterogeneity (Risser et al. 1984)
What is Landscape Ecology?

• ....is motivated by a need to understand the development and dynamics of pattern in ecological phenomena, the role of disturbance in ecosystems, and characteristic spatial and temporal scales of ecological events (Urban et al. 1987)
What is Landscape Ecology?

• ....emphasizes broad spatial scales and the ecological effects of the spatial patterning of ecosystems (Turner 1989)

• ....emphasizes the interaction between spatial pattern and ecological process, that is, the causes and consequences of spatial heterogeneity across a range of scales (Turner et al. 2001)

• And more definitions in the textbook
Definitions

Landscape: an area that is spatially heterogeneous in at least one area of interest.

Patch: the elements that make up a landscape.

Pattern: the arrangement and composition of the patches that compose a landscape.
Definitions

Landscape Structure: spatial relationships among landscape elements

Landscape Function: how the elements act and interact

Landscape Change: alteration of the structure and function of the landscape over time

Landscape Management: the management of structure and function to achieve a desired condition
Key questions in landscape ecology

1. What process(es) creates landscape pattern?

2. What are the consequences?

3. How do we measure pattern? At what scale?

4. How does pattern change through time?

5. How do we predict and manage pattern?
Themes in Landscape Ecology:

I. *The study of larger areas*

- Implicit in the focus on scaling issues is that Landscape ecology deals with the study of larger areas (landscapes) than has been the case in “traditional ecology.” *(But not always!)*

- How large is a landscape? No hard and fast rules. “…a kilometers-wide mosaic over which local ecosystems recur” *(Forman 1995)*

- A more general definition that does not require an absolute scale: “…..an area that is spatially heterogeneous in at least one factor of interest” *(Turner et al. 2001; p. 7)*
II. *The real world is patchy*

- Patch: a surface area that differs from its surrounding in nature or appearance
- Patches can occur in space or time
- Edge effects matter!
- Traditionally, ecologists tried to ignore edges. Sample sites located in the middle of large uniform patches of vegetation.
Themes in Landscape Ecology:

III. *Analysis of connectivity in patchy environments*

- How does the arrangement and characteristic of patches influence ecosystem processes?
- Wildfire spread
- Juvenile dispersal success
- Seed dispersal success
- Hydrologic response
IV. *Explicit consideration of the role of humans*

- Role of humans often ignored when focused on the study of 1m² plots
- The role of humans cannot be ignored at the landscape scale (spatial domain)
- The legacy of human land use can persist for centuries to millennia (time domain)
Themes in Landscape Ecology: V. *Interdisciplinary*

- Ecology, Biology, Computer Science, Geography, Statistics, Aerospace Engineering (remote sensing), Physics
- For each paper you read this semester, take a moment to look at the mailing address of the authors. What academic department are they from? What agency? This gives you a hint about the perspective they bring to any given analysis
Unique perspectives to landscape ecology

- Landscape ecology often (not always) focuses on larger spatial extents than traditionally examined in ecology.

- Landscape ecology often (not always) focuses on the role of humans in affecting patterns and processes – but it also recognizes that humans are but one agent affecting landscapes.
History of Landscape Ecology
History of landscape ecology: the European School

- Traced to Von Humboldt in 1807
- “Landscape ecology” coined by Troll in 1939
- Emphasizes typology, classification, nomenclature, and deals mostly with human-dominated systems
- In EU, found in Landscape Architecture, Urban Planning, Landscape Design, and Geography Depts.
- Also the foundations of hierarchical land classification
History of landscape ecology: the American School

- Much younger; effectively launched at Allerton Park, IL in 1983.
- Much stronger focus on natural systems, more a branch of ecology.
- Deals more with statistics, models, technology, and theory
- Found in Biology, Ecology, Forestry, and Natural Resources Departments in the US.
History of landscape ecology: school comparison
(Wiens 1997)
Why has Landscape Ecology emerged as a discipline?
Why has landscape ecology emerged?

#1: Spatial scale of environmental problems has increased

- Habitat Fragmentation
- Invasive species
- Urban sprawl
- Fire
- Widespread human disturbance
Why has landscape ecology emerged?

#2: A growing appreciation of spatial context
Why has landscape ecology emerged?

#3: Development of the necessary theories

Hierarchy Theory

Climate, landform, soil

Forest Stand

Tree physiology, establishment, competition, etc.
Why has landscape ecology emerged?

#4: Concepts of disturbance have changed

Equilibrium paradigm -----------------------> Dynamic paradigm

- Species composition is relatively constant in a community.
- Disturbance and succession alter communities but are less important than the climax community itself.
- Ecosystems can be understood within the context of the ecosystem itself, because the ecosystem is self-contained and controlled internally.

- Species composition may (or may not) reach equilibrium based on interactions between disturbance and communities.
- Disturbance is an essential part of ecosystems and ecosystem dynamics.
- Ecosystems must be understood within a larger spatial and temporal context, because ecosystems are open systems and incorporate disturbances at multiple scales.
Why has landscape ecology emerged?

#5: Technological advances

**Geographic Information Systems**

- Technological advances
  - Geographic Information Systems
  - Remote Sensing
  - Models, Programming, Computing Power
    - Object Oriented Design (OOD)
    - Modularity (programming)
    - Dynamic

- The Internet, Available Data

- Satellite data
- High altitude data
- Low altitude data
- Ground Observation
Why has landscape ecology emerged?

#6: Management needs applied ecology

Landscape ecology ‘scales up’ ecological data/knowledge to a scale that is meaningful to management.
Tools for Landscape Ecology:
I. Computers

- **fast, cheap computers**
  ...and they keep getting faster

- Processing speed closely linked to transistor density. This has been doubling about every 18 months for nearly 40 years (Moore’s law)

- A common desktop computer today was a super one 20 years ago!

*Science 1996. 274:1834*
Tools for Landscape Ecology: II. Statistics

• Shift from parametric statistics (t-test, ANOVA, linear regression) to spatial statistics

• Geostatistic: exploiting spatial autocorrelation, spatial interpolation, and scale dependent relationships (spectral analysis, wavelet analysis)
Tools for Landscape Ecology:
III. GIS and Remote Sensing

• Made possible by improvements in computers
• These tools have made it possible to work effectively with large spatial data sets (maps).
• Often used as tools to prepare datasets for use in various models
• GIS also often used to display and help analyze output from these models.
Tools for Landscape Ecology: IV. Landscape Metrics

• As with many new fields of study, the early years of landscape ecology (the 1980s) focused on the development of tools to describe landscape patterns

• These metrics include, patch size, shape, proximity, edge density, dominance, diversity, fractal dimension, and many more
Tools for Landscape Ecology:
V. Models

- Probability models (Markov chain model, cellular automata model)
- Spatially explicit models (diffusion models, process-based models)
Landscape ecology: Tools and concepts

Landscape Ecology Concepts

- Scale and hierarchy theory
- Finding the correct scale for a study
- Detecting/characterizing landscape structure
- Agents of pattern: physical templates, biotic processes, disturbance
- Implications of structure to organisms, communities, and ecosystems
- Landscape dynamics – centered on landscapes as well as organisms
- Applied landscape ecology: conservation, land use, planning
Landscape ecology: Tools and concepts

Tools:
- Markov transition models
- Landscape metrics (IAN, APACK, FRAGSTATS)
- Spatial statistics: Semivariograms and correlograms
- Neutral landscape models
- Percolation theory
- Basic simulation modeling
- Historical range of variability and management in disturbed landscapes
- Individual-based modeling
Bigger and deeper thinking on pattern and process

- Universe: pattern & process, little knowledge
- Globe: Ocean, atmosphere, land (forest, grassland, desert, urban…), know little on functions and interactions
- Region: definition is unclear??
- Landscape: forests, shrubs, grassland, cropland, rivers, lakes, bare soil/rocks, roads, houses, powerlines …
- Ecosystem: plants, animals, microbes…
- Individual: tree, grass, flower
Continue

- Leaf: shape, lobed, tooth, vein, stomata…
- Cell: cellular organs
- Molecule: molecular structure
- Atom: electron, neutron, proton
- …
What does pattern mean?

- Collectively, pattern means homogenous within the pattern and meanwhile pattern means heterogeneous in differentiating one pattern with the other or its background (contradicting??)
- Pattern is the variation/variance and variation is information (open your book, you can read it because the text/words (different patterns) provide you the information. Can you read a blank paper or a black paper?)
- Think about a system starts from nothing or an empty space (no variation), as long as a pattern is created, the variation starts growing
Change/destroy patterns??

- Lose or gain processes/functions. E.g. By cutting trees you lose photosynthesis/transpiration; But forest thinning may increase photosynthesis/productivity. Crossing out the words on a paper you lose the information!
Change/destroy patterns at one scale may change functions at other scales

- E.g. forest fire oxides carbohydrates to make CO2 and water vapor at molecular level, but you also lose photosynthesis at ecosystem level
Interaction among patterns

- Change or loss of a pattern may cause the loss of other patterns, e.g., clearing vegetation may dry up the rivers and lakes.
- Different parts of a system are linked or networked directly or indirectly.
- A landscape is a system focusing on the spatial configuration and arrangement of landscape elements/members.