Understanding landscape metrics

The link between pattern and process.
Roadmap

Introduction
Methodological considerations
  Spatial autocorrelation
  Stationarity
Processes
  Abiotic
  Biotic
  Anthropogenic
  Disturbances (e.g., fire, landslides)
Landscape structure (form)
Quantification of pattern
"The problem of pattern and scale is the central problem in ecology, unifying population biology and ecosystems science, and marrying basic and applied ecology. Applied challenges ... require the interfacing of phenomena that occur on very different scales of space, time, and ecological organization. Furthermore, there is no single natural scale at which ecological phenomena should be studied; systems generally show characteristic variability on a range of spatial, temporal, and organizational scales." (Levin 1992; italics added)

This quote equally applies to health studies, crime analysis, etc., and emphasizes the fact that geography is a fundamental element of any and all analyses.
Why study landscapes?

**Landscape ecology** is concerned with the reciprocal interactions between spatial pattern and ecological processes that occur on landscapes.

A simple definition of a ‘landscape’: an area that is spatially *heterogeneous* in at least one factor of interest (such that spatial patterns influence ecological processes).

Human effects are often most evident at the landscape-scale (and all ecosystems have been affected by human effects).

Management decisions are often at the landscape-scale.
Processes -> Form

The ultimate aim of landscape ecology is to understand process through an examination of form (i.e., landscape pattern). Such knowledge can be used in both a descriptive and prescriptive manner.

In order to understand what quantification of pattern on the landscape can tell us about the processes that have occurred / are occurring on a landscape, we should first consider the causes of landscape pattern.
Form -> Processes

It is also important to note that form itself can modify processes. For example, how forest fires behave is not simply a function of the forest and the available fuels, they also are affected by the topography.

Therefore, our ability to identify the process responsible for a particular form becomes even more difficult since there can be feedback between the two.
Maps as realizations of a process

Many spatial scientists take the view that an observed map pattern is (only) one of the possible patterns that might have been generated by a hypothesized process.

Statistical analysis then focuses on issues around the question:

Could the pattern we observe have been generated by this particular process?

Which leads to:

A spatial process is a description of how a spatial pattern might be generated.
Landscape ecology explicitly addresses the role that spatial configuration (spatial heterogeneity) plays in ecology.

**Fundamental assumptions:** that things vary among locations, and that where things are, and where they are relative to other things, can have important consequences.

**Leading to:** if the mosaic composition or arrangement were different, how would that affect the ecology?
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Types of spatial autocorrelation

Patterns develop if the objects / events we are studying exhibit **spatial autocorrelation** (that is, if the objects / events were randomly distributed about the landscape no meaningful patterns would be observed).

If the patterns develop as a result of a response to an environmental factor (such as soil, slope position, water bodies), this is referred to as a **first-order process**.

If the patterns develop as a result of interactions between the objects / events themselves (such as contagious diseases, dispersal / diffusion limitations), this is referred to as a **second-order process**.
Stationarity

A process is considered **stationary** if the processes that govern the placement of an object or event do not change over space / do not *drift* over space: differences in values may depend on the *relative location* of the measurements (i.e. the distance and direction between two points) but not on the *absolute location* of the measurements.

A process can be **first-order stationary** if there is no variation in the *intensity* over space (that is, the mean ($\bar{x}$) for any arbitrary region is the same).

A process can be **second-order stationary** if there is no interaction between objects / events (that is, the autocorrelation function depends solely on the degree of separation of the observations in time or space, not on where those objects occur).
Stationarity

Stationarity implies that the **process regime** remains constant.

- **Homogeneous landscape**
  - First-order
  - Stationarity

- **Heterogeneous** (lakes, rocks)

- **Locally homogeneous**
- **Globally heterogeneous** (patchy landscape)
Second-order stationarity

Dengue fever is a viral infection transmitted by *Aedes* mosquitoes that has recently re-emerged globally as a major arboviral disease. These are some of the results of a study: Reconstructing historical changes in the force of infection of dengue fever in Singapore: implications for surveillance and control.

Second order stationarity

Another study: The effect of segregation of flowering time on fine-scale spatial genetic structure in an alpine-snowbed herb (*Primula cuneifolia*)

http://www.nature.com/hdy/journal/v100/n4/full/hdy20081a.html
The influence of direction

Stationarity also assumes that the process does not exhibit a directional bias.

Isotropic patterns: the process does not exhibit a directional bias.

Anisotropic patterns: the process does exhibit a directional bias.
The influence of direction

Appalachian Mountain’s Ridge and Valley Province
(strong anisotropy)
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Quantification of pattern
Spatial effects in ecological data

**Scale-dependent response:** The scale of response to the environment depends on the organism.

**Spatial dependence:** Physical processes create spatial structure in the environment, including deterministic structure in organism distributions.

**Spatial autocorrelation:** Biotic processes such as dispersal or interactions create patchiness in organism distributions.

Figure 3 in Wagner and Fortin, 2005
Processes?

What are the natural processes that we have identified as operating on the landscape?
What are the not-so natural processes that we have identified as operating on the landscape?
Processes

Abiotic conditions such as:
   Climate
   Topography
   Soils

Biotic interactions

Disturbance:
   Past and present patterns of human settlement and land use
   The dynamics of natural disturbance and succession
Climate

Long-term climate change
Climate acts as a strong control on biogeographic patterns.
Climate

Changes in the ranges for three tree taxa based on pollen records.
This is the subject of the field of paleoecology.
Predicting potential range changes in British Columbia as a result of global climate warming.
Topography

Topographic influences:
- Rain and radiation (elevation, slope and aspect) variations
- Changing the relative proportion of inputs
- The impact of form (on wind, fire)
- The relation of form to landslides, animal movements, etc.
Topography
Topography
Biotic factors

Biotic interactions such as competition create spatial patterns, even in a completely homogeneous space.

Keystone species
Biotic perspectives

a) What is habitat? For a bear, the left map might represent habitat vs. non-habitat, while for a deer, the right map might be better. As a result, the area is poorly connected for a bear, but for a deer, it is well connected.

b) Are distances between habitat patches innately traversable? For a bird, who can travel up to 100km, the area is connected. For a salamander, who can only travel up to 50m, the area is poorly connected.

c) How difficult is it to travel through non-habitat? For a squirrel, it may be safe or easy to travel through non-habitat (left map), but for a tiger, it may be nearly impossible. As a result, the area is well connected for a squirrel, but poorly connected for a tiger.
Human land use impacts

The loss of virgin old-growth forest in the contiguous United States from 1620 to 1920.
Disturbance processes

Fires, volcanic eruptions, floods and storms
Relatively discrete events in time that disrupt ecosystems, communities, or population structures.

Mount Saint Helens – tree blowdown
Multiple processes and scales

What we see on the landscape today is a reflection of many different processes operating at different temporal and spatial scales.
Multiple scales
Spatial scale modulates the strength of ecological processes
Complex systems

Characteristics of Complex Systems

- A ‘complex’ system
- Emergent behavior that cannot be simply inferred from the behavior of the components

Complex Systems

- Involve: Many Components
- Dynamically Interacting and giving rise to A Number of Levels or Scales which exhibit Common Behaviors

A ‘simple’ system

Emergence

Hierarchies

Self-Organization

Control Structures

Composites

- Substructure
- Decomposability

Transdisciplinary Concepts

Across Types of Systems, Across Scales, and thus Across Disciplines

Evolution

Chaos

Fine Scales Influence Large Scale Behavior

Time Scale
Review of lecture so far...

Types of spatial autocorrelation?
Definition of stationarity?
The types of processes considered was split into several groups. They were?
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Quantification of pattern
Creating and maintaining heterogeneity

Three general causes of spatial pattern:

- Local uniqueness (i.e., the unique features of a place in space, such as abiotic variability or unique land uses; balds or serpentine areas)
- Phase differences: variation in spatial pattern resulting from disturbances
- Dispersal: which prevents landscapes from becoming uniformly covered with a single, dominant population
<table>
<thead>
<tr>
<th>Environmental and landscape structure changes</th>
<th>Processes and factors creating or maintaining boundaries</th>
<th>Type of boundary</th>
<th>Ability to detect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharp environmental changes</td>
<td>Geomorphology, topography, biogeochemistry, climate</td>
<td>Sharp, narrow, persistent</td>
<td>Possible to detect abrupt changes in diversity or abundance</td>
</tr>
<tr>
<td>Gradual environmental changes</td>
<td>Geography, climate, species’ ranges (physiological limits), species interactions</td>
<td>Blurred, wide, persistent or transient</td>
<td>Difficult to detect changes in biomass and abundances; possible to detect compositional changes</td>
</tr>
<tr>
<td>Spatial heterogeneity within large disturbances</td>
<td>Fires, storm, drought, species interactions, succession</td>
<td>Sharp to smooth, transient</td>
<td>Possible to difficult depending on the intensity of the disturbance</td>
</tr>
<tr>
<td>Spatial heterogeneity within small gaps</td>
<td>Treefall, species interactions, succession</td>
<td>Blurred, transient</td>
<td>Difficult to detect due to qualitative and quantitative noise</td>
</tr>
<tr>
<td>No environmental changes</td>
<td>Species interactions, dispersal ability</td>
<td>Sharp, persistent</td>
<td>Possible to difficult depending on species interactions</td>
</tr>
</tbody>
</table>

Creating and maintaining boundaries

Table 4.1, Fortin and Dale, 2005
Understanding form leads to ...

The fundamental premise: that processes are linked to, and can be predicted from, some (often unknown) broad-scale spatial pattern.

Therefore, methods by which spatial patterning can be described and quantified are necessary.
Why?

Examples of where knowledge of pattern is important:

- Is the pattern at time $t + 1$ different from time $t$ and, if it is, how is it different? [Relate to changes in distributions: birds, plants, diseases, but also crimes]
- Is the pattern at place $i$ different from the pattern at place $j$?
- How will policy A impact the landscape differently than policy B? [For example, different forest harvest policies.] [There are also landscapes of fear.]
- How does the pattern of the landscape relate to the processes observed? [Such as the spread of a natural disturbance or the spread of an alien pest.]
What are the effects?

Forest cover change in Costa Rica (UNEP)

Grazed vs ungrazed
Pattern -- Fragmentation

Processes?
- gene flow
- hydrology
- wind movement
- nutrient cycling and ecosystem productivity
- species interactions

- Increases
  - isolation
  - edge species
  - exotic species
  - generalists
  - extirpation rate

- Decreases
  - rare species
  - interior species
  - disturbance-averse species
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Quantification of pattern
Five classes of metrics (out of 55) were identified by Riitters et al. (1995):

1. The number of classes or cover types
2. Texture measures (fine or coarse patterns)
3. The degree to which patches are compact or dissected
4. Whether patches are linear or planar
5. Whether patch perimeters are complicated or simple in shape

What constitutes a significant change in a measure? (Is there a null hypothesis?)

The quantification of pattern
Metrics of landscape composition
proportion occupied
relative richness
diversity and dominance
connectivity

Measures of spatial configuration
probabilities of adjacency
contagion
patch area and perimeter
connectivity
proximity index
area-weighted average patch size

Fractals

Quantifying landscape pattern
Metrics of landscape composition

These metrics measure what is present and their relative amounts or proportions, without reference to where on the landscape they may be located.

- **Relative richness**—the proportion of the number of cover types potentially present (e.g., based on the past or other landscapes).
- **Dominance**—the deviation from the maximum possible evenness.
- **Diversity**—a reflection of richness and how evenly the proportions of cover types are distributed.
- **Connectivity**—based on a user-defined threshold, a measure of how connected the patches are (think of movements between two patches).
Measures of spatial configuration

Probabilities of adjacency--the probability that a grid cell of cover type i is adjacent to cover type j.

Contagion--distinguishes between overall landscape patterns that are clumped or rather dissected.

Connectivity--how fragmented is a habitat type.

Proximity index--the degree to which patches in the landscape are isolated from other patches of the same cover type.

Area-weighted average patch size--to account for the frequently observed skewed distribution in patch sizes (e.g., many small, few large), use an area-weighted average to better reflect the probability of randomly selecting a patch.
Fractals
Landsat MSS false color image of part of the Great Victoria desert. Blue and white areas are dry lake beds (Lake Throssel and Lake Rason). Note the numerous fire scars (lighter beige patches), their tongues and spatial complexity. Fires frequently reticulate, leaving behind isolated patches of unburned habitats (darker brown patches embedded within fire scars) which act as refuges. Scene is approximately 100 km by 150 km.

http://uts.cc.utexas.edu/~varanus/biogeog.html
A multivariate approach is the appropriate approach to take when using landscape metrics.
Conclusion

We have only reviewed a few of the metrics that have been developed (although many of them do measure similar characteristics of the landscape in only slightly different ways), and I strongly encourage you to explore Fragstats in more detail.

Remember, behind any analysis must be an understanding of the processes you feel are important on that landscape, an understanding of the scale at which those processes operate, and knowledge of how those processes impact the landscape.