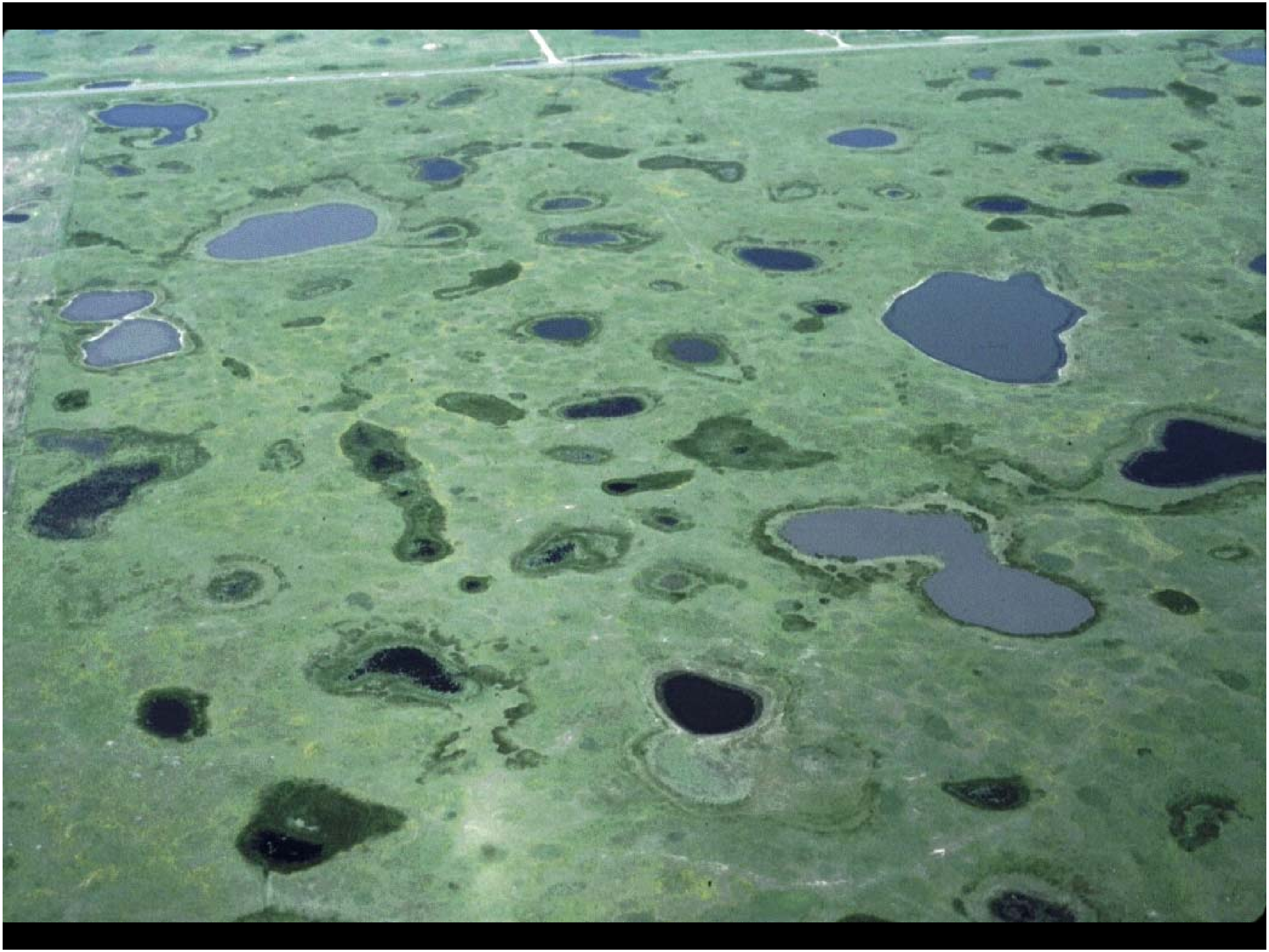
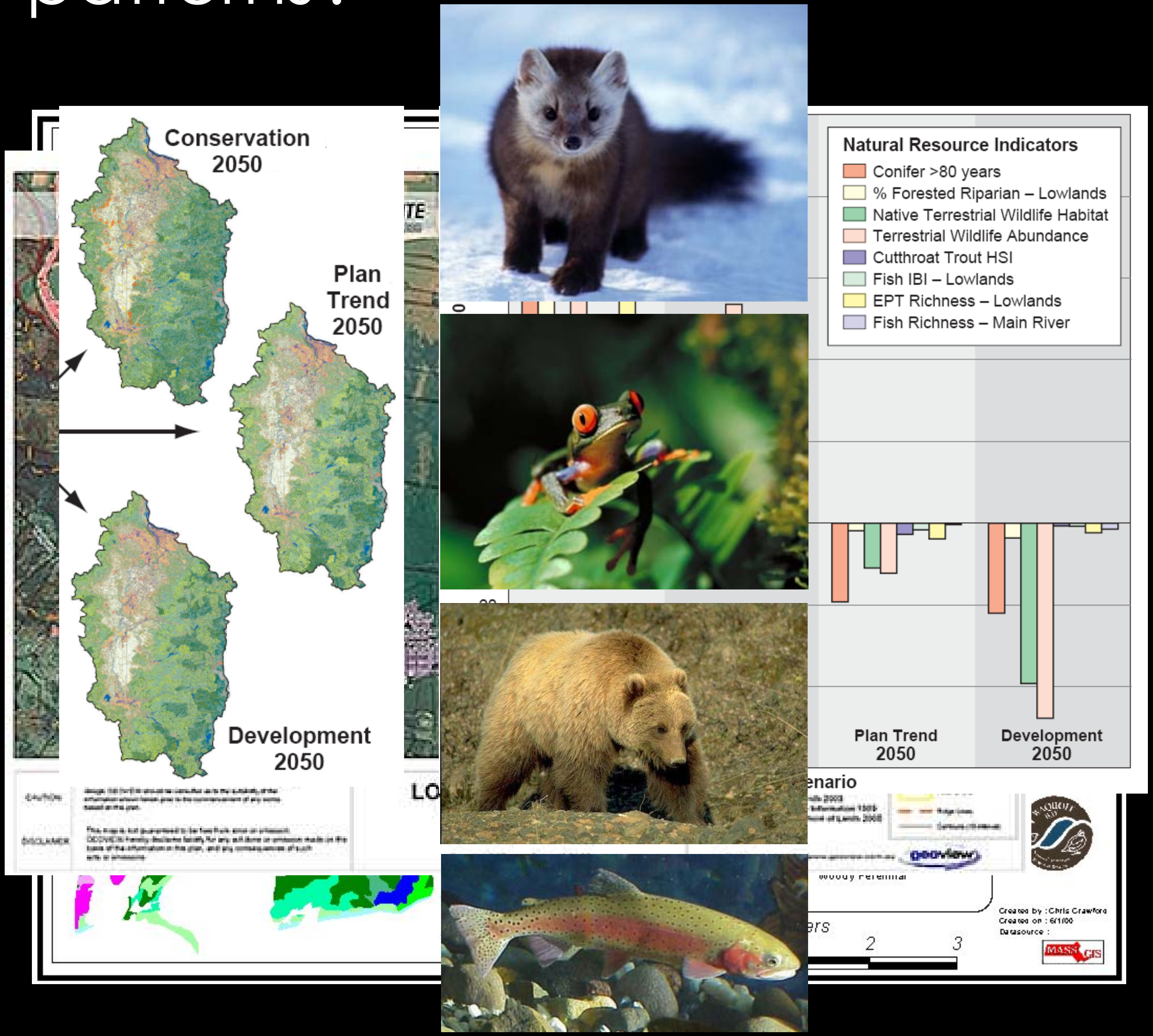
Measuring landscape pattern



Why would we want to measure landscape patterns?

- Identify change over time
- Compare landscapes
- Compare alternative landscape scenarios
- Explain processes



Steps in Application of a Metric

Spatial Data Set
orthophoto, satellite image, digital map

Scale definition
Extent of analysis, resolution of elements

Classification
Supervised or automated (unsupervised)

Application of metric

Interpretation

Number of Attribute Classes

- Just how diverse is the landscape in terms of defined patch elements?
- Southwestern U.S.
  - Bottomland hardwoods, bald-cypress swamp, pine savanna, oak thickets, grasslands, agricultural, pine plantations, upland hardwoods, etc. (diverse)
- Tierra del Fuego:
  - Tundra, southern beech forest, pampas, barren (relatively low)
- Antarctica
  - Ice. Rock. More ice. 2 vascular plant spp. somewhere.

Quantifying Landscape Pattern

Landscape Composition:

What elements make up the landscape?

How much of each element is there?

Landscape Configuration:

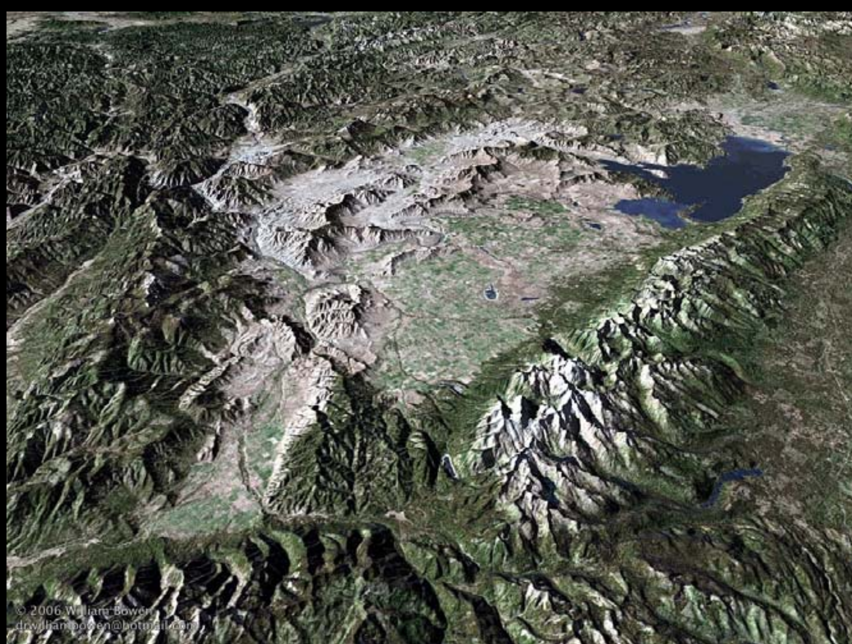
How are the elements of the landscape arranged?

What types of shapes do they take?

How do they relate to each other spatially?

Composition

Richness
Evenness
Diversity



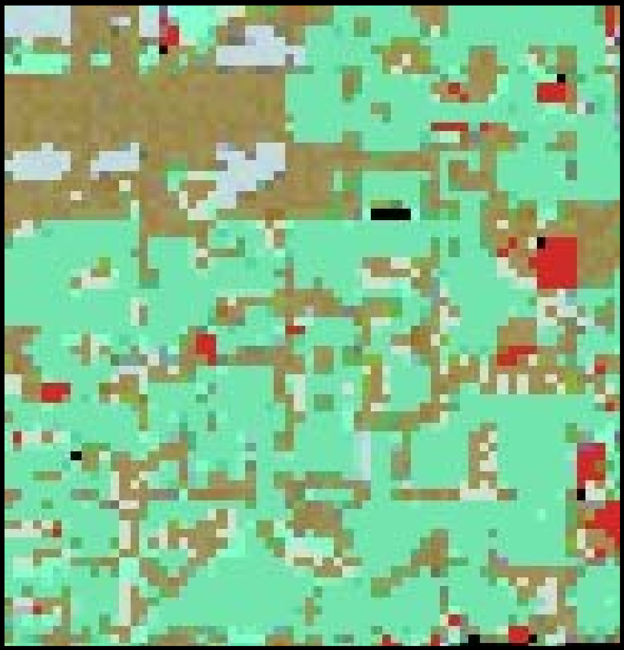
Configuration

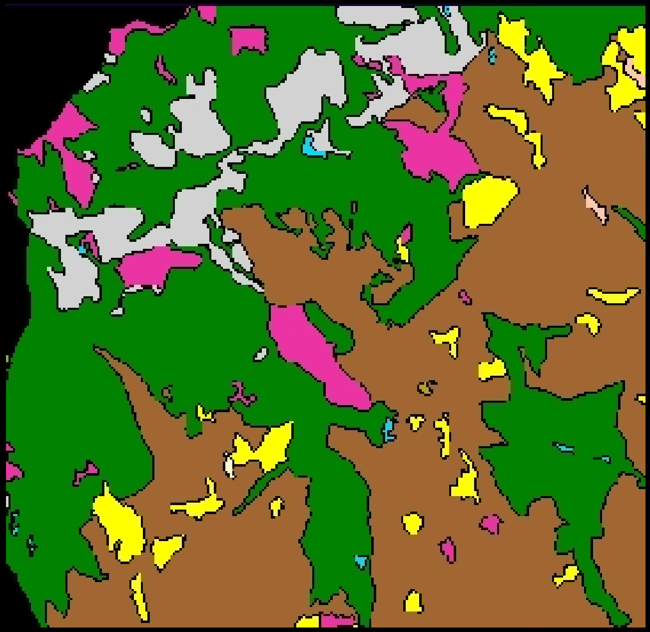
Size
Shape
Edge length/density
Isolation
Fragmentation
Contagion
Connectivity
Interspersion
Dispersion

Raster and vector images

Rasters consist of grid cells with individual values.

Vector coverages are composed of shapes (polygons) that are defined by connected points





Defining the landscape

We often use remotely sensed data to measure landscape pattern.

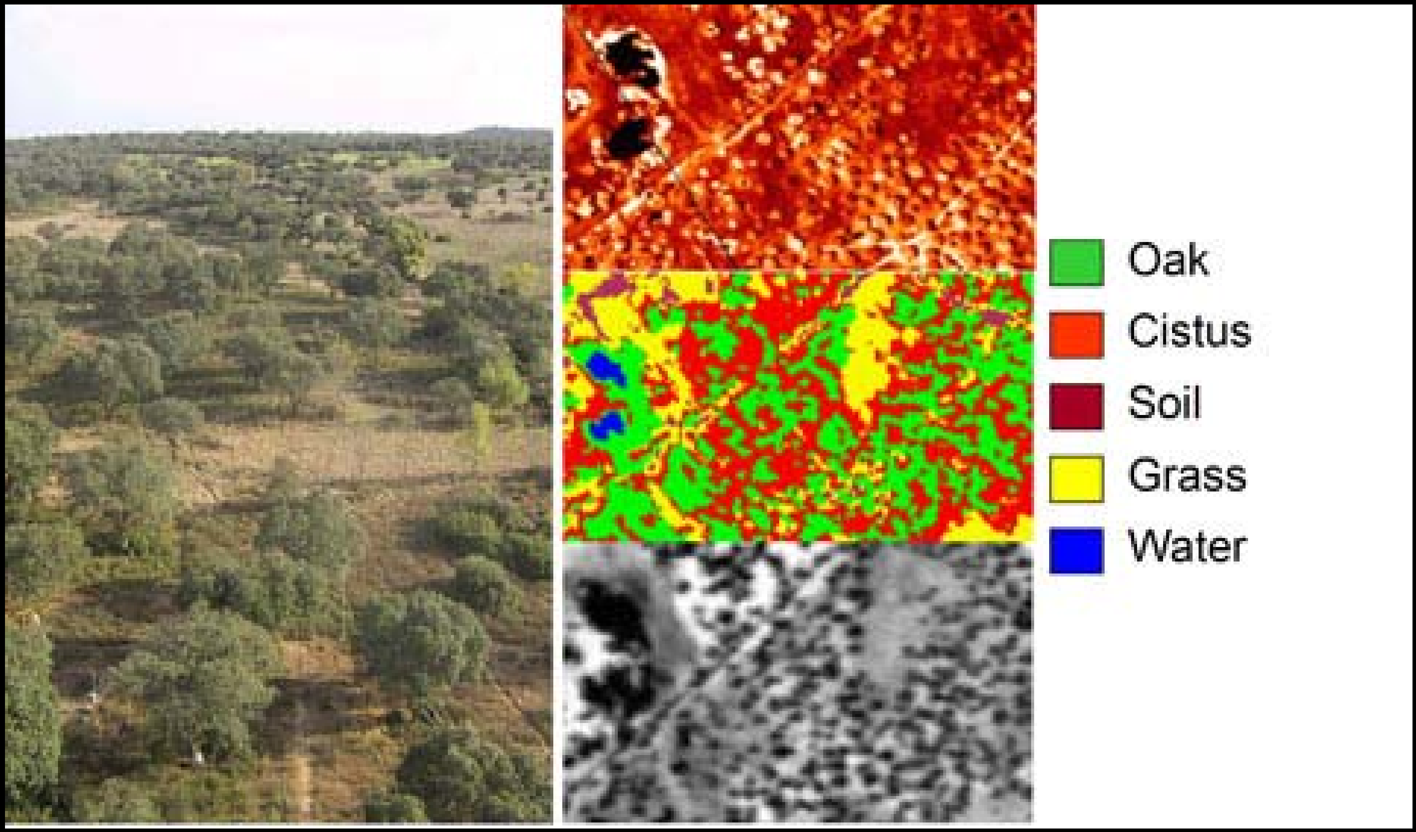
Aerial photos

Satellite imagery

Classifying a landscape

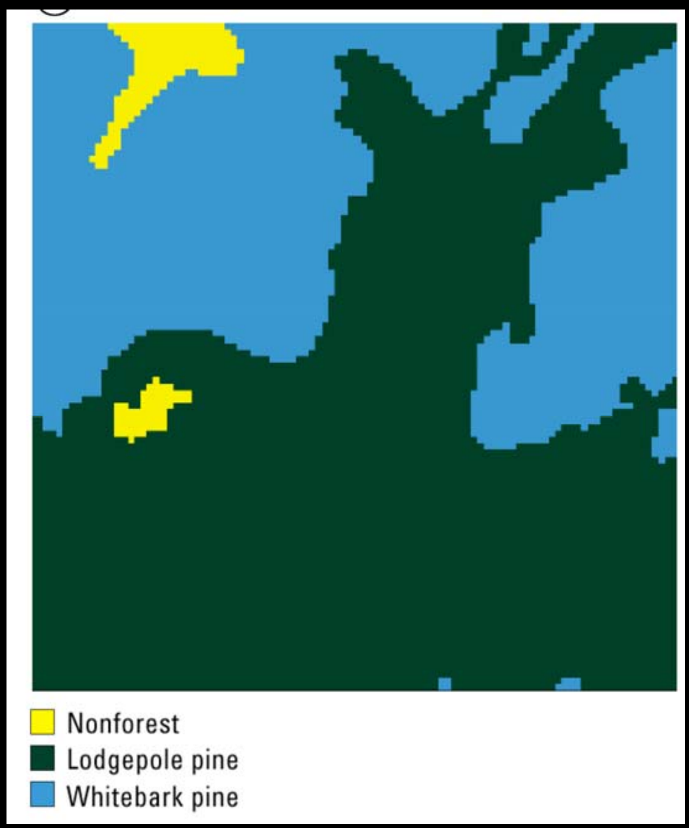
We often define landscapes using discrete categories.

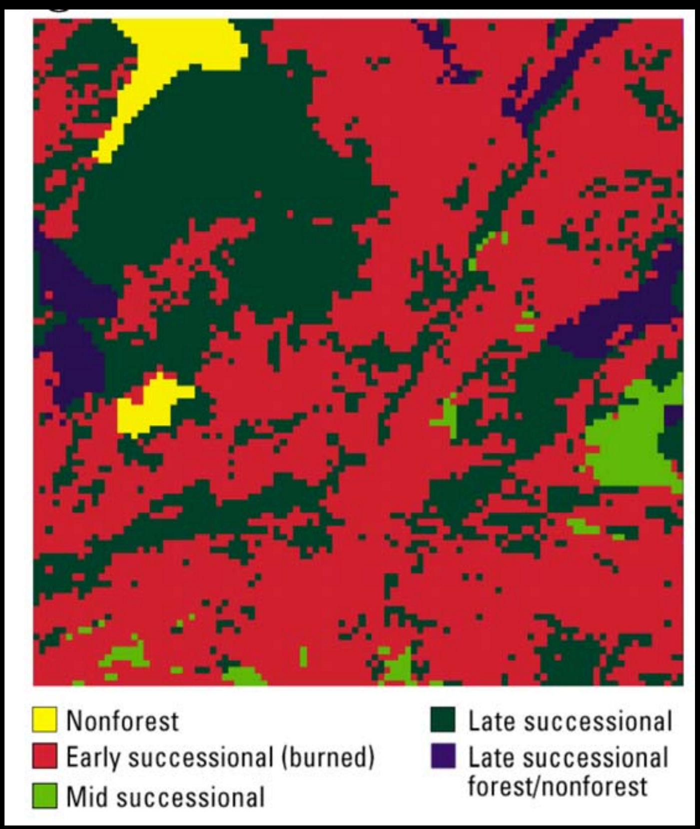
Thus we must "classify" images.



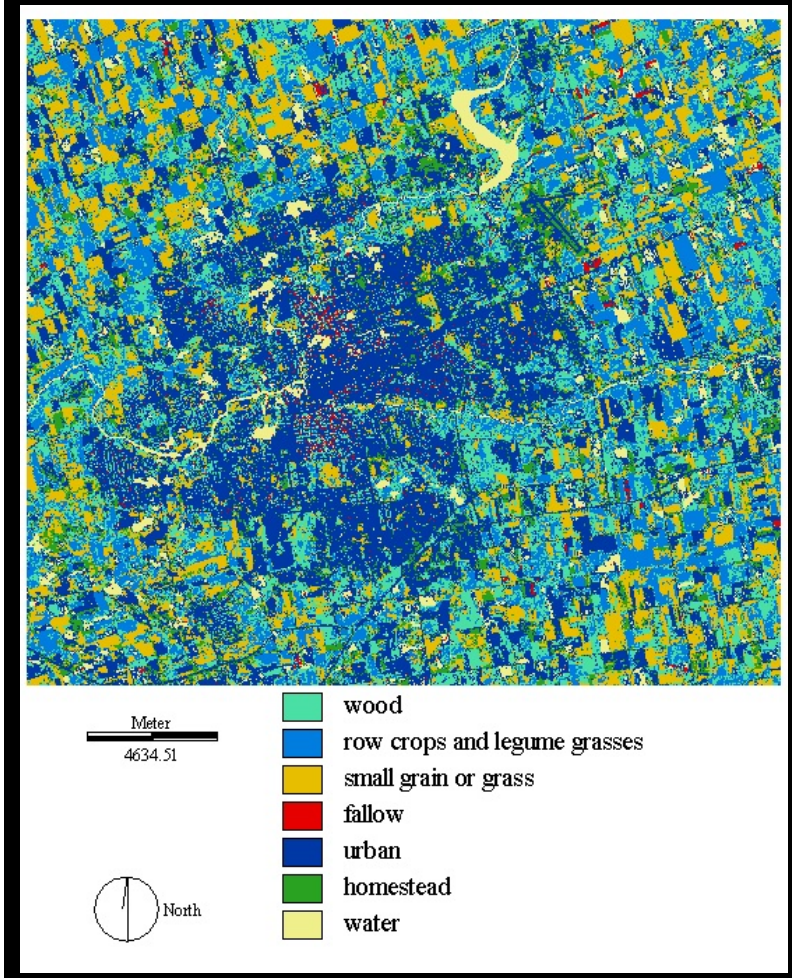
Classifying a landscape

The choice of the classification scheme depends on the question being asked or the subject being addressed





Landscape Composition



Richness-
number of patch types

Proportional coverage-
% of landscape covered by each type

Evenness-
how evenly are the types represented
- Shannon's Evenness Index
- Simpson's Evenness Index

Diversity-
how diverse is the distribution of types
- Shannon's Diversity Index
- Simpson's Evenness Index
- Dominance

Richness vs. evenness

- Hill (1973): all measures of biodiversity differ only in how much weight (importance) is allocated to common species vs. rare species
- How strongly do we want our index to differentiate between landscapes with species proportions:
  - 20:20:20:20:20 (5 species, evenly distributed)
  - 96:1:1:1:1 (5 species, but 1 super-common!)

Dominance (O'Neill *et al.* 1988)

- To what extent do one or a few patch types dominate the landscape?
- The higher the D, (D_1 in paper), the more one or a few types dominate.
- Values range from 0.19 to 1.5 in O'Neill paper (can be normalized to be between 0 and 1).

Landscape Composition

Conifer = 75%
Meadow = 10%
Water = 5%
Rock = 5%
Roads = 5%

Dominance = 1 – evenness, or

*Ln(5) + (.75*ln(.75) + .10*ln(.10) + .05 *ln(.05) + .05*ln(.05) + .05*ln(.05))*
= 0.714

$D_1 = \ln(M) + \sum[(p_i * \ln(p_i)]$,

where M = # patch types
p_i = fraction of *M* that are type *i*

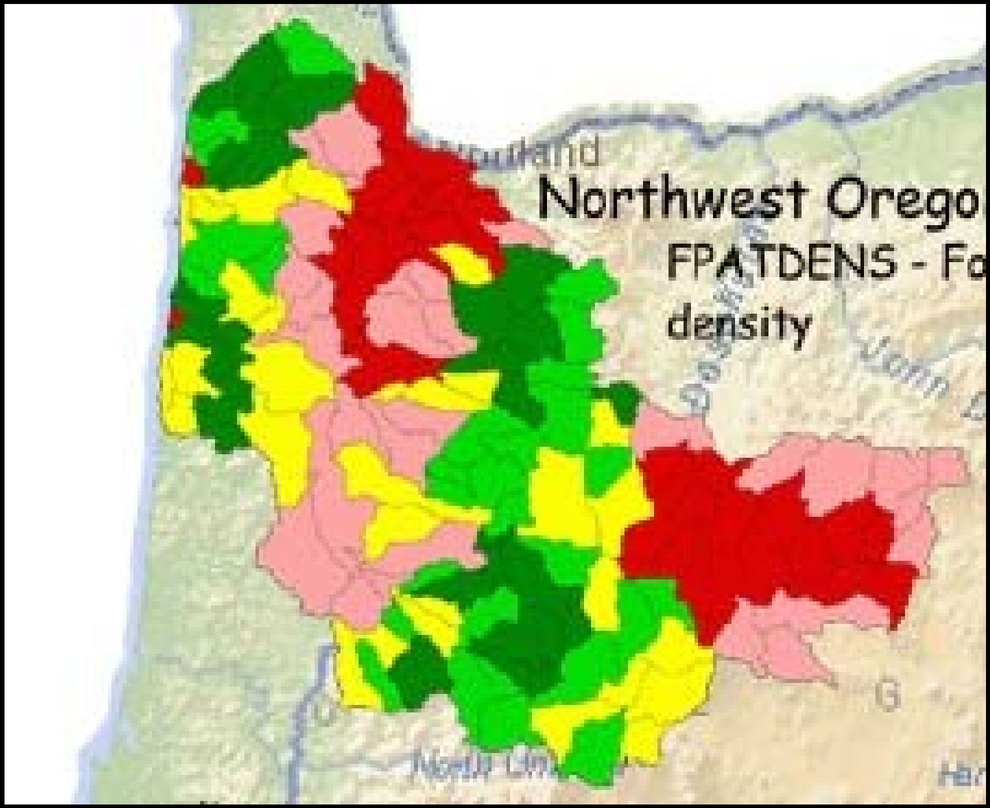
Conifer = 25%
Meadow = 20%
Water = 22%
Rock = 21%
Roads = 12%

*Ln(5) + (.25*ln(.25) + .20*ln(.20) + .22*ln(.22) + .21*ln(.21) + .12*ln(.12))*
= 0.026

Landscape Configuration

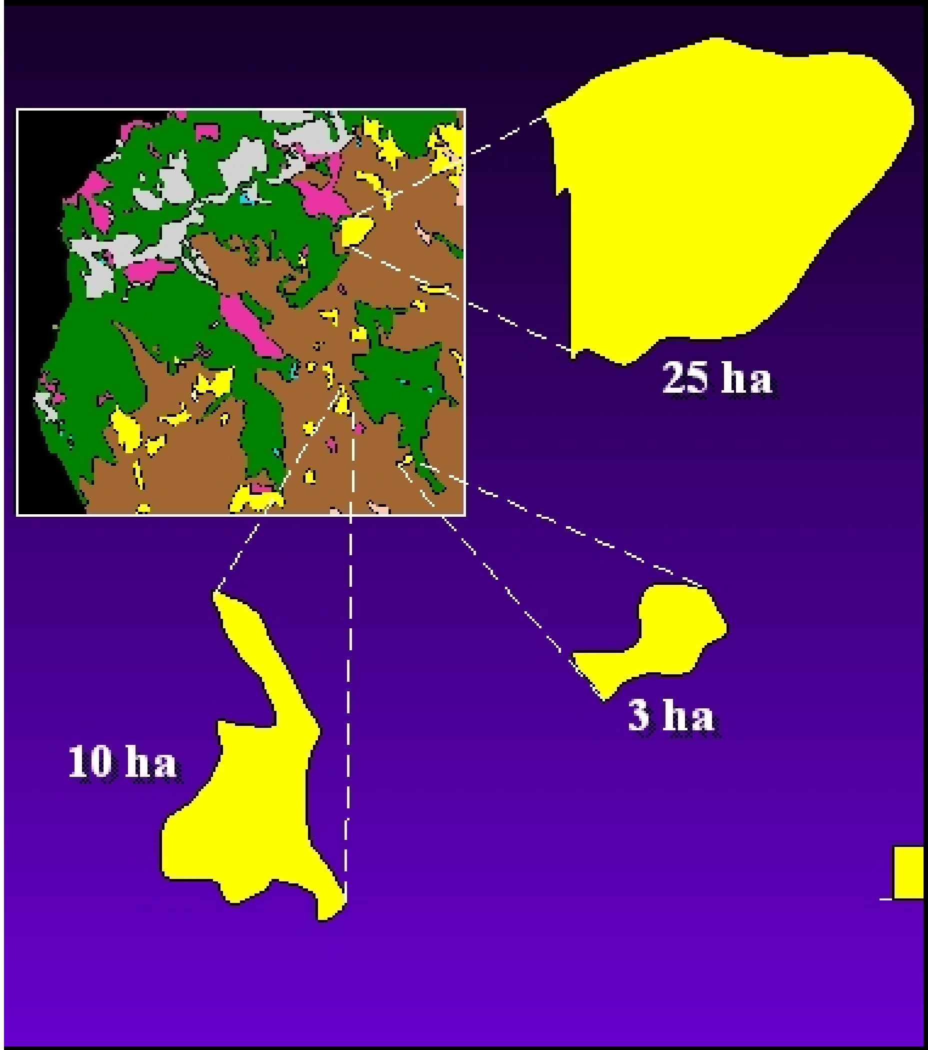
Patch level metrics – summarize aspects of individual patches

Landscape level metrics – summarize entire landscapes and thus the spatial pattern of patches



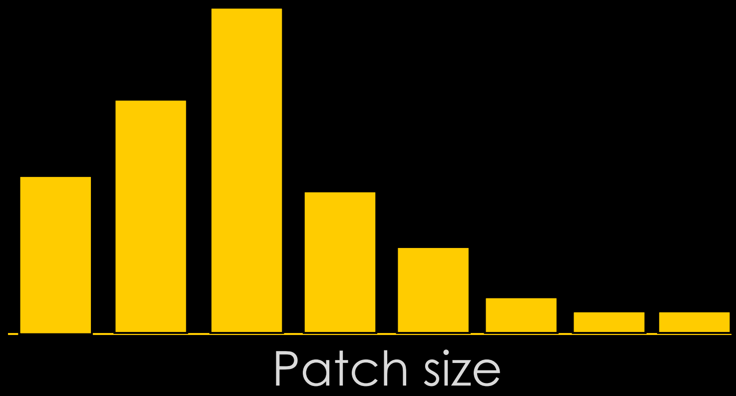
http://www.umass.edu/landeco/research/fragstats/documents/Conceptual%20Background/Landscape%20Metrics/Landscape%20Metrics.htm

Patch metrics



Patch size distribution and density

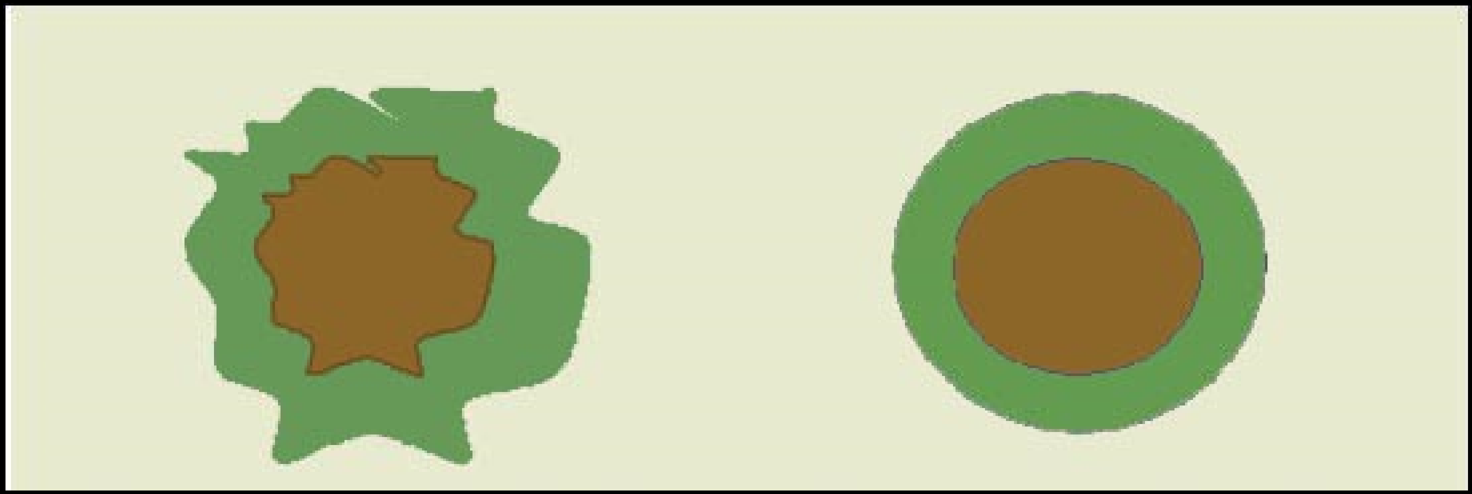
- Mean patch size
- Area of the largest patch
- Variation in patch size
- Patch density



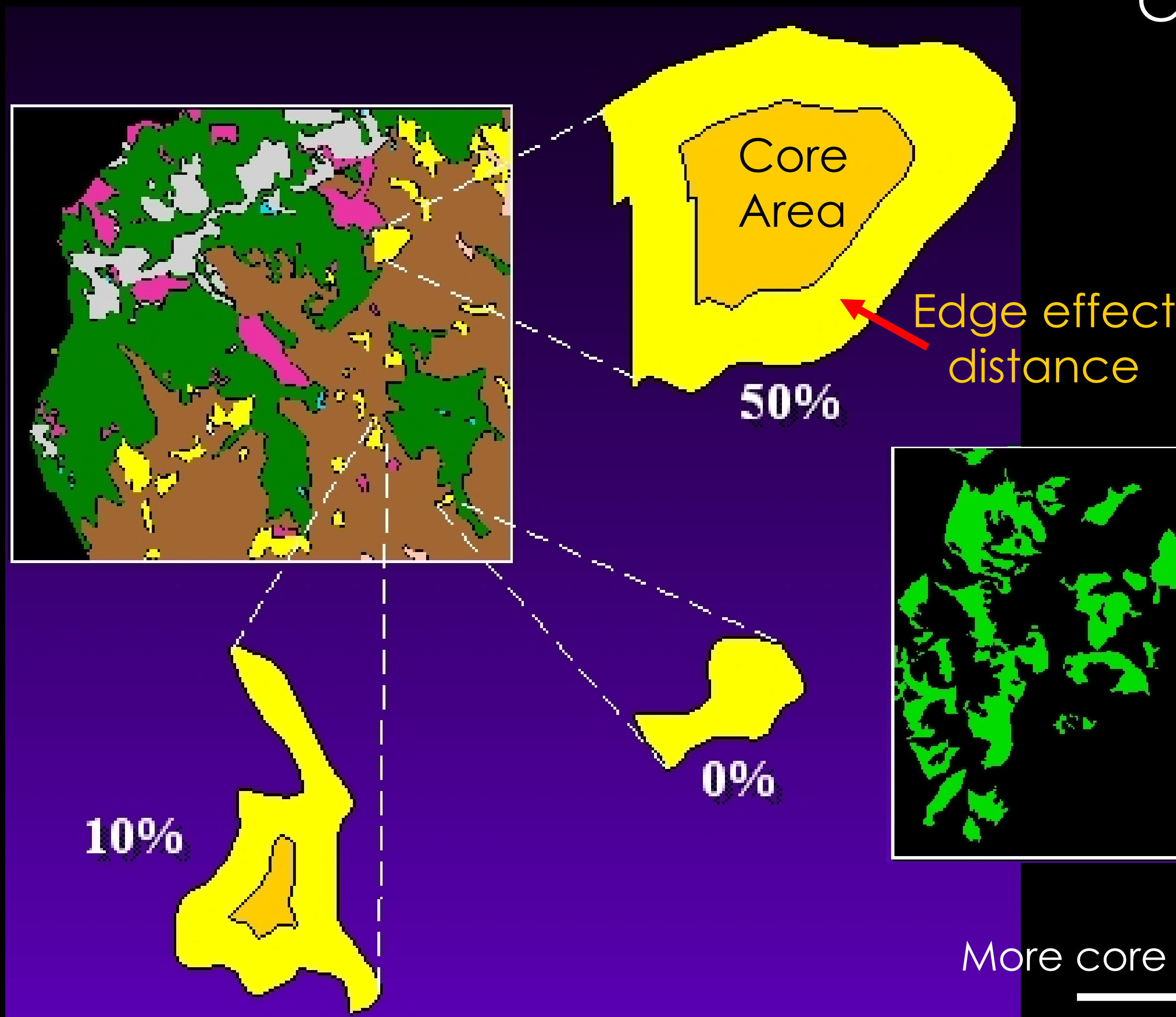
Patch metrics

Edge

- Edge length
- Edge to area ratio
- Edge contrast

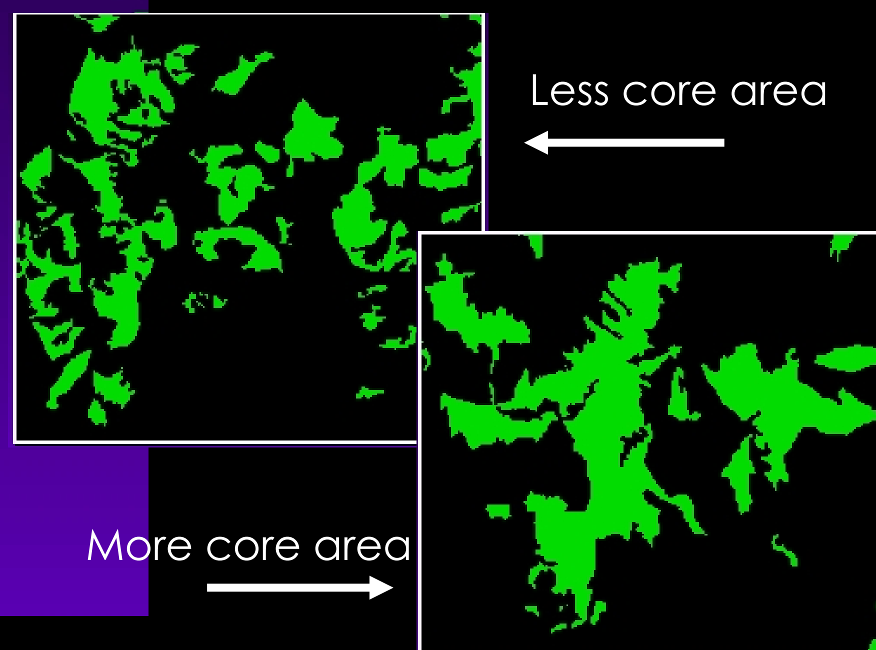


Patch metrics



Core area

- Number of core areas
- Mean core area
- Variation in core area
- Core area density

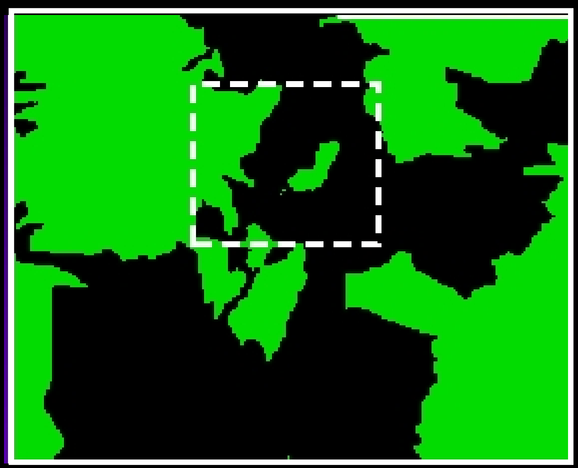


Patch metrics

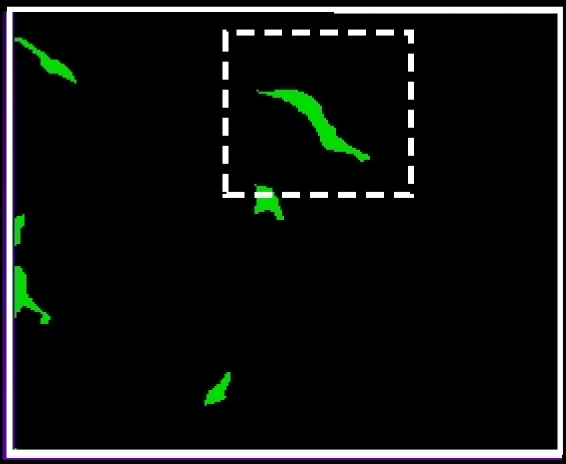
Isolation/proximity

- Mean nearest neighbor distance
- Proximity index

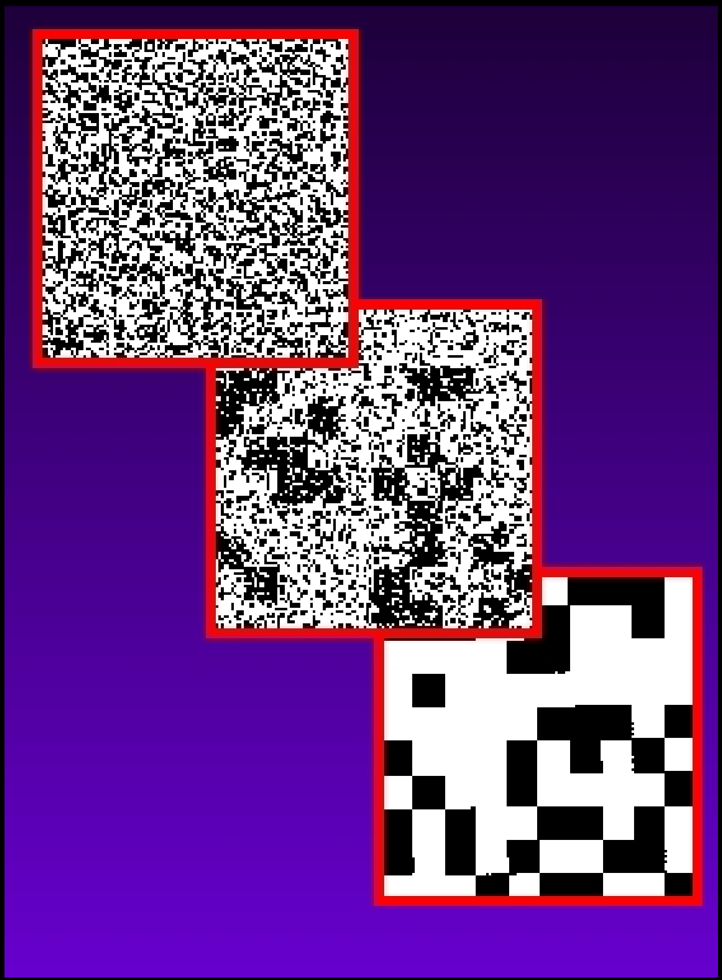
Low isolation/high proximity



High isolation/low proximity



Landscape-level metrics



Dispersion

Nearest Neighbor Relative Variance Index

Nearest Neighbor Index of Dispersion
(Clark & Evans Statistic)

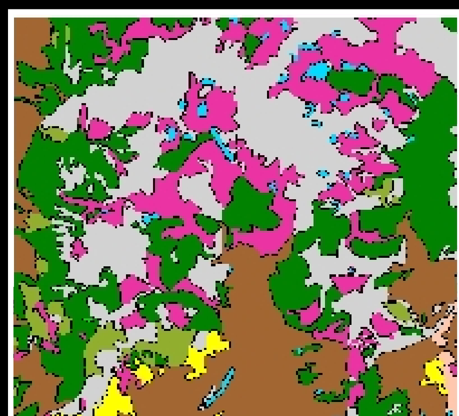
Contagion (Texture) Index

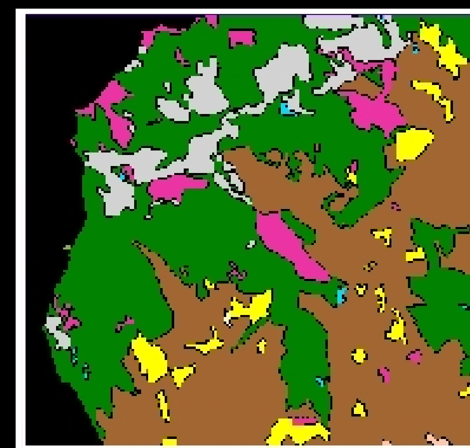
- Nothing to do with **disease** (unless forest pathogens involved)
- Just how “mixed up” or “clumped” is the landscape?
- Straightforward interpretation: the greater the index, the more *aggregated* the landscape elements
- unitless

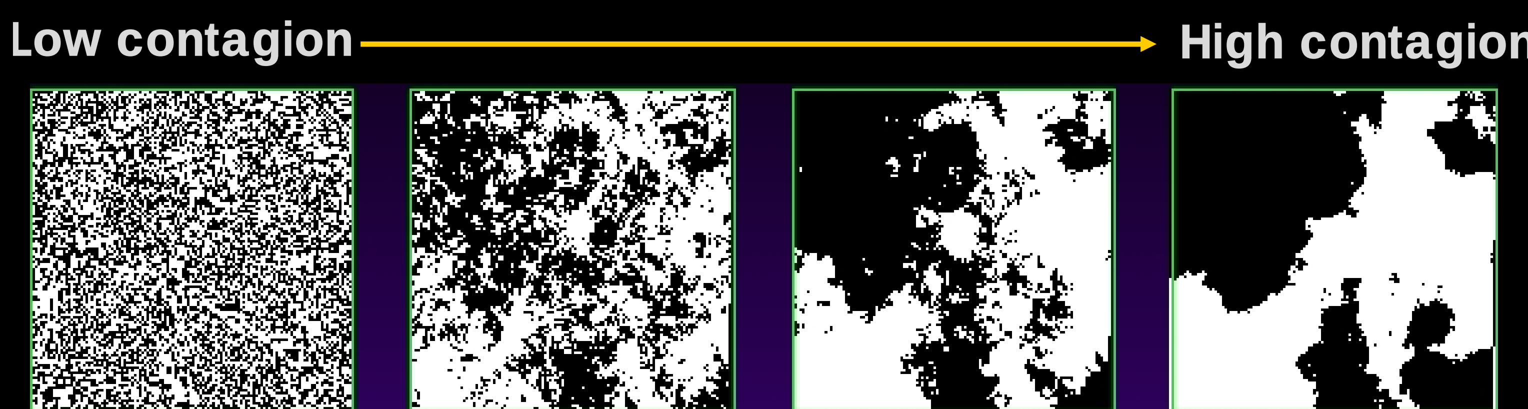
Landscape-level metrics

Contagion

Contagion index







Calculating the Contagion Index

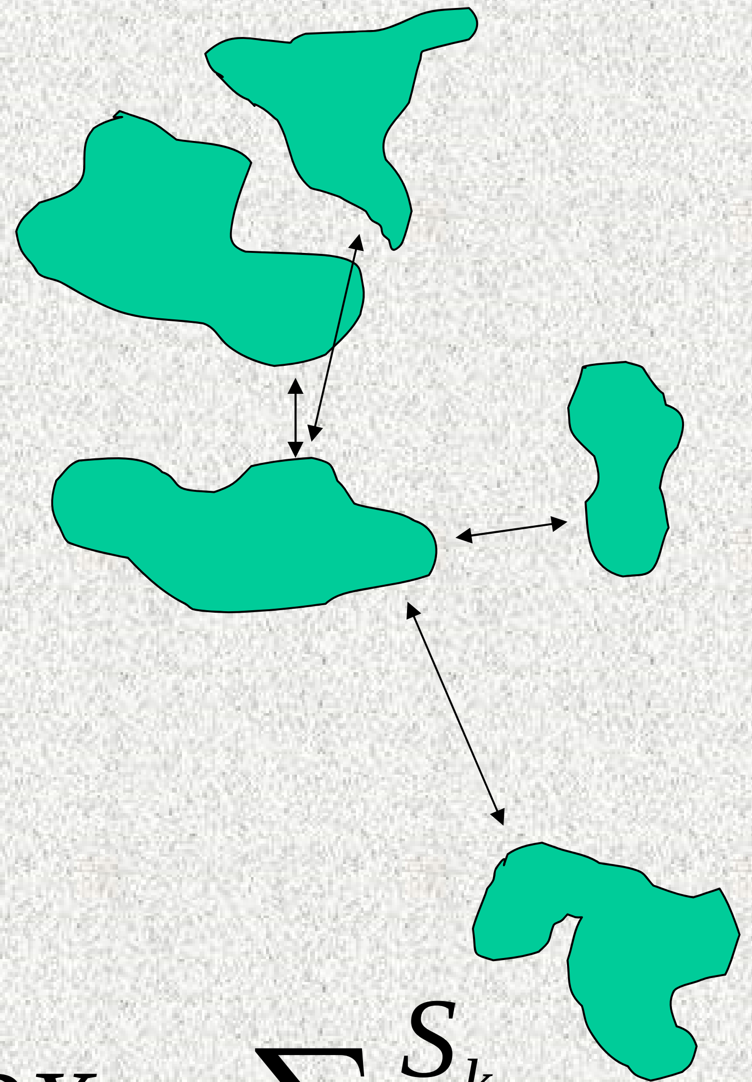
$$C = 2n \ln n + \sum_{i=1}^{n} \sum_{j=1}^{n} P_{ij} \ln P_{ij}$$

Where: n= number of grid cells, P_{ij} is probability of having a neighbor of type *j* for every cell of type *i*.

In analysis of 94 quadrangles by O'Neill *et al.* 1988, C (called D_2 in paper) ranged from 9.5 (low "clumping") to 22.8 (high "clumping").

Proximity Index

- Calculated for an individual patch
- Used to show relative isolation of patch from others of its kind
- Low values = isolated, high = close
- Calculated as:
  - Where S_k=area of k^{th} patch
  - n_k = nearest-neighbor distance between focal patch and nearest cell of patch of same type
  - "search radius" is arbitrary, and depends on objectives!



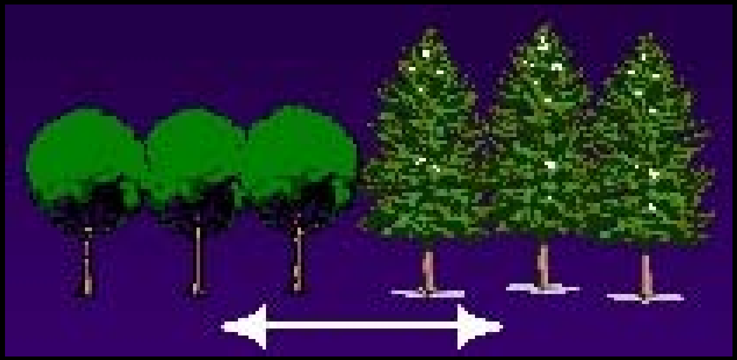
$$PX_i = \sum \frac{S_k}{n_k}$$

Landscape-level metrics

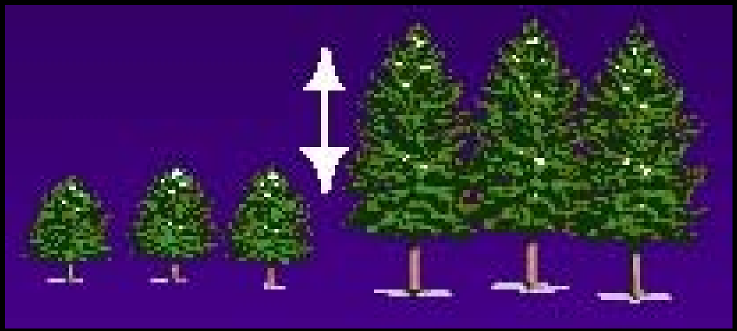
Contrast

- Total Edge
- Edge density
- Edge contrast index
- Contrast-weighted edge density
- Neighborhood contrast index

Floristic or type contrast



Structural contrast



$$CWED = \frac{\sum_{i=1}^{m}\sum_{k=i+1}^{m}(e_{ik} * d_{ik})}{A}(10{,}000)$$


1
2
3
4
5
6
7
8
9

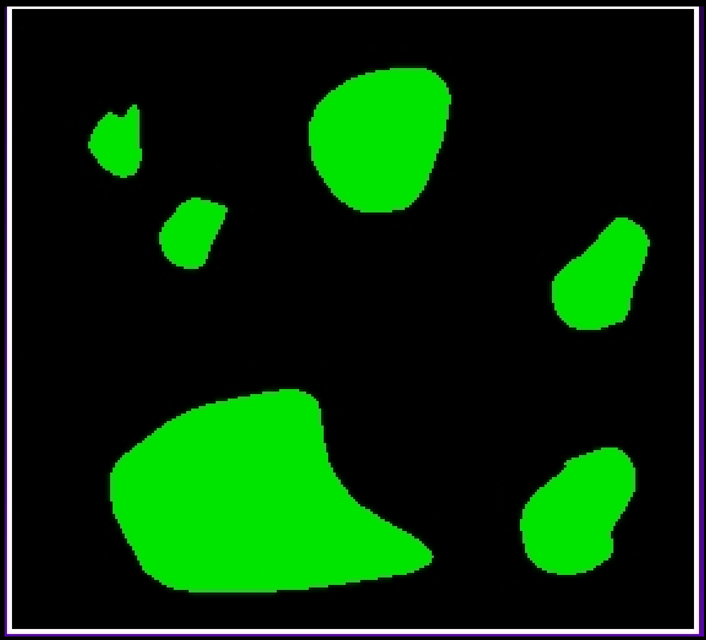
Landscape-level metrics

Shape complexity

Edge density

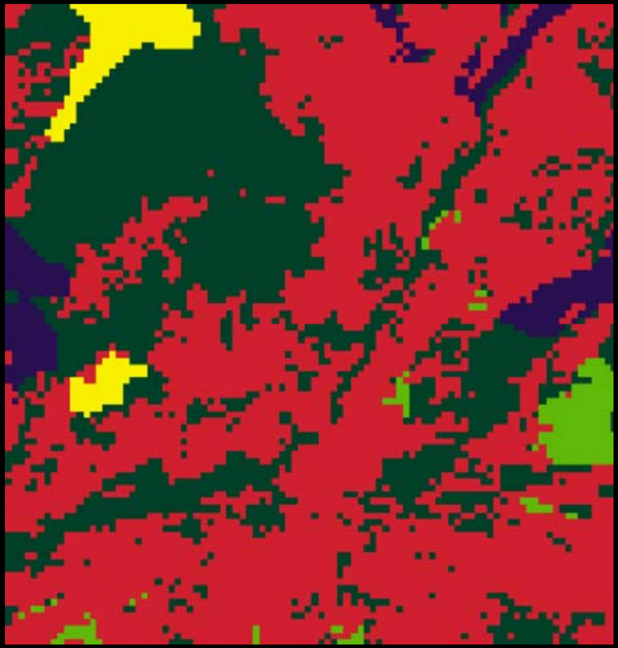
Shape index

Complex geometry



Simple geometry

Landscape-level metrics



Connectivity

Connectance

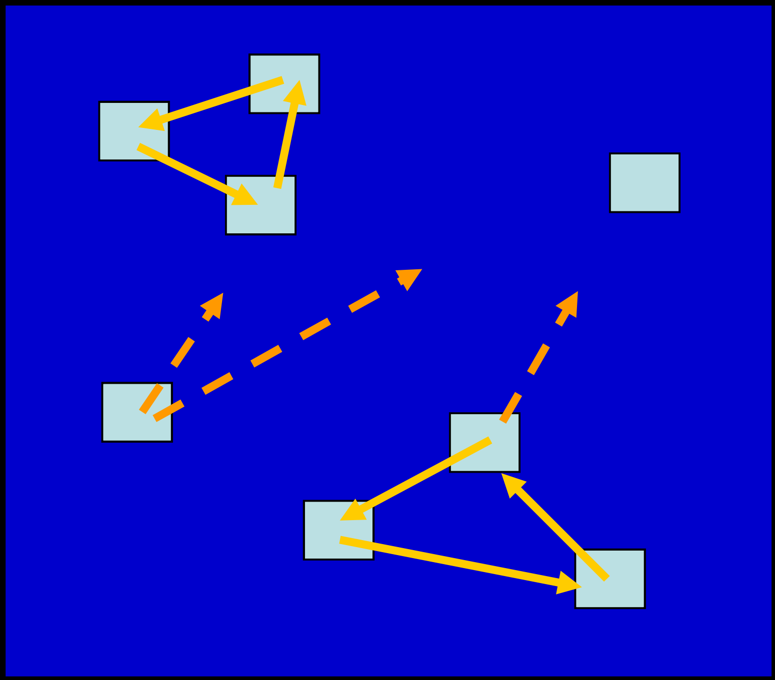
Patch cohesion index

- Resistance
- Percolation theory

Like contrast, connectivity depends on the object of investigation

"connected with respect to… "

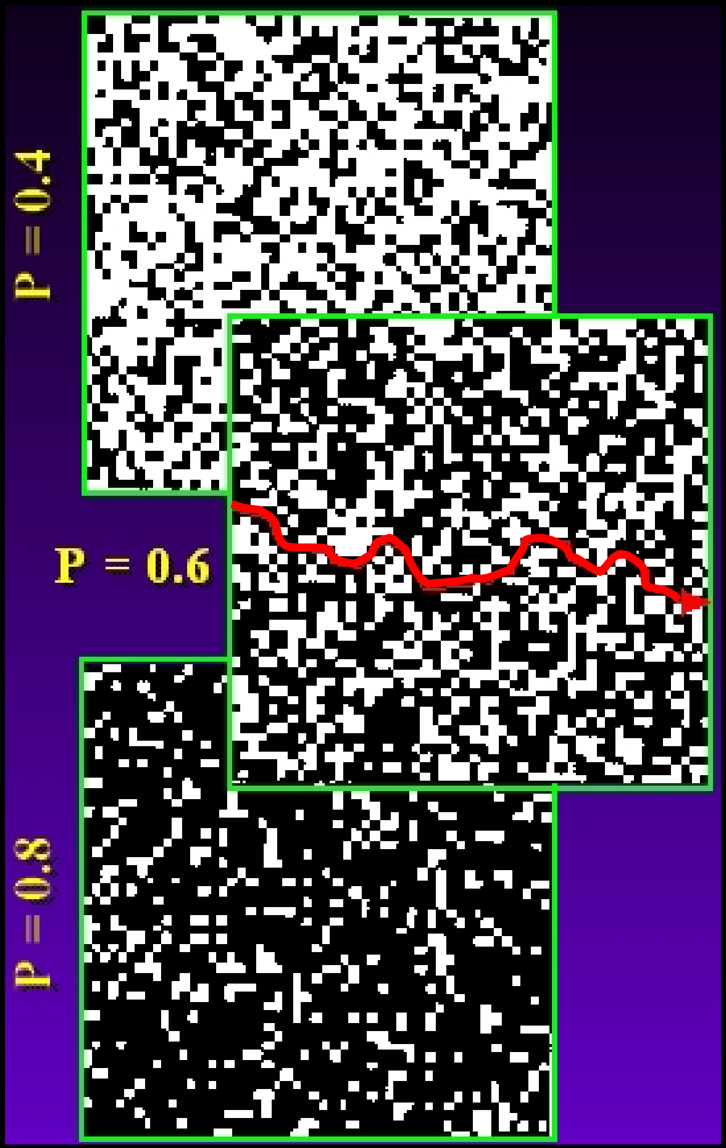
Connectivity



Connectance

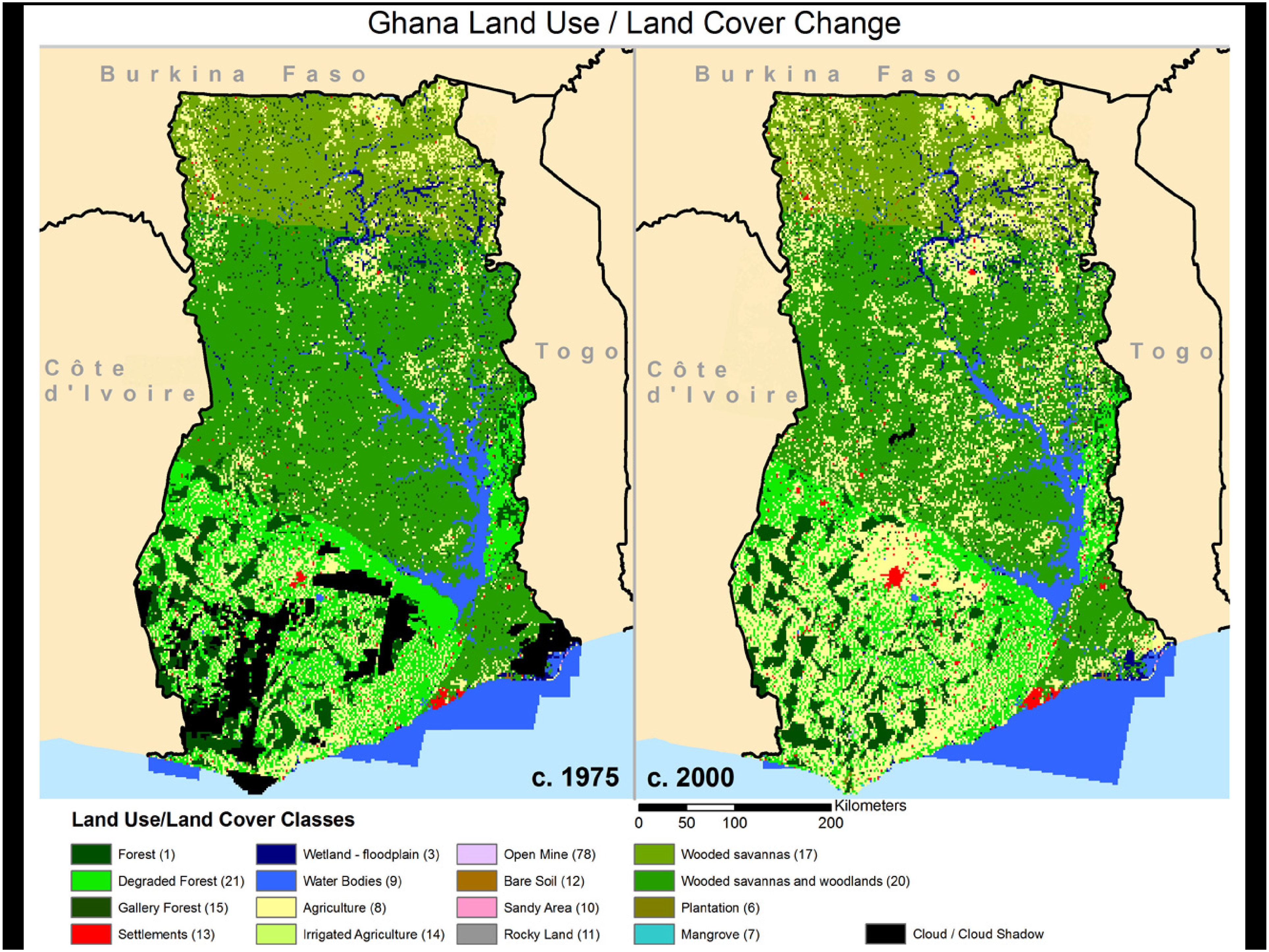
- Defined as the number of functional joinings
- Each pair of patches is either connected or not (0/1) based on a user-specified distance
- Distance can be Euclidean or resistance-weighted
- Expressed as a percent of all possible joinings between patches of the same type.

Connectivity



Percolation theory

- Connectivity can be inferred from patch density.
- Connectivity increases in a nonlinear fashion as the proportion map occupied by a given patch type (*p*) increases.
- Once *p* = 0.5928 (0.41 for the 8-neighbor rule), the largest connected cluster will span the map edge-to edge


Ghana Land Use / Land Cover Change
Burkina Faso
Côte d'Ivoire
Togo
c. 1975
Burkina Faso
Côte d'Ivoire
Togo
c. 2000
0 50 100 200 Kilometers
Land Use/Land Cover Classes
Forest (1)
Degraded Forest (21)
Gallery Forest (15)
Settlements (13)
Wetland - floodplain (3)
Water Bodies (9)
Agriculture (8)
Irrigated Agriculture (14)
Open Mine (78)
Bare Soil (12)
Sandy Area (10)
Rocky Land (11)
Wooded savannas (17)
Wooded savannas and woodlands (20)
Plantation (6)
Mangrove (7)
Cloud / Cloud Shadow

Issues with measuring landscape patterns

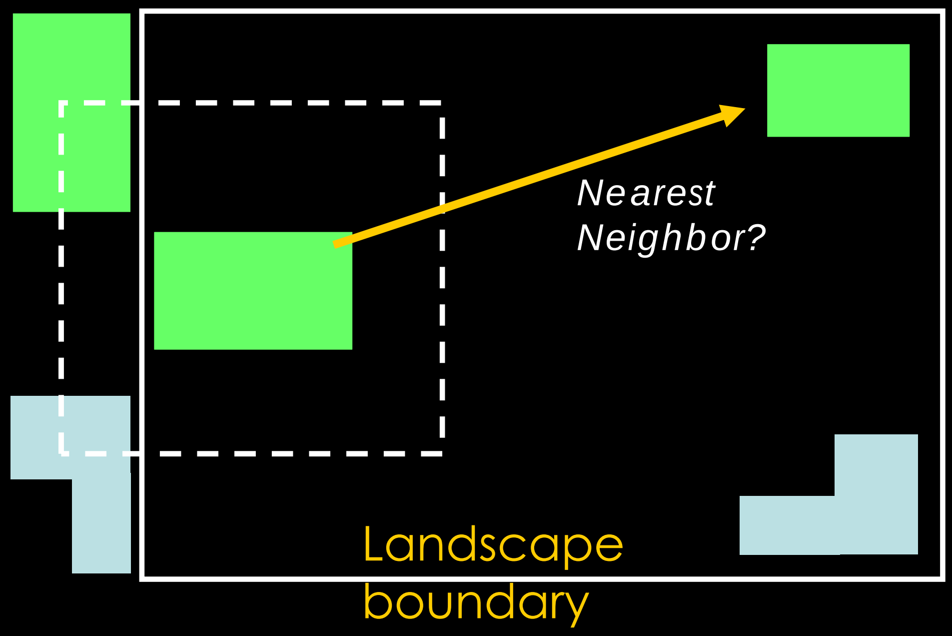
Boundary effects

Scale effects

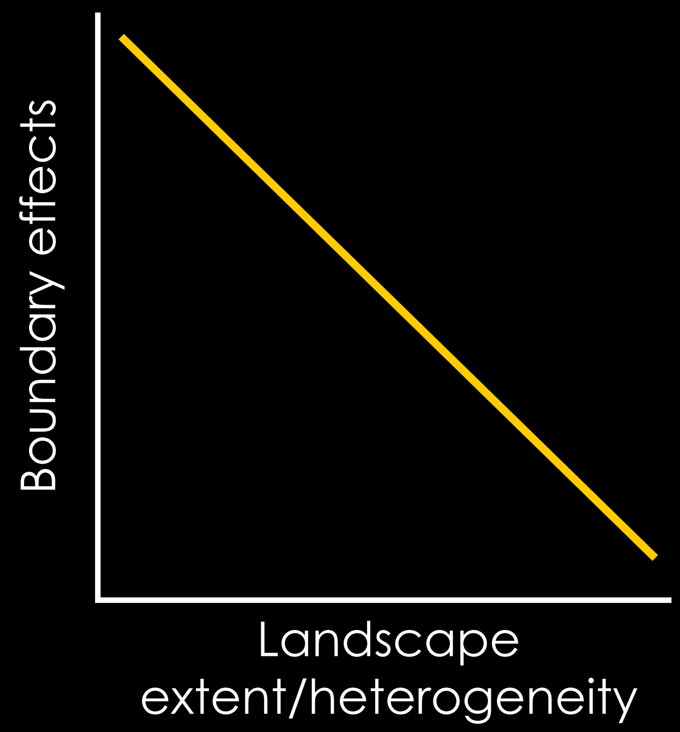
Redundancy

Rules / Approaches

Boundary Effects

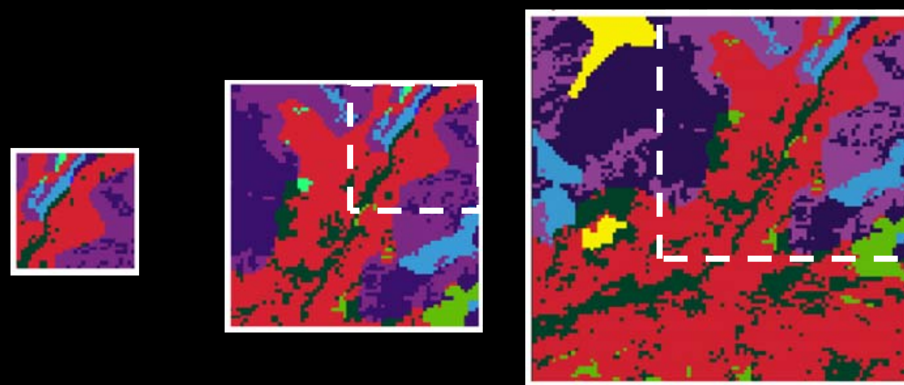


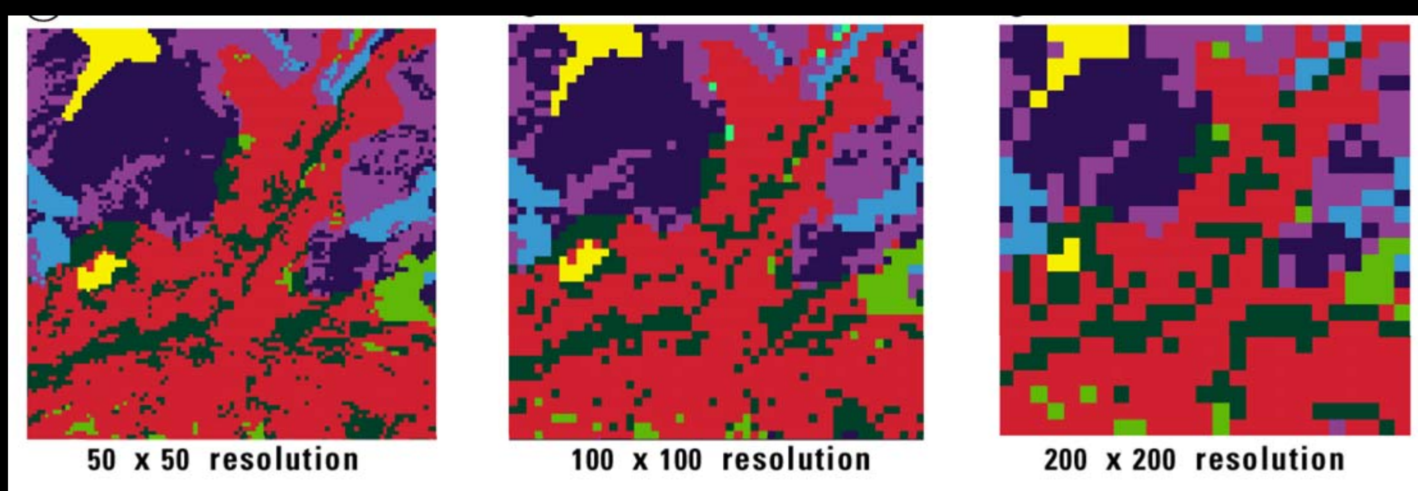
Boundary Effects



Scale effects

Both grain and extent affect how landscape metrics are interpreted, and must be consistent across landscapes to be compared.





Effects of scale on pattern measurement

Relationship between extent and three landscape metrics

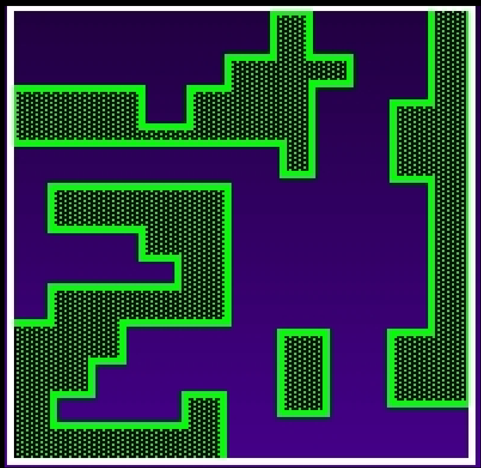
Table 8. Regression of three landscape indices with extent (log area). Values are the slopes and (r^2).

Scene	Landscape parameter		
	Diversity (H)	Dominance (D)	Contagion (C)
Goodland, KS	0.008 (0.19)	0.197 (0.88)	3.253 (0.78)
Natchez, MS	0.127 (0.78)	-0.015 (0.02)	1.535 (0.72)
Knoxville, TN	-0.058 (0.38)	0.111 (0.87)	0.938 (0.47)
Greenville, SC	0.023 (0.10)	0.067 (0.70)	0.067 (0.67)
Waycross, GA	0.044 (0.84)	0.081 (0.50)	1.519 (0.57)
Macon, GA	-0.006 (0.06)	0.077 (0.93)	1.373 (0.66)
Athens, GA	0.041 (0.42)	0.081 (0.57)	1.569 (0.83)

Turner et al. 1989

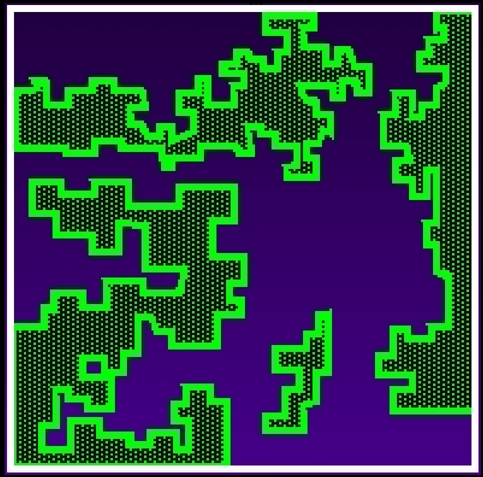
Scale effects

Coarse-grained



Edge = 1000

Fine-grained



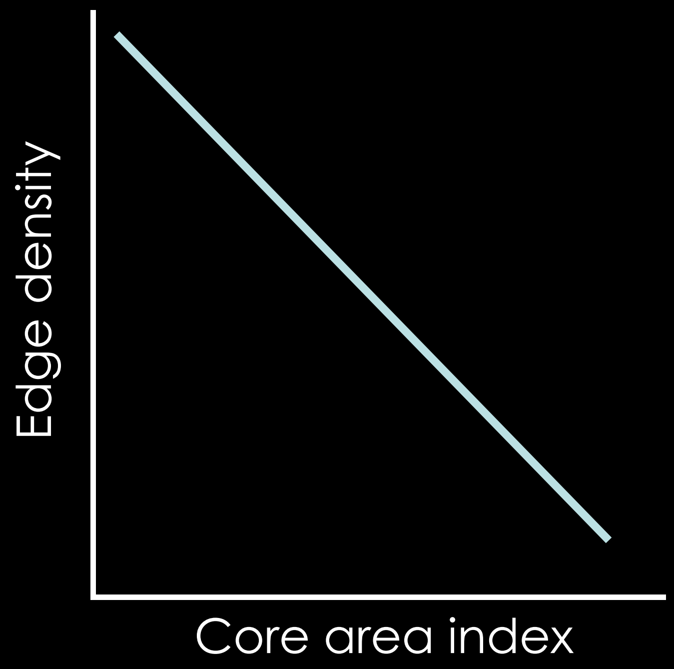
Edge = 1500

Redundancy

Many measures are highly correlated

$$\text{Mean Patch Size} = \frac{\text{Total area}}{\text{Number of patches}}$$

$$\text{Patch Density} = \frac{\text{Number of patches}}{\text{Total area}}$$



Redundancy

Riitters et al. (1995) found that only five metrics were needed to explain most of the variability in their landscapes:

- Number of patch types
- Mean edge/area ratio
- Contagion
- Average patch shape
- Fractal measurements

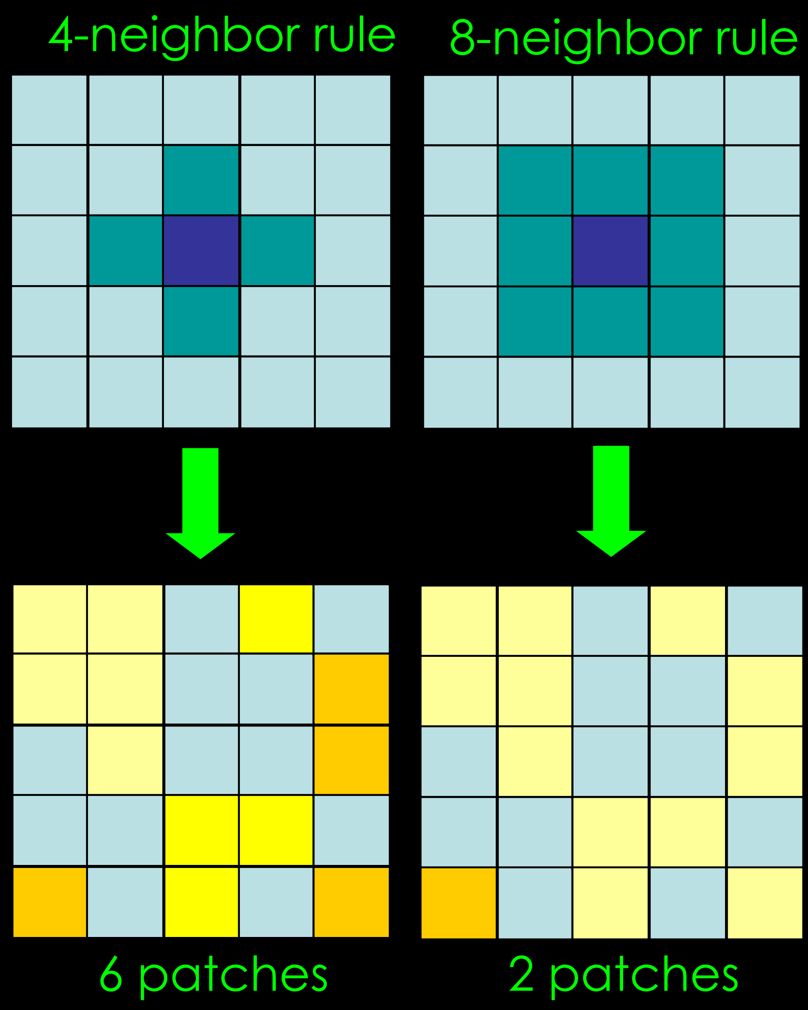
Riitters *et al.* 1995

- How did they do it?
  - Calculated 55 metrics for 85 landscapes (55*85=4675)
  - Created a table of correlation coefficients (0=no correlation, 1= perfect correlation) between the metrics (*factor analysis*)
  - Used high correlation coefficients to distinguish "families" of indices
  - Indices that explained most variation in data set were selected as "representative indices"

Rules / approaches

Neighbor rules are critical in defining landscape metrics.

Contrast weights will affect weighted edge indices.



Characteristics of Patch Elements

- Patch analysis is incomplete without examining the intrinsic nature of patches
- GET INTO THE PATCH! Without these metrics, a patch is just a pretty polygon on a map or GIS.
- Patch characteristics determine:
  - Utility by organisms
  - Edge effects
  - Susceptibility to disturbance

Function

- Net Primary Productivity:
  = GPP (photosynthesis) – Respiration = NPP
- Production of wildlife numbers (head of elk, young spotted owls, tailed frogs, etc.)
- Watershed regulation (Andrews LTER example)
- Silt and sediment regulation (TSS- total suspended solids)
  - Compare regions w/ harvest vs. unharvested (control)
- CWD production

Composition

- Landscape elements cannot be considered without considering composition
- Several ways to measure this

 α and β-**richness**: mere number of species in a spatial context

  – Whittaker (1977): *inventory diversity*: point (100-500 m^2), α (<1-625 ha), γ (gamma)(625-2500), ε (epsilon)(>2500 ha)

  -comparison of functional groups: trees, shrubs, etc.

- **Evenness**
- Biodiversity **Indices**: a composite of richness and evenness
  – Simpson
  – Shannon-Wiener

1.

2.