University of Idaho
College of Natural Resources

Landscape Ecology REM429

Scale and Hierarchy Theory

Scale

- Temporal or spatial dimension of an object or observation (Turner et al. 2001)

Components of scale

- Grain: finest level of resolution
- Extent: size of the area or time frame assessed

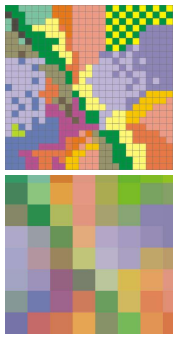
Grain: the minimum resolution

Cell size in raster data

Minimum mapping unit in vector GIS data.

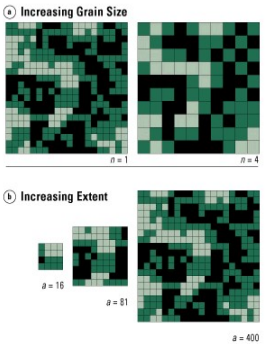
Plot size in field data

Pixel size in satellite imagery



Isn't a finer scale always better?

Changing grain and extent



- As grain size increases, smaller patches are averaged into the surrounding patch types and may no longer visible
- As extent increases you often find more patches and more patch types

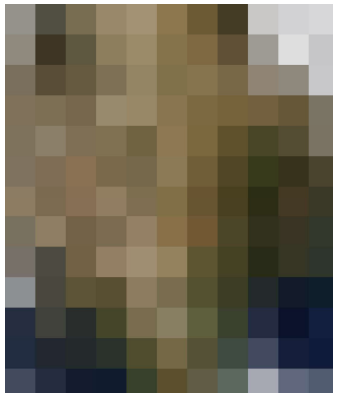
Source: T,G & O 2001 Figure 2.2

Grain and Extent

Can you determine the grain size of this image?

The extent?

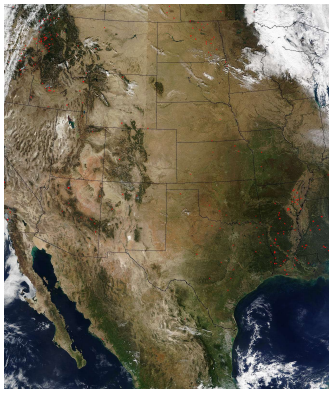
What does this image show?



Now the pixels (grain) are so small, they are hard to see.

Can you determine the grain size now?

How about the extent?



Spatial variance

- With a coarse grain, small patches are averaged together with the larger ones around them
- With increasing grain, the spatial variance decreases (more is incorporated within samples and averaged into sample means (i.e. there is more within and less between sample variance.

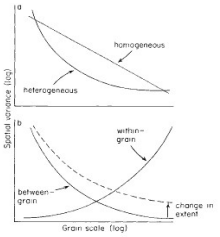


Fig. 2. (a) As the grain of samples becomes larger, spatial variance in the study system as a whole decreases, albeit differently for homogeneous and heterogeneous areas. This is related to the within- and between-grain (sample) components of variation. (b) With increasing grain scale, less of the variance is due to differences between samples and more of the overall variation is included within samples (and therefore averaged away). An increase in the extent of the investigation may increase the between-grain component of variance by adding new patch types to the landscape surveyed (Fig. 1), but within-grain variance is not noticeably affected.

Source: Wiens , J.A.1989. Spatial scaling in ecology. Functional Ecology 3:385-397.

Grain and extent affect inferences about species richness across space

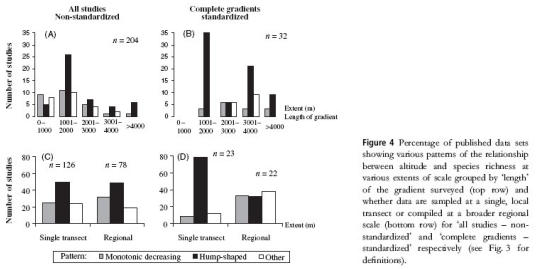
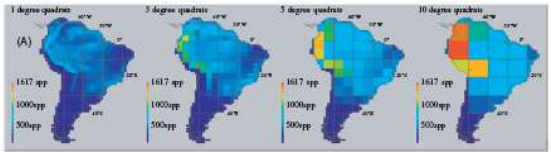


Figure 4 Percentage of published data sets showing various patterns of the relationship between altitude and species richness at various extents of scale grouped by 'length' of the gradient surveyed (top row) and whether data are sampled at a single, local transect or compiled at a broader regional scale (bottom row) for 'all studies – non-standardized' and 'complete gradients – standardized' respectively (see Fig. 3 for definitions).

Source:Rahbek 2005

Effects of scale of analysis (grain size) on spatial variation in species richness

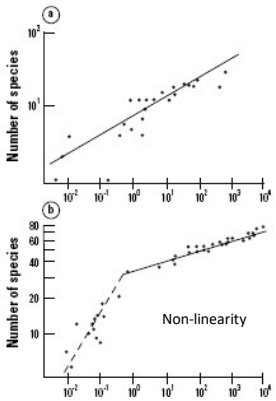


Source: Rahbek and Graves 2001

Examples of species-area relationships

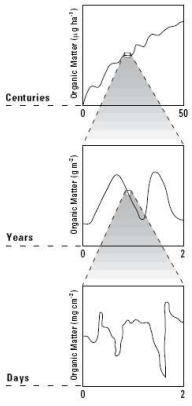
A: Species-area plot for 24 islands in the Sea of Cortez (Cody 1983)

B: Species-area plot for birds in the Solomon Islands (Diamond and Mayr 1976, Williamson 1981



Source: T,G & O 2001. Figure 2.3

Changes in the apparent dynamics of in soil organic matter when observed over three temporal scales



Source: T,G & O 2001. Figure 2.6

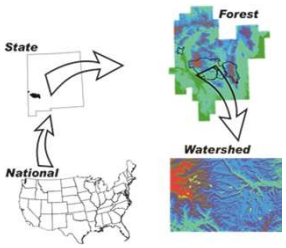
Comparison of the attributes of fine- and broad-scale studies

Attribute	Scale	
	Fine	Broad
Detail resolution	High	Low
Effects of sampling error	Large	Small
Experimental manipulation	Possible	Difficult
Generalizable results	Low	High
Model form	Mechanistic	Correlative
Replication	Possible	Difficult
Sampling adequacy	Good	Poor
Study length	Short	Long
Survey type	Quantitative	Qualitative
Testability of hypotheses	Possible	Difficult

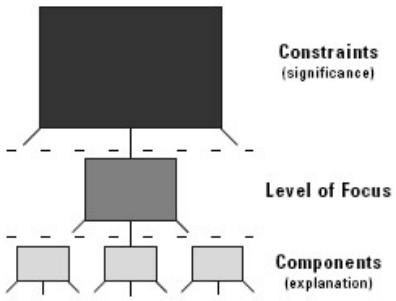
Source: T,G & O 2001. Table 2.2

Hierarchy Theory

- Discrete functional units at several scales
- Nested
- Functionally linked within and across scales
- Each patch is at once
  - a whole,
  - part of a higher level system,
  - and made up of finer scale functions and patches



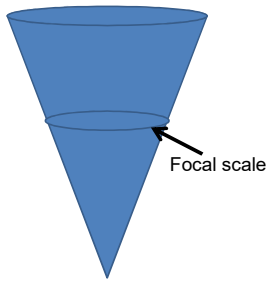
Levels of a hierarchy



Source: T,G & O 2001. Figure 2.5

Hierarchy Theory

- Broader scales give context; they encompass the process of interest
- Focal scale: interaction between nearby elements at the same scale
- Finer scale give explanation and contribute variability

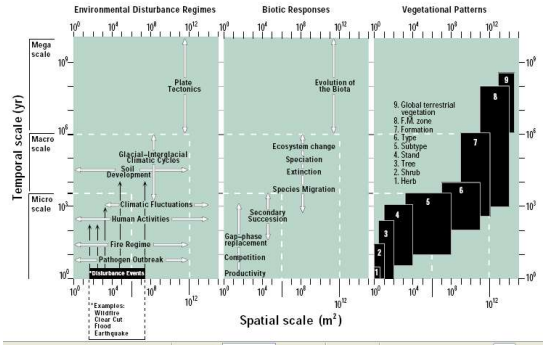


If the focal scale is a forest stand, what could the broader and finer scales represent?

Avoid the ambiguous terms: large and small scale

- Cartographic scale: ratio of distance on a map to distance on the ground
- Broad/coarse: shows a large area
- Fine: shows pattern in a small area, & there is less difference between map and ground observations

Space-time hierarchy



Source: T,G & O 2001. Figure 2.1

Studying plant growth over varying spatio-temporal scales

Scale of measurement	Time frame	Measured variables
Single leaf (multiple cells)		
Individual plant (multiple leaves)		
Population (multiple plants)		
Community (multiple populations)		
Landscape (multiple communities)		

Choosing scales

- Theory: Hierarchy
- Functional:
  - Organism home range
  - Ecosystem processes structuring the landscape
  - Issues and constraints
- Practical: available data and tools
- Analysis: Statistics, experimental design
- By application: Why do you need to know?
- Arbitrary: Funding, administrative

Resolution affects….

- Size of objects we can see
- Precision of measurement
- Our ability to render a sharply defined image
- What we can detect and the resulting information and inferences
- REMEMBER that while resolution is usually spatial or temporal, it can also be **thematic** or floristic, and that it always affects our inferences

Scale issues

Most restoration efforts are small and site-specific.

Many restoration needs are broad (cover large areas) and longer-term.

Scale issues

Most invasive species control measures are small and site-specific.

Effective invasive species management needs are broad (cover large areas) and longer-term.

Be a skeptic about maps

- Maps and GIS data have inherent errors, intentional or not
- Maps are abstractions of reality
- Ask about scale and accuracy
- The conclusions that we draw depend upon the resolution of the underlying data and the resolution at which it is displayed.

Source: Monmonier, M. 1991. How to lie with maps. Univ. of Chicago Press. 176 p.

Prairie Pothole Wetlands — Northern Great Plains

Photo: The Nature Conservancy

Mississippi River Delta, Louisiana Wetlands, Marsh and Barrier Islands

Photo: Alysha Jordan

Modifiable Aerial Unit Problem

MAUP

Scaling problem
– data is aggregated in fewer larger spatial units

Zonation problem
– variations in results with alternate configurations of spatial units when the number of units are held constant

Fotheringham and Wong 1991; Svancara et al. 2002

Scaling Problem

1	2	3	1
2	4	6	2
3	6	9	3

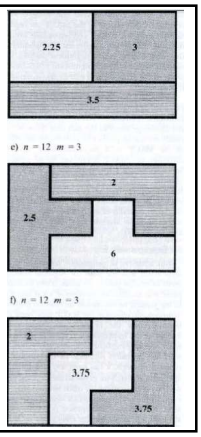
1.5	2
3	4
4.5	6

1.75
3.5
5.25

Svancara et al. 2002

Zoning Problem

1	2	3	1
2	4	6	2
3	6	9	3



Svancara et al. 2002

Problems in spatial overlay analysis

- Correlations depend on the number of configurations of spatial units
  - Oppenshaw and Taylor 1979 showed correlation coefficients ranging from -0.99 to 0.99 depending on configuration
  - Fotheringham and Wong 1991 showed that regression parameter estimates were essentially unpredictable
  - There is no way to determine or predict the effect of MAUP within a particular spatial dataset (Oppenshaw 1984)

Svancara et al. 2002

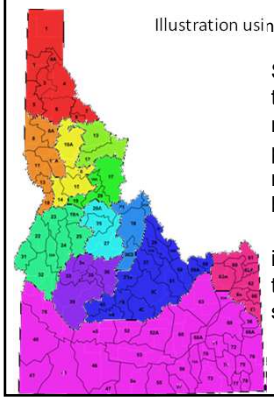


Illustration using Game Management Units

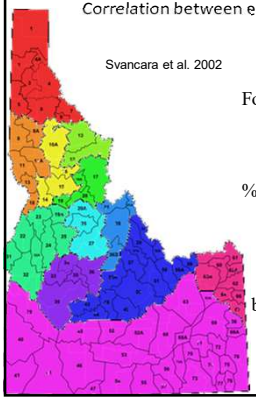
Svancara et al. 2002 explored the relationship between elk recruitment and (1) forest productivity, (2) proportion of non-batholith land, and (3) bull density

in game management units that were aggregated at 3 scales with 3 configurations

Svancara et al. 2002

Illustration using Game Management Units

Correlation between elk recruitment and the 3 variables

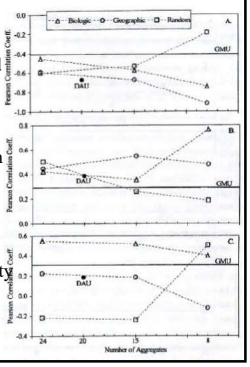


Svancara et al. 2002

Forest prod

% batholith

bull density



MAUP: Solutions?

- There are no general solutions to MAUP, it will be a problem in any analysis based on areal units
- Aggregate units that are similar, to minimize the loss in variation in both independent and dependent variables
- Maximize between-aggregate variation
- Meaningful results will only result when the unit boundaries are relevant to the problem in question
- Select units that are ecologically meaningful
- "MAUP will disappear once geographers know what the areal objects they wish to study are" Oppenshaw 1996

Svancara et al. 2002

Key ideas and concepts: scale and hierarchy theory

- Definition of scale includes: grain and extent.
- We can reach different conclusions at different scales, and different processes happen at different scales.
- Hierarchy theory helps us to understand the linkages among scales in both time and space.
- How are scale(s) for analysis chosen?