



## What is a Landscape?

*Instructor:* K. McGarigal

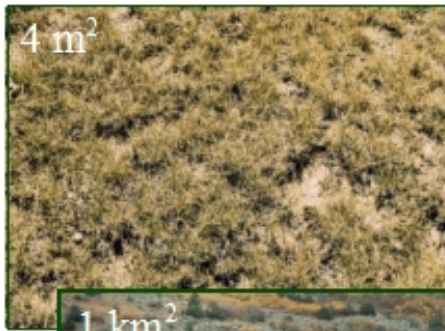
*Assigned Reading:* McGarigal (Lecture notes)

*Objective:* Provide a basic understanding of the concept of a “landscape” to serve as a foundation for understanding landscape ecology topics. Review basic approaches for defining a landscape. Highlight importance of landscape definition in resource management planning and analyses.

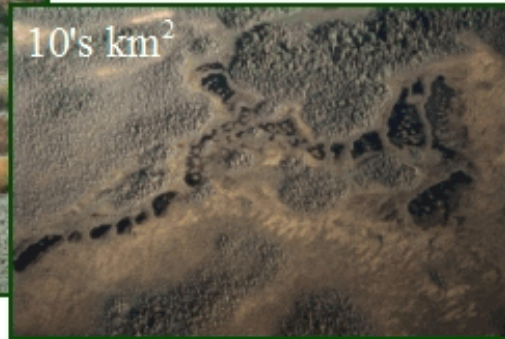
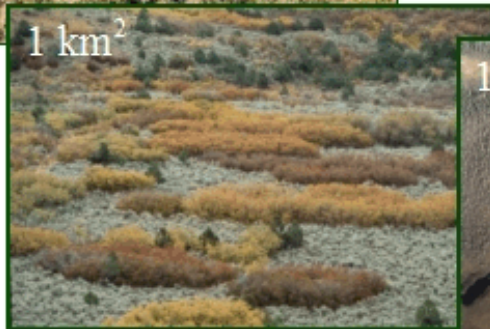
*Topics covered:*

1. What is a landscape?
2. The landscape concept – structure and function
3. Defining the landscape – importance of content, scale and context
4. Why do scale and context matter?
5. Digital reality
6. Defining the landscape – example

## Landscape Defined



- From an *ecological* perspective, a landscape is a mosaic of interacting ecosystems (at any scale); an area spatially heterogeneous in at least one factor of interest.

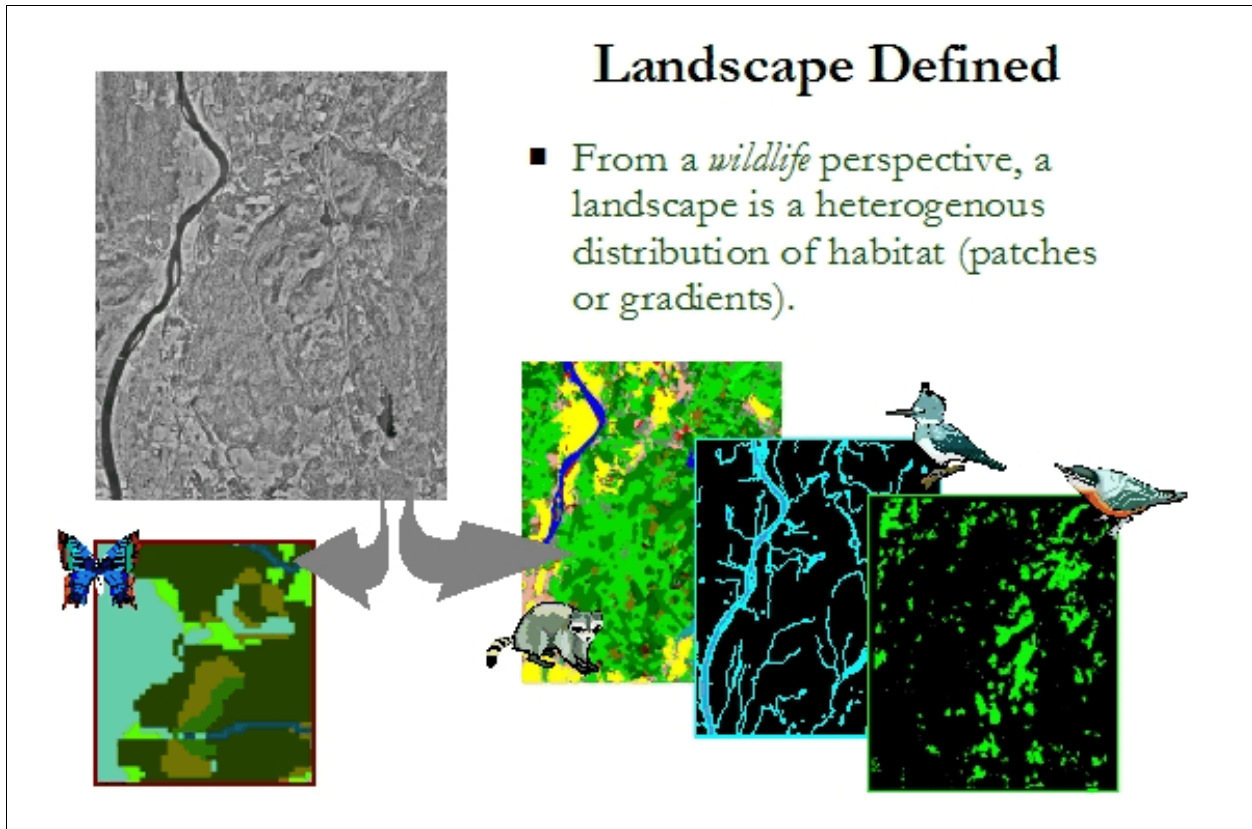


### 1. The Landscape Defined

Landscape ecology by definition deals with the ecology of landscapes. So what are landscapes? Surprisingly, there are many different interpretations of the term “landscape.” The disparity in definitions makes it difficult to communicate clearly, and even more difficult to establish consistent management policies. Definitions of landscape invariably include an area of land containing a mosaic of patches or landscape elements (see below). Forman and Godron (1986) defined landscape as a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout. Turner et al (2002) define landscape as an area that is spatially heterogeneous in at least one factor of interest. The landscape concept differs from the traditional ecosystem concept in focusing on groups of ecosystems and the interactions among them – the focus is on spatial heterogeneity and its impact on process. There are many variants of the definition depending on the research or management context.

## Landscape Defined

- From a *wildlife* perspective, a landscape is a heterogeneous distribution of habitat (patches or gradients).



For example, from a *wildlife* perspective, we might define landscape as an area of land containing a mosaic of habitat patches, often within which a particular "focal" or "target" habitat patch is embedded (Dunning et al. 1992). Because habitat patches can only be defined relative to a particular organism's perception and scaling of the environment (Wiens 1976), landscape size would differ among organisms. However, landscapes generally occupy some spatial scale intermediate between an organism's normal home range and its regional distribution. In-other-words, because each organism scales the environment differently (i.e., a salamander and a hawk view their environment on different scales), there is no absolute size for a landscape. From an organism-centered perspective, the size of a landscape varies depending on what constitutes a mosaic of habitat or resource patches meaningful to that particular organism; a landscape could range in absolute scale from an area smaller than a single forest stand (e.g., a individual log) to an entire ecoregion. If you adopt this organism-centered definition of a landscape, a logical consequence of this is a mandate to manage habitats across the full range of spatial scales; each scale, whether it be the stand or watershed, or some other scale, will likely be important for a subset of species, and each species will likely respond to more than 1 scale.

# Landscape Defined

## How About...



- From a *silvicultural* perspective?
- From a *fuels* (fire management) perspective?
- From a *hydrological* perspective?
- From a *recreational* perspective?
- Other perspectives?

There are many other possible perspectives for defining a landscape. How about from a silvicultural perspective, fuels (fire management) perspective, hydrological perspective, or recreational perspective? Each of these perspectives would require a different definition of a landscape.

## Landscape Defined – Key Point



- A landscape is not necessarily defined by its size; rather it is defined by a spatially heterogeneous area relevant to the phenomenon under consideration.

**KEY POINT:** *It is not my intent to argue for a single definition of landscape. Rather, I wish to point out that there are many appropriate ways to define landscape depending on the phenomenon under consideration. The important point is that a landscape is not necessarily defined by its size; rather, it is defined by an interacting mosaic of patches relevant to the phenomenon under consideration (at any scale). It is incumbent upon the investigator or manager to define landscape in an appropriate manner. The essential first step in any landscape-level research or management endeavor is to define the landscape, and this is of course prerequisite to quantifying landscape patterns.*

## Landscape Defined – In Practice



- HOWEVER, from a *management* perspective, it is most useful to consider landscapes as having a large extent (1,000's-10,000's of hectares) composed of an interacting mosaic of ecosystems and encompassing populations of many species.

HOWEVER, from a management perspective it is perhaps more pragmatic to consider landscapes as having a large extent corresponding to an area of land equal to or larger than, say, a large basin (1,000's-10,000's of hectares) composed of an interacting mosaic of ecosystems and encompassing populations of many species. Indeed, Forman and Godron (1986) suggested a lower limit for landscapes at a "few kilometers in diameter", although they recognized that most of the principles of landscape ecology apply to ecological mosaics at any scale.

# The Landscape Concept – Structure & Function

- Landscapes vary markedly in *structure* (pattern) and *function* (process) due to natural and anthropogenic factors.
- Landscapes vary in the role of humans in creating and affecting the patterns and processes.



Colorado

Massachusetts



Colorado

Idaho



## 2. The Landscape Concept – Structure and Function

Regardless of how landscape is defined, the “concept” of a landscape is unequivocal. All landscapes have a user-defined structure (pattern) that is hypothesized to influence its function (process). This interaction between spatial pattern and process defines the landscape concept.

Landscape structure.—The structure of a landscape is defined by the particular spatial pattern being represented, and it consists of two components: composition and configuration. The *composition* of a landscape is defined by the spatial elements that are distinguished in the map and believed to be relevant to the landscape function under consideration. Composition represents the nonspatial aspect of a landscape, since only number and abundance of landscape elements is considered, not their spatial configuration. The *configuration* of a landscape is defined by the spatial character, arrangement and context of the elements. Configuration represents the spatial aspect of a landscape. Together these two components define the spatial pattern or heterogeneity of the landscape.

Landscape function.—The function of a landscape is defined by the phenomena under consideration and can be a multitude of different things. In general, the services that landscapes provide to humans are functions and include things like providing for biological diversity, recycling nutrients, sequestering carbon, producing clean water, etc..

## Defining the Landscape

### *Major Challenges*



- Choosing a conceptual model of landscape structure
- Selecting the thematic content and resolution
- Selecting the spatial scale (grain and extent)
- Dealing with fragmenting features
- Considering the landscape boundary and context

### 3. Defining the Landscape

Once the analysis or management objectives have been established, the most critically important step in any landscape ecological application is to define the landscape in a manner that is relevant to the phenomenon under consideration given the objectives. This step has several major challenges:

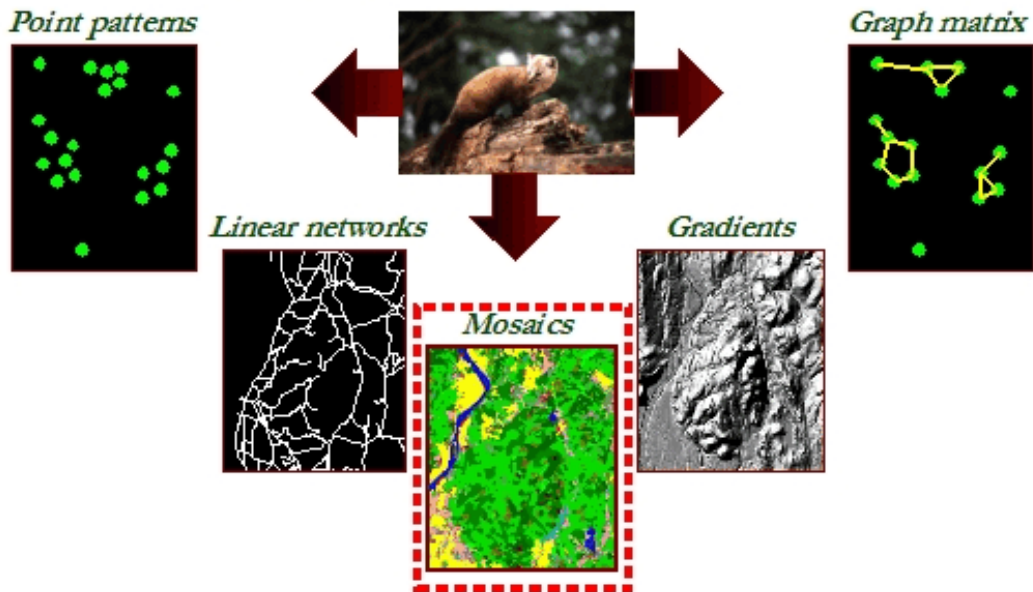
- Choosing a conceptual model of the landscape structure consistent with the objectives
- Selecting the appropriate thematic content and resolution
- Selecting the appropriate spatial scale (grain and extent)
- Dealing with potential fragmenting features
- Considering the landscape boundary and context

Meeting these challenges is immensely important because any quantitative or qualitative measures of landscape pattern-process relationships are ultimately constrained by the definition of the landscape. If the landscape is not defined properly (in terms of its content, scale and context) relative to the phenomenon under consideration and the stated objectives, then no amount of quantitative assessment of landscape pattern-process will reveal meaningful relationships.



## Defining the Landscape *Conceptual Model*

- The conceptual/organizational structure of the landscape

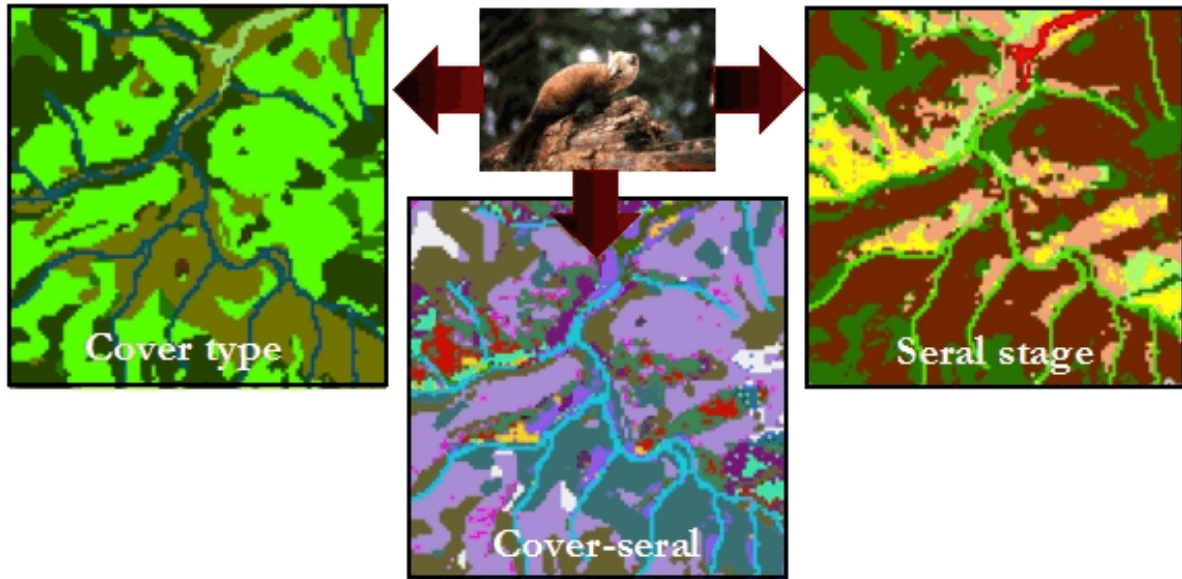


Conceptual model.—The most important challenge in defining a landscape is choosing an appropriate conceptual model of the landscape consistent with the stated objectives. Essentially, this involves determining how to best represent the landscape in map form. In this regard, there are many different ways to model or represent landscape structure corresponding to different perspectives on landscape heterogeneity: (1) point pattern model; (2) linear network model; (3) patch mosaic model based on categorical map patterns; (4) landscape gradient model based on continuous surface patterns; and (5) graph-theoretic model. For the time being, we will simply adopt the conventional patch mosaic model, but we will come back to this topic in great detail in the next section.

## Defining the Landscape

### *Thematic Content*

- The environmental variable(s) represented

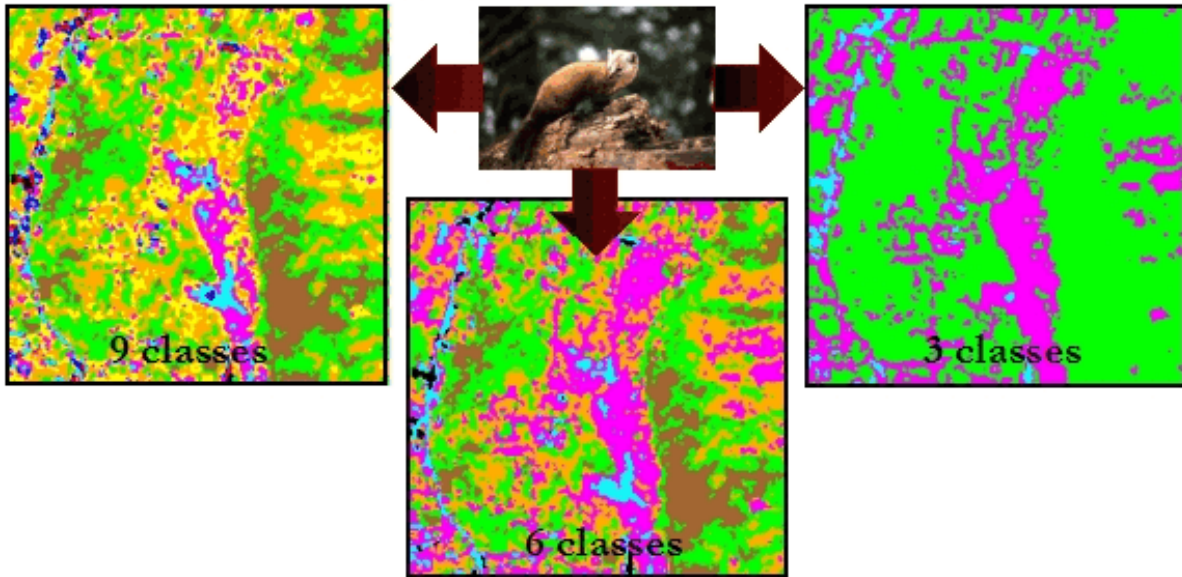


Thematic content.—One of the biggest challenges in defining any landscape is determining the appropriate thematic content. For example, on the Lolo National Forest in western Montana, a high elevation landscape being defined for American marten habitat management purposes could be defined on the basis of vegetation cover type, seral stage, or a combination of cover type and seral stage, among other possibilities. Vegetation attributes may be relevant thematic material in many cases, but determining which vegetation attribute or attributes to represent is often very challenging. In addition, while vegetation may be meaningful in many cases, it may not be the best thematic content in others. For example, soil organisms are likely to be more sensitive to soil characteristics (e.g., depth, texture, wetness, organic matter, pH, etc.) than to vegetation. For these organisms, we might classify the landscape based on soil properties. There are in fact many other legitimate frameworks for classifying the landscape. The key point here is that there are many ways to “slice” the landscape and therefore the “best” thematic classification ultimately depends on the phenomenon under consideration and the availability of data.

## Defining the Landscape

### *Thematic Resolution*

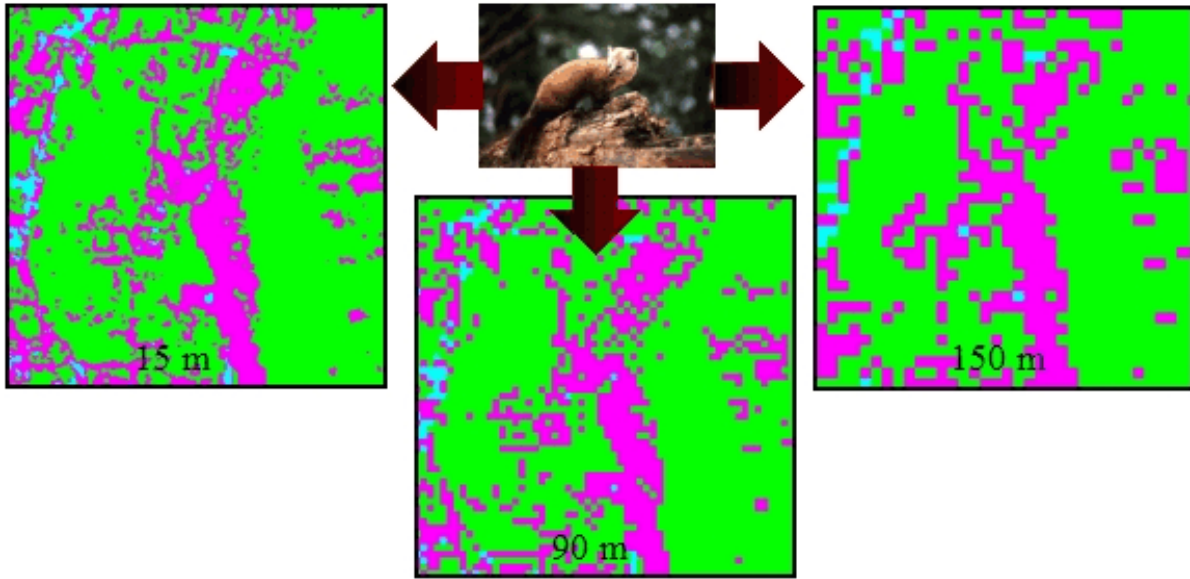
- The resolution in environmental variation represented



Thematic resolution.—Beyond the thematic content, one of the greatest challenges in representing a categorical landscape mosaic is determining the appropriate thematic resolution. Briefly, the thematic resolution refers to how finely the map classes resolve differences in the underlying environment. For example, on the nearby Lolo National Forest in western Montana, the same high elevation landscape can be represented at different thematic resolutions. We might represent each cover type and seral stage as a separate class and consider each class as providing habitat of varying degrees of suitability that differentially affect the connectivity of late-seral spruce-fir habitat patches. While some organisms may perceive and respond to changes in the amount and distribution of late-seral spruce-fir forest, other organisms may exhibit more general associations with late-seral *conifer* forest of any composition. In this case, we might represent the landscape with more broadly defined classes, for example where late-seral spruce-fir forest is aggregated with other conifer forest types (e.g., mixed-conifer) into a “late-seral conifer” condition. Or for some organisms it might be more meaningful to consider all “late-seral forest”, including both deciduous (e.g., aspen) and coniferous forest, or perhaps all “forest” as a single comprehensive class. In practice, data availability is often the limiting factor in determining the thematic resolution, since often our desire to resolve thematic differences exceeds our ability to do so with existing data. Thus, the final thematic resolution is usually a compromise between the ideal number and types of classes from the perspective of the focal phenomenon and the number and types of classes that can be resolved accurately with existing data.

## Defining the Landscape *Spatial Grain*

- The resolution in spatial pattern represented

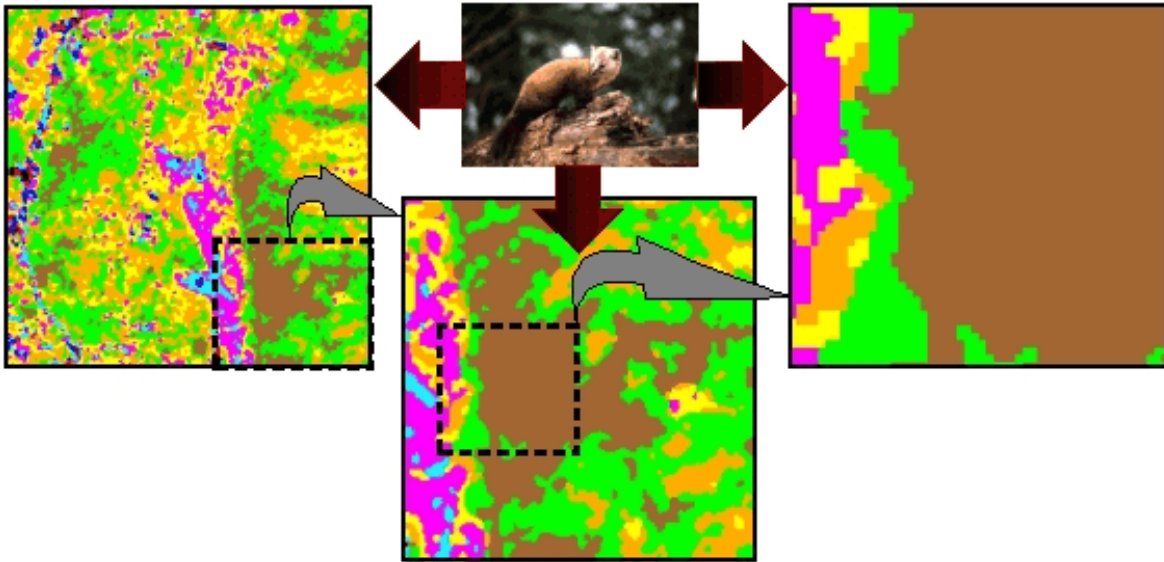


Spatial grain.– To the extent possible, the *grain* of the data should represent a balance between the desire for accurate calculations of landscape pattern, computational efficiency, and the desire to scale patterns appropriately for the chosen landscape extent. On the one hand, the grain should be kept as fine as possible to ensure that small and narrow, yet meaningful, features of the landscape are preserved in the data model. On the other hand, the grain should be increased in relation to the extent so that unnecessary detail is not confused with the important coarse-scale patterns over large spatial extents. This may be achieved by increasing the minimum mapping unit above the resolution set by the grain. In practice, these decisions are often guided by technical considerations owing to the source of the data and the data processing software available. At a minimum, the scope and limitations of the analysis given these scaling considerations should be made explicit.

## Defining the Landscape

### *Spatial Extent*

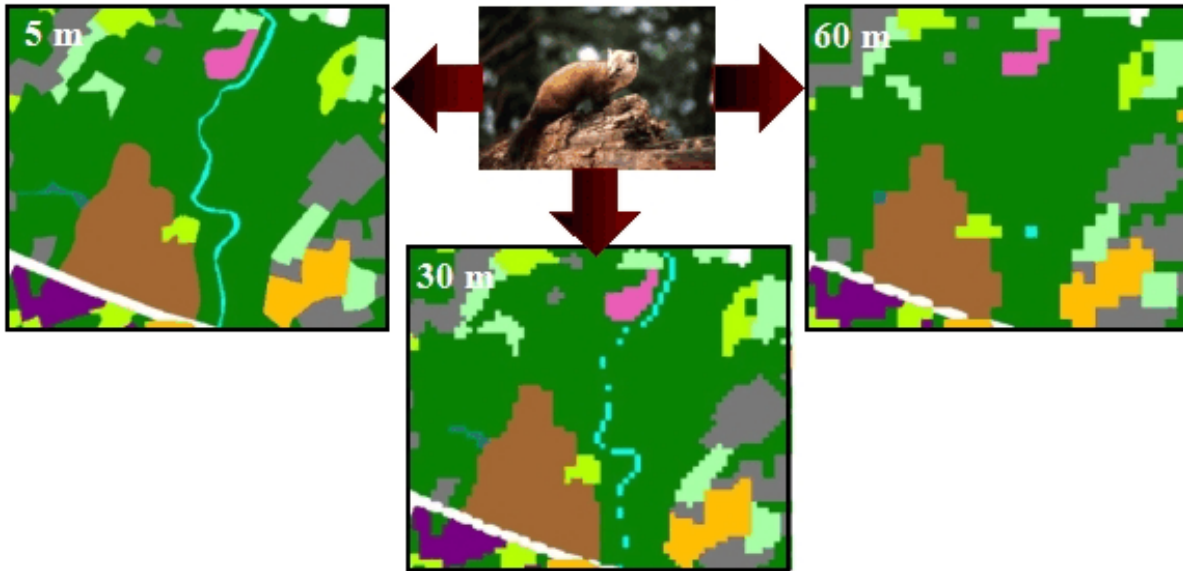
- The spatial extent of pattern represented



Spatial extent.—To the extent possible, the *extent* of the landscape should be meaningful ecologically given the scale at which the target phenomenon operates. For example, the local range of a focal species or of a local population or metapopulation, or the range of a focal community within an ecoregion may be suitable as a basis for delineating the landscape. In many cases, however, there will be practical considerations that must be taken into account. For example, the landscape extent may have to correspond to a specific project planning area (e.g., timber sale area), a timber or wildlife management unit, a watershed, or an administrative unit (e.g., ranger district or national forest). If the landscape extent is small relative to the scale at which the phenomenon operates, then it is likely that patterns in the broader surrounding landscape (i.e., the landscape context) will have as much (or more) effect on the phenomenon as patterns within the specified landscape. At a minimum, the scope and limitations of the analysis given these scaling considerations should be made explicit.

## Defining the Landscape *Fragmenting Features*

- Linear features that disrupt physical continuity



Fragmenting features.—An important issue in establishing both the thematic and spatial scale for a categorical landscape is deciding which landscape elements to consider as fragmenting features. This entails deciding what constitutes a meaningful boundary for a patch. This is an issue for linear landscape elements in particular, such as roads and streams. For example, does a small forest road bisecting contiguous forest constitute a fragmenting feature and split the forest into two distinct patches? What if the road is an expressway? How about a small first-order stream, or a larger river? These and other linear landscape elements are often important features of the landscape, but whether they function to disrupt the physical continuity of landscape enough to warrant treatment as patch boundaries or not depends on the phenomenon under consideration. The specification of linear fragmenting features has practical implications for the measurement of landscape pattern based on conventional approaches, which we discuss in subsequent lecture.

One final point regarding fragmenting features. The issue of fragmenting features is limited to the categorical model of habitat in which habitat patches form the basic spatial unit under consideration. However, in the gradient model of landscape structure, where heterogeneity is viewed as a continuously varying property, patches per se are not delineated. Thus, patch-based metrics are not relevant.

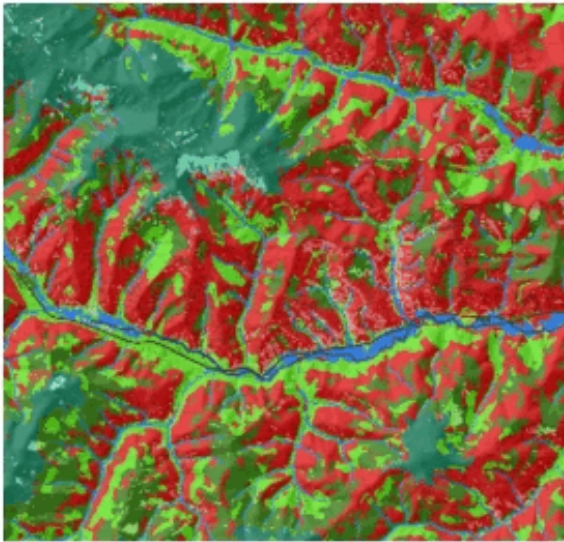
## Defining the Landscape

### *Landscape Boundary and Context*



Landscape boundary and context.--Landscapes do not exist in isolation. Landscapes are nested within larger landscapes, that are nested within larger landscapes, and so on. In other words, each landscape has a context or regional setting, regardless of scale and how the landscape is defined. The landscape context may constrain processes operating within the landscape. Landscapes are "open" systems; energy, materials, and organisms move into and out of the landscape. This is especially true in practice, where landscapes are often somewhat arbitrarily delineated. That broad-scale processes act to constrain or influence finer-scale phenomena is one of the key principles of hierarchy theory and 'supply-side' ecology. The importance of the landscape context is dependent on the phenomenon of interest, but typically varies as a function of the "openness" of the landscape. The "openness" of the landscape depends not only on the phenomenon under consideration, but on the basis used for delineating the landscape boundary. For example, from a geomorphological or hydrological perspective, the watershed forms a natural landscape, and a landscape defined in this manner might be considered relatively "closed". Of course, energy and materials flow out of this landscape and the landscape context influences the input of energy and materials by affecting climate and so forth, but the system is nevertheless relatively closed. Conversely, from the perspective of a bird population, topographic boundaries may have little ecological relevance, and the landscape defined on the basis of watershed boundaries might be considered a relatively "open" system.

## Defining the Landscape – Key Point



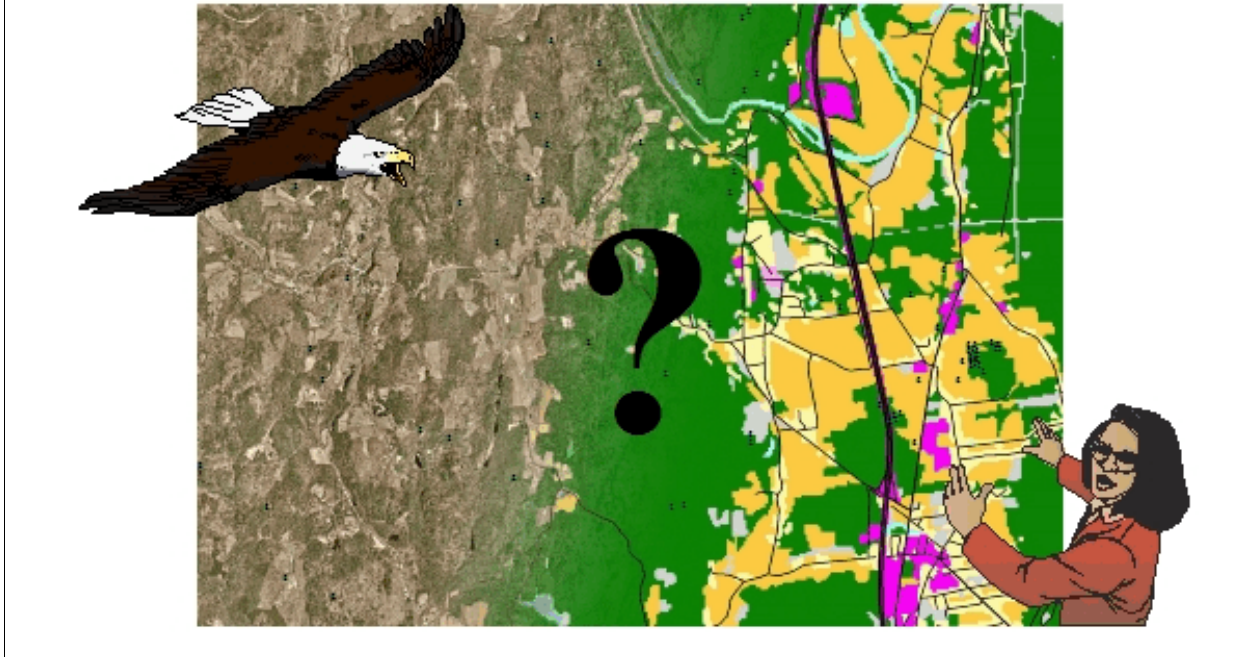
- It is incumbent upon the investigator or manager to define the landscape appropriate to the phenomenon under consideration, because any interpretation of pattern-process is ultimately constrained by the landscape definition.

**KEY POINT:** *Any digital model of a landscape requires an explicit identification of thematic and spatial scale. Unfortunately, in many applications, thematic and spatial scale are selected arbitrarily or defined by technical considerations and the ecological significance of the scale-imposed limitations are dismissed or not recognized. It is incumbent upon the investigator or manager to define the landscape in terms of content, scale and context that is appropriate to the phenomenon under consideration, because any interpretation of landscape structure is ultimately constrained by the scale.*



## Digital Reality...how real is it, really?

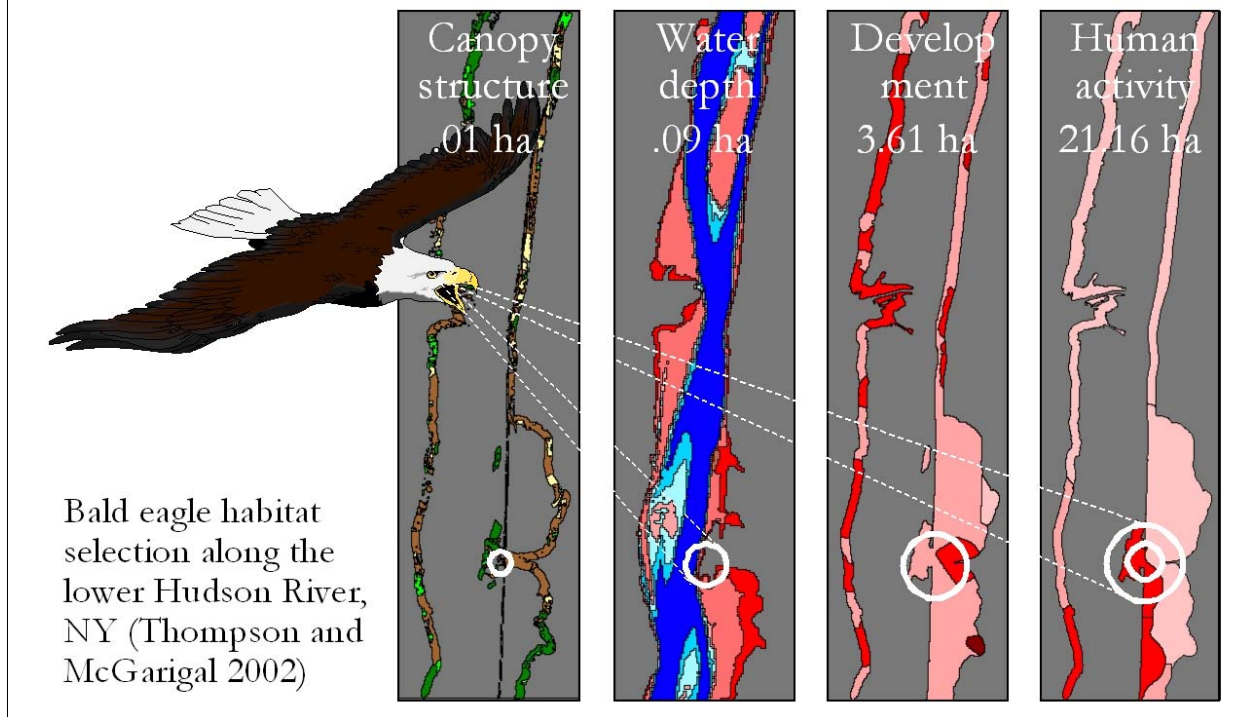
*Measured heterogeneity vs functional heterogeneity*



### 5. Digital Reality

In landscape ecological investigations, we almost always represent landscapes as digital maps. It is important to recognize that all maps are human constructs - representations of reality based on a particular perspective (and scale) – and are always derived from incomplete and/or imperfect data. Consequently, maps often do not represent the landscape as you intended it to and they contain errors. While map error is a universal concern in any quantitative landscape analysis, it is especially a concern when using classified (i.e., categorical) landscapes due to the potential for misclassifications. No classified map is ever completely correct and it is the responsibility of the analyst to gain an understanding of map accuracy. Ideally, a formal accuracy assessment should be completed that involves an extensive ground truthing of the map. This will allow precise estimates of both errors of omission (i.e., a cell of class A that is incorrectly classified to class B) and errors of commission (i.e., a cell assigned class A that is in truth class B). In practice, however, map error is often unknown and moreover it is often beyond the capacity or authority of the analyst to conduct a formal accuracy assessment. In these cases, it is important to gain at least a qualitative assessment of map accuracy.

## Defining the Landscape – Example



### 6. Defining the Landscape – Examples

#### *Bald eagle habitat on the lower Hudson River, NY*

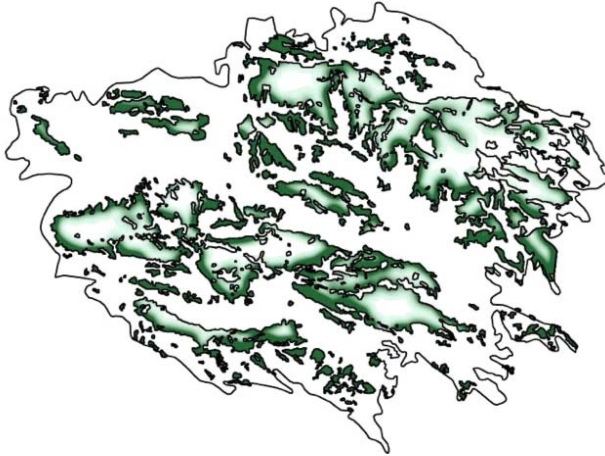
This example involves a study of habitat selection by bald eagles on the lower Hudson River, New York (Thompson and McGarigal 2002); more specifically, a study of the influence of research scale (grain and extent) on bald eagle habitat selection as described previously. Here, we sought to define the landscape from an eagle's perspective. To do this, we defined the landscape for each habitat variable at a range of spatial scales and let the eagles determine which scale or scales were most relevant for each habitat component. For each habitat component we systematically varied the minimum mapping unit (i.e., grain) to create a gradient from very fine- to very coarse-grained maps, and then used statistical procedures to assess habitat use versus availability at each scale. Using the "best" minimum mapping unit scale (i.e., grain) for each habitat component, we then systematically varied the local extent (or window size) and used statistical procedures to identify the local ecological neighborhood size in which to assess habitat use versus availability on the basis of local habitat patterns. The combination of best grain size and best local extent was deemed the scale or scales at which eagle's most strongly respond to habitat patterns, and thus the appropriate scale or scales for assessing habitat use. Thus, we let the eagle's define the landscape for us.

Specifically, for this study we defined the landscape as follows:

- Landscape model – we adopted the patch mosaic model for each habitat component.
- Thematic content – the thematic content varied with each habitat component; e.g., classified water depth was used as the surrogate for foraging habitat quality.
- Thematic resolution – for each habitat variable, we defined a different number of classes based on what seemed biologically meaningful and given the limitations of the available data; e.g., water depth was divided into four classes (0-1 m above mean low tide, 0-1 m below mean low tide, 1-3 m below mean low tide, and >3 below mean low tide).
- Spatial grain – we systematically varied the grain of each habitat map between 0.01-25 ha.
- Spatial extent – we systematically varied the spatial extent for the analysis of each habitat component between 50-500 m radius. However, the extent of the entire landscape (study area) was approximately 30 miles of the upper Hudson River between Stuyvesant and Kingston.
- Fragmenting features – not relevant in this study.
- Landscape boundary and context – our landscape (study area) encompassed all bald eagle breeding pairs on the Hudson River at the time and, moreover, encompassed the entire breeding season home range of each pair. Therefore, we treated the landscape as effectively closed; i.e., the patterns in the landscape beyond our study area boundary were assumed to have no meaningful influence on habitat selection within the landscape.

## Defining the Landscape – Example

Ponderosa pine regeneration following high severity 1977 La Mesa fire, NM (Haire and McGarigal 2008, 2009, and 2010)



### *Ponderosa pine regeneration following the high severity La Mesa fire, NM*

This example involves a study of ponderosa pine regeneration following the high severity La Mesa fire of 1977, NM (Haire and McGarigal 2008, 2009, and 2010). Here, the pattern of interest was patches of high versus low severity within the perimeter of the burn and the process of interest was ponderosa pine regeneration in the high severity patches.

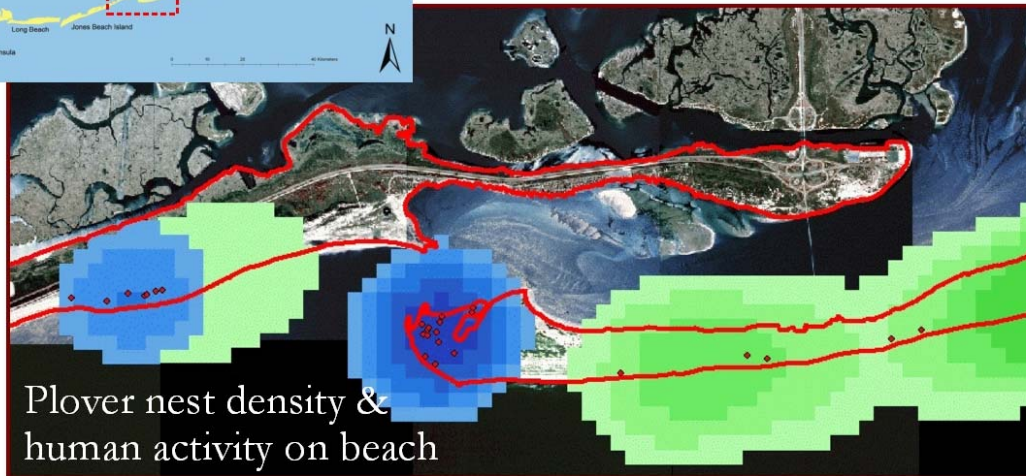
Specifically, for this study we defined the landscape as follows:

- Landscape model – we adopted the patch mosaic model to represent severity.
- Thematic content – we classified patches based on severity, which represents the ecological effect of the fire; in this case, defined by overstory tree mortality.
- Thematic resolution – we defined two severity classes: high severity (complete overstory mortality) and low severity or unburned (residual or untouched overstory); representing whether a seed source existed or not.
- Spatial grain – our minimum mapping unit was two tree crowns.
- Spatial extent – the extent was the perimeter of the fire.
- Fragmenting features – not relevant in this study.
- Landscape boundary and context – we considered the landscape closed as our focus was on regeneration within the high severity patches and our mapped perimeter contained a sufficient buffer of low severity/unburned to function as seed trees.

## Defining the Landscape – Example



Distribution, abundance and productivity of piping plovers on Long Island, NY (Seavey and McGarigal)



### *Distribution, abundance and productivity of piping plovers on Long Island, NY*

This example involves a study of piping plover distribution, abundance and productivity on Long Island NY in relation to a suite of environmental factors (Seavey et al. 2010). Here, the pattern of interest was plover distribution and productivity, and the distribution of a suite of environmental variables. The process of interest was plover habitat selection and productivity.

Specifically, for this study we defined the landscape as follows:

- Landscape model – we adopted the landscape gradient model to represent the variables of interest (i.e., nest density, productivity, and environmental variables).
- Thematic content – we establish a gradient representation of each variable using kernel estimators; the content varied with each variable.
- Thematic resolution – no relevant in the landscape gradient model.
- Spatial grain – each gradient had a 5 m cell resolution.
- Spatial extent – the extent was the 93,000 ha barrier island landscape of Long Island, NY.
- Fragmenting features – not relevant in this study.
- Landscape boundary and context – we considered the landscape relatively closed as our focus was on plover distribution and abundance on Long Island and we believed that habitat factors outside of the barrier island system likely had little impact on distribution and productivity.