Extension Note

Biodiversity
Management Concepts in Landscape Ecology

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"… an important way to maintain biodiversity at the landscape level is to mimic natural spatial patterns in managed forests …"

Spatial Patterns and Landscape Ecology: Implications for Biodiversity PART 3 OF 7[1]

Introduction

Spatial patterns? To get a good idea of what we mean by spatial patterns in forested landscapes, bail out of an airplane at 10 000 m over British Columbia on a clear day. As you drift down, you begin to notice patterns in the landscape, a many-hued mosaic of different patches. Splashes of ice and snow top impossibly sharp mountains, branching rivers deeply dissect plateaus, shimmering leaden sheets reveal valley-bottom lakes. Angling down in altitude, you see more detail in the mosaic, especially the different shapes, colours, and textures of the forested patches. Some patches obviously contain clumps of large old-growth trees, some snake linearly, protecting stream waters from your view. Others are bare or, with their slight tinge of green, hold the promise of regrowth.

All of these patterns are "spatial" in the sense that they occupy three-dimensional space. The study of spatial landscape patterns is one of the central interests of landscape ecologists. Landscape ecology enlarges our understanding of dynamic ecological patterns, the role of disturbances in ecosystems, and the characteristic spatial and temporal scales of ecological events.

The Forest Practices Code acknowledges the importance of landscape ecology concepts by enabling district managers to designate planning areas called landscape units, each with specific landscape unit objectives. The *Biodiversity Guidebook* (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995), a component of the Code, recommends procedures to maintain biodiversity at both landscape and stand levels. These procedures, which use principles of ecosystem management tempered by social considerations, recognize that an important way to maintain biodiversity at the landscape level is to mimic natural spatial patterns in managed forests.

This extension note is the third in a series designed to raise awareness of landscape ecology concepts and to provide background for the ecologically based forest management approach recommended in the *Biodiversity Guidebook*. The focus here is on spatial patterns in forested land-

1 January 2000. Policy direction for biodiversity is now represented by the Landscape Unit Planning Guide. This Extension Note should be regarded as technical background only.

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scapes.[2] We first define basic spatial landscape patterns and describe the "whys and wherefores" of their existence. We then discuss some of the ecological principles underlying spatial pattern development, and review the major spatial processes that can alter landscape patterns and threaten biodiversity. We conclude by examining how these concepts can be applied in landscape-level planning situations.

What Spatial Landscape Patterns Are

Landscape ecologists talk about landscapes as "mosaics." These complex patterns are composed of interconnected or repeating land uses, habitats, or ecosystems over a kilometres-wide area. The landscape patterns we see today result from the interplay of:

- environmental, or physical, constraints;
- disturbances; and
- biological, or "biotic," processes (Bourgeron and Jensen 1994).

Physical constraints include a highly influential array of "abiotic," or non-living, physical factors such as climate, geology, landforms, and soil types. Together these agents create the underlying foundation, or "geomorphic template," upon which the biological landscape is constructed. The characteristics of this template, how it was shaped by moving water, ice, and wind, greatly affect the natural patterns and structural elements we see in the overlying landscape (Forman 1995).

This mantle of landscape is transformed by both natural and human-caused disturbances. Natural disturbances occur at differing intensities across various space and time scales with an attendant range of effects on spatial landscape patterns. Wildfire, insect epidemics, pathogens, windthrow, landslides, and floods are the major agents of disturbance in the unmanaged landscape.[3] In managed landscapes, the increasing expansion of urban centres, the growing development of agriculture, and the continued harvesting of forests all contribute to changes in landscape pattern. Both natural and human-caused disturbances can modify the landscape's fundamental structure by altering vegetation and hydrologic regimes. Some disturbances may produce more complex, resilient spatial patterns; for example, small-scale windthrow events can deposit large organic debris (trees) in a stream, which can potentially improve its spawning habitat. Other disturbances may simplify spatial patterns and therefore affect biotic processes at a landscape scale; for example, large wildfires may create even-aged stands which can become susceptible to massive insect attacks.

In response to the landscape's physical constraints and disturbance regimes, living organisms evolve and adapt their biotic processes. These processes in forested landscapes include:

- soil formation through microbial activity;
- nutrient cycling;
- seed germination, tree replacement, and succession; and
- species development, migration, and elimination.

Through the interplay of physical constraints, disturbances, and biological processes, the spatial patterns in a

2 Eng's chapter in Voller and Harrison's *Conservation Biology for Forested Landscapes* (1997, in prep.) is a good reference for those readers wanting an in-depth understanding of spatial patterns in forested landscapes.

3 Natural disturbance ecology is discussed in more detail in Part 2 of this Extension Note series.

forested landscape can strongly influence both energy flows and functions. For instance, the flows of energy (e.g., the movement of fire) create patterns (e.g., the patchy landscapes created by wildfire movement), which in turn, because of their underlying structure, can influence other flows of energy and the movement of species (e.g., burnt-over lands may alter air drainage and affect seed germination and dispersal patterns). Linkages or feedback between a landscape's existing structure (i.e., the composition and arrangement of its basic elements) and those biological functions is also evident, further transforming the spatial patterns of the land mosaic over time.

A Model to Describe Landscape Patterns

The key to describing these land mosaics is to be able to detect patterns and recognize how and why they vary. Some landscape ecologists use a simple, three-component model as a conceptual tool to classify a landscape's spatial elements (or "structure"): every point is either within a patch, a corridor, or a background matrix (Forman 1995) (Figure 1).

Matrix The "matrix" is the most common and extensive pattern in a landscape mosaic. Because it tends to be the most uniform of these landscape elements, the matrix exerts the greatest control over landscape function. It can be likened to an open

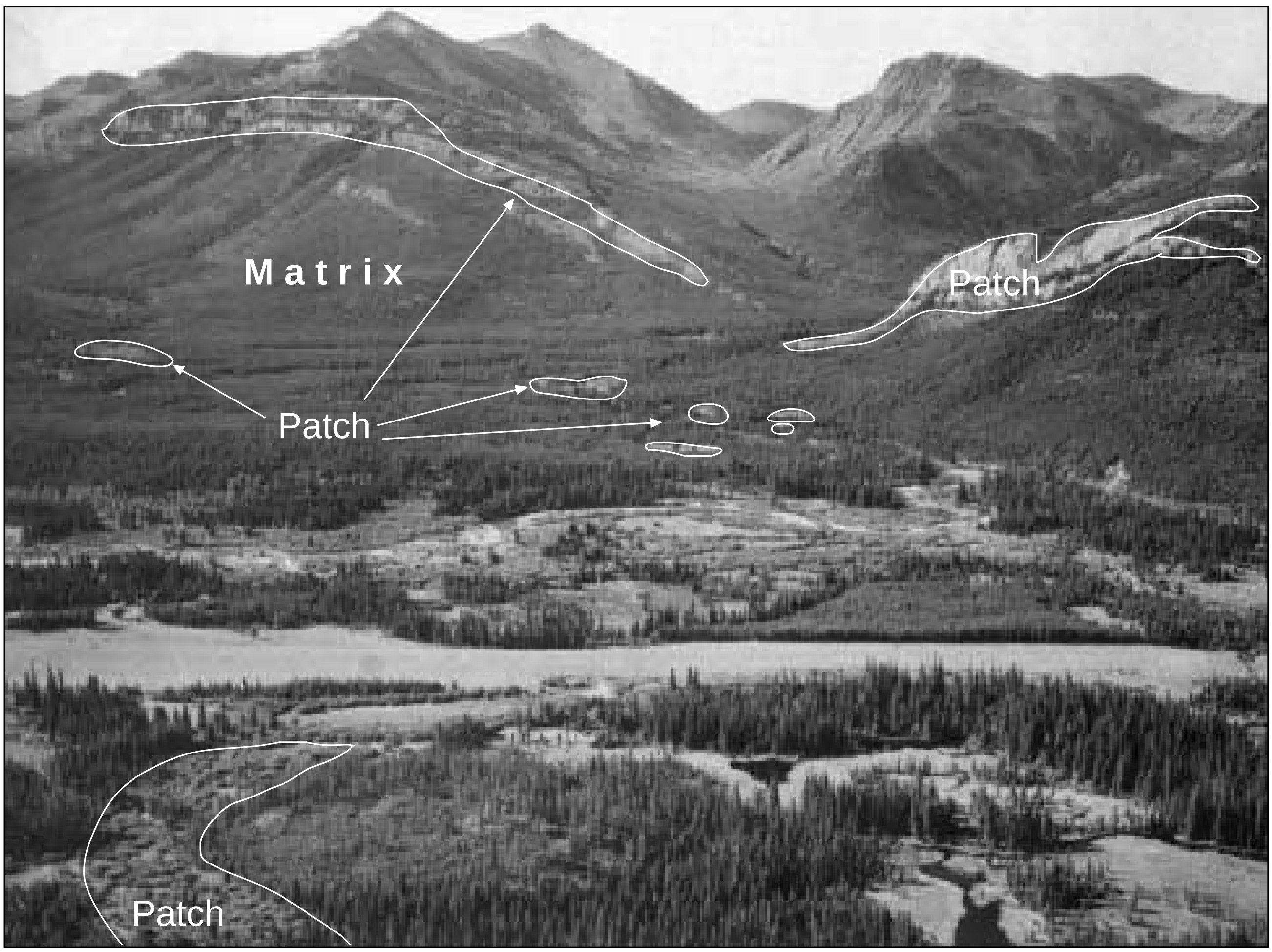

FIGURE 1 *Aerial photo showing patch and matrix elements of a landscape mosaic (adapted from U.S. Forest Service 1993).*

expanse of ocean in which energy (waves) and objects (fish) can move freely from one portion of the water to another. In reality, the matrix may not be completely uniform. Nevertheless, in a forested landscape a non-uniform matrix can still fulfil the habitat needs of many species, and therefore it will seem homogeneous.

In British Columbia, the matrix may consist of continuous mature forest cover or grass lands. The kind of matrix vegetation will depend largely on the geomorphic template (as indicated by the area's biogeoclimatic ecosystem classification) and the land uses (e.g., forestry, agriculture) to which the template is subjected.

Patch An area within the landscape that is distinct from the matrix and isolated from other similar areas is called a "patch." Patches can be large or small, elongated or round, convoluted or smooth. Like islands in the ocean, patches in a forested landscape lack apparent connections with the matrix. Because of their heterogeneity, various patches will have different values for different species. A patch may consist of a single unvegetated opening or gap in a forest created by wildfire, windthrow, or harvesting, or it may be a remnant mature forest stand in a landscape dominated by regenerating young trees or harvested cutblocks.

Corridor The third element in this conceptual model is the "corridor." Corridors are strips that differ from their surroundings on both sides. Like warm currents in the ocean, corridors in a forested landscape provide important connections between portions of the matrix. Corridors provide suitable habitat to link populations of species. Natural features such as riparian habitats along a stream or river provide important landscape connections, often joining upper elevations and midslopes with valley bottoms.

Landscape Patterns: Ecological Principles

Hierarchy Theory and Scale

To landscape ecologists, the concept of spatial patterns and the scale at which they occur are intimately woven together. Hierarchy theory helps explain the connections between complex landscape patterns and the scale of the many processes that influence these patterns. When applied to landscape ecology, this theory allows the components of an ecosystem, or set of ecosystems, to be defined, their patterns and processes identified, and the linkages between the different scales of ecological organization traced (Bourgeron and Jensen 1994).

Hierarchy theory divides multiscaled systems (such as forested landscapes) into an ordered progression of interrelated spatial scales or levels. This concept of interrelatedness is important in the theory. Ecological systems at every level are functional entities that also exist as part of a larger whole. Like the layers of an onion, each spatial level is embedded within another. Our forest management efforts usually occur at regional, landscape, watershed, and stand levels. Progressing through the hierarchy in one direction takes one down to ever smaller (or finer-grained) spatial units such as tree gaps and patches of various species and sizes within a forested matrix. Progressing in the other direction takes one up to ever larger (or coarser-grained) spatial scales such as the continental and global (Table 1).

An Example of Spatial Scale To get a better idea of how spatial hierarchies relate to the complex patterns we see in landscapes, imagine this scenario: A fierce coastal wind storm snaps the bole of a 400-year-old western hemlock. As the windthrown tree falls to the forest floor, its trunk damages two or three smaller conifers, creating a gap in the canopy of about 0.1 ha. The

TABLE 1 *Characterizing ecosystems at different scales (from Bourgeron and Jensen 1994)*

Scale	Vegetation patterns	Biotic processes	Environmental constraints	Disturbances
Continent	Biomes/ formations	Speciation/ extinction	Climatic region	Glaciation
Ecoregion	Series	Species migration	Geology	Fire
Landscape	Communities (seral or climax)	Succession	Landforms	Windthrow (major storms)
Plot	Community/ tree dynamics	Tree replacement	Soils	Treefall

downed tree in its newly formed gap is located in a 10-ha stand composed predominantly of old-growth western hemlock. However, when examined more closely, this stand proves to be a mosaic of gap-sized patches. These patches reflect the wind-dominated nature of the natural disturbance regime in the region. This old-growth western hemlock stand occurs in a coastal watershed thousands of hectares in size. This, together with several similar watersheds, makes up a landscape-sized unit in the Coastal Western Hemlock biogeoclimatic zone. The size, or spatial scale, of that zone equals 10 000 ha. Combined with adjacent areas of like physiographic and climatic features, this landscape forms one component of a regional ecosection which may include three biogeoclimatic zones, the Coastal Western Hemlock, the Mountain Hemlock, and the Alpine Tundra.

An Example of Temporal Scale

Superimposed on this spatial hierarchy is a continuum of time scales. The time scales associated with the landscape patterns we can observe typically range from years to centuries, although variations in stream flow and bank structure can be traced over hours or days, and changes in biomes occur over millennia (Figure 2).

In our example of a windthrown western hemlock, the temporal scale would vary depending on the biological process of interest or the return interval of disturbances. For instance, the gap created by the windthrown tree might regenerate with shrubs in a few years and with trees within a few decades. The downed tree might take up to 400 years to decompose, gradually recycling nutrients into the gap. The temporal scales associated with the stand where this gap occurs would be related to the individual trees in the stand (e.g., 250 years) or the stand's age (1000 years). The wind events that repeatedly recycle parts of the stand may have a return interval of less than 100 years. At the watershed level, the process of vegetation growth may take hundreds of years and erosion processes thousands of years. The landscape containing the watershed would have evolved over thousands of years since the last ice age.

Disrupting Landscape Patterns

By disregarding the relationships between the spatial and temporal scales of ecological systems, we can disrupt formerly coherent landscape patterns and therefore their ecosystem functions. Of the five spatial processes that can alter landscape patterns (see sidebar), fragmentation has received the most attention, becoming an environmental issue worldwide over recent decades (Wilcove et al. 1986).

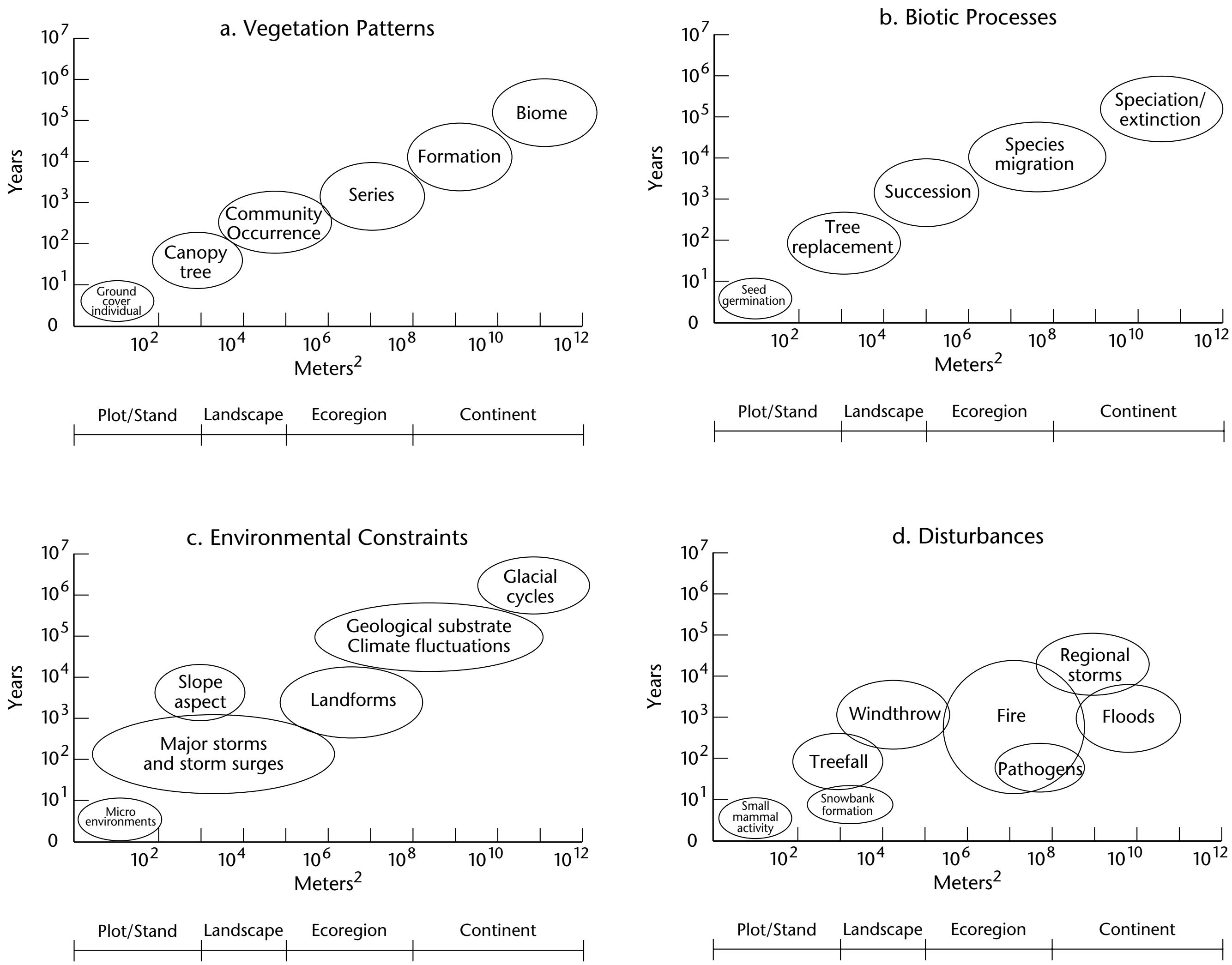

FIGURE 2 *Spatial and temporal scales of (a) vegetation patterns, (b) biotic processes, (c) environmental constraints, and (d) disturbances in a subalpine forest (from Bourgeron and Jensen 1994).*

Forested landscapes become fragmented in three phases (Franklin and Forman 1987):

1. The matrix of mature forest is perforated by cutting units or natural disturbances; the uncut or undisturbed matrix remains connected.
2. The mature forest is increasingly perforated; harvested patches or disturbed areas begin to merge and the remaining mature forest exists as isolated, remnant patches.
3. The landscape is "de-fragmented"; continued harvesting or natural disturbances finally produce increasing amounts of young forest and this young forest becomes the matrix.

The fragmentation, or disruption, of "natural" forest patterns results in physical and biogeographic changes. These changes in turn may affect species that depend on the habitat conditions in the original forest. As remnants of mature forest become increasingly smaller, the amount of edge, that is, the interface between adjacent patches, increases. Edges can modify the microclimate of the habi-

Five Ways to Disrupt Landscapes

Landscape patterns and their underlying ecological systems are transformed through a broad, often overlapping (i.e., some steps may occur simultaneously), five-phase sequence of spatial processes (Forman 1995).

1. ***Perforation****, the most common way of initiating the sequence, is the process of making holes in landscapes or habitats (e.g., an extensive forest may be perforated by logged clearings).*
2. ***Dissection,*** *an alternate way to begin the sequence, is the carving up or subdividing of an area using equal-width lines (e.g., a landscape may be dissected by a road network).*
3. ***Fragmentation*** *is the breaking of a landscape into smaller parcels, similar to breaking a plate on the floor (e.g., a forest may be fragmented by widely and unevenly separated logged clearings and fire-damaged areas).*
4. ***Shrinkage*** *is the decrease in size of landscape or habitat patches (e.g., the amount of old-growth forest that is available for animal refuge during severe winters may be diminished through harvesting, wildfire, or disease).*
5. ***Attrition*** *is the disappearance of a particular landscape or habitat patch (e.g., pristine salmon-spawning streams may no longer exist in a landscape because of the effects of human disturbance).*

Each of these processes result in spatial ecological changes to the landscape mosaic and increased habitat loss and isolation.

tat remnants by causing changes in temperature, moisture, light, and wind regimes. These edge effects[4] may extend far beyond the physical location of the edge (Saunders et al. 1991).

As forested landscapes are increasingly disrupted, the total area of available habitat shrinks and the threat to biodiversity grows. Small remnants of mature or old-growth forest may simply not provide enough habitat to meet the needs of certain species. For instance, many species of birds and most large mammals cannot maintain viable populations in small habitat patches. As these remnants become progressively smaller, the species that depend on these patches congregate in what is left, often degrading the quality of the habitat through overuse. With increased aggregation, species can also become vulnerable to predators and disease epidemics. Furthermore, the lack of connection with other habitat patches creates barriers to gene flow and dispersal, which leads to local extirpation and the loss of biodiversity.

Applying Spatial Landscape Pattern Concepts

Forest management activities that attempt to maintain biodiversity can be successfully integrated into forested landscapes if attention is paid to natural spatial patterns. Forest managers should first gather information to help them describe and analyze past and present landscape patterns. Next, they should determine which spatial and temporal scales are appropriate for the forestry activities to be undertaken in the landscape unit. With this information, they can then select management options that will mimic natural spatial patterns and maintain biodiversity.

Describing Past and Present Landscape Patterns

Understanding landscape patterns, their components, and the processes that generate them is central to understanding the patterns of biodiversity in a specific area. The spatial elements of a landscape (matrix, patch, and corridor) can be described by their composition, size, shape, and boundary characteristics. The whole landscape can be characterized by its dimensions (extent), the relative abundance and arrangement of its spatial elements, and the association of those elements with other aspects of the environment, such as topography and hydrology (Forman and Godron 1986).

A knowledge of past landscape-scale patterns is also required by those involved in designing future forest management activities. In British Columbia, biodiversity objectives reflecting the historical range of ecosystem states have been specified for each of five defined natural disturbance regimes (Lertzman et al. 1997). Since it can take some species thousands of years to adapt to a particular set of conditions, any deviation from this range may put these species at risk. Clearly then, information about a landscape's historic range of ecosystem conditions and disturbance regimes can provide the forest manager with a reference point when planning for patch size distribution, patch arrangement, and other ecosystem attributes. For instance, where recurrent large-scale disturbance is the natural regime, larger clearcuts with small remnants may be the most appropriate pattern of harvest disturbance. On the other hand, where forests are normally replaced in small patches, smaller clearcuts, patch cuts, shelterwood, or selection cutting may be more ecologically relevant (Kimmins 1992).

4 Edge effects are discussed in more detail in Part 6 of this Extension Note series.

Some Measures of Landscape Diversity

Richness: *the number of different community types present in the landscape.*
Evenness: *the proportion of the total area covered by each community type; maximum evenness occurs when every type occupies an equal area of the landscape.*
Dominance: *the influence that a particular community type exerts over a landscape; it is measured by the type's basal area per unit of landscape ground surface or by the proportion of the basal area of the landscape it accounts for.*
Diversity: *the number of community types and their relative abundance (evenness) in a landscape; low diversity refers to relatively fewer community types or more uneven abundance; high diversity refers to a higher number of community types or more even abundance.*

Using Landscape Indices to Describe Patterns

The simplest way to describe landscape structure and pattern is to use one or more of the vast array of available landscape indices. These indices allow a user to detect landscape changes by comparing and contrasting features in different localities or the condition of the same feature. Indices can measure the following landscape features (modified from Eng 1997):

- *Dimensions* (of individual elements), such as area, perimeter, average size; and *shape*, which is usually based on the relationship between measures of perimeter and area.
- *Landscape composition,* such as the abundance of patches measured as density, or the percentage of the landscape area in patches; *landscape diversity* indices, such as the richness, evenness, dominance, and diversity of vegetation community types (see sidebar) (Romme 1982); and *edge density*, measured as the length of various types of edge per unit area.
- *Spatial arrangement of elements,* measured as the distance between patches (e.g., nearest neighbour distances) and according to dispersion and contagion indices; measures of *landscape connectivity* and its converse, *fragmentation*; and *size of matrix patches.*

Four "Indispensable" Landscape Patterns

When information about landscape patterns is difficult to obtain, resists analysis, or seems hard to translate into ecologically sound landscape design principles, the forest manager can still turn to some general guidelines for direction. Forman (1995) suggests four "indispensable patterns" as the essential foundations of any landscape plan. These are landscape patterns that maintain:

1. a few large natural vegetation patches;
2. wide vegetated corridors protecting water courses;
3. connections for dispersal of key species among the large patches; and
4. small patches and corridors providing heterogeneous bits of natural habitat throughout disturbed areas.

Forman defines such spatial solutions as "spatial arrangements of ecosystems and land uses that make ecological sense in any landscape or region."

Because the structure, dynamics, and function of landscapes depend on scale, it is critical to recognize the connections between complex landscape patterns and the scale of the many processes that influence these patterns. If the scale of forest harvesting does not mimic the scale of the natural processes occurring in the forest, then we can expect ecological changes that decrease biological diversity and that interfere with other ecological processes such as energy and nutrient cycling. Therefore, forest managers must be aware of how all forest management practices can affect landscape patterns and processes at all spatial and temporal scales.

Text by Susan Bannerman

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