Landscape Dynamics, Disturbance, and Succession

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Abstract
A landscape is a place where natural and human forces interact. Both forces lead to landscape change over large spatial extents and long temporal spans. These forces are usually referred to as landscape disturbances. This entry discusses both natural and anthropogenic disturbances and their roles in affecting landscape dynamics. The disturbances along with other spatial processes, such as seed dispersal and exotic species invasion, are termed landscape processes. Landscape processes are spatially continuous processes directly related to landscape position, spatial heterogeneity, and patch geometrics and adjacencies. They operate across a range of spatial extents (10^3–10^6 ha) and temporal span (10^1–10^3 year) and are often the main forces shaping the landscapes and interact with landscape succession. Because the interaction of spatial and temporal factors across the landscape can be so complicated that it is beyond human comprehension, computer simulation modeling becomes a useful tool for understanding future trajectories of landscape dynamics. The lack of management experience at the landscape scales and the limited feasibility of conducting landscape-scale experiments have resulted in increasing the use of scenario modeling to analyze the effects of different management actions on focal forests and wildlife species.

INTRODUCTION
Traditionally, a landscape is considered to be an expanse of scenery extending as far as the eye can see. It usually implies an area so large that a person cannot readily traverse it on foot. With the advancement of technologies such as remote sensing and geographical information systems, the capacity to acquire, process, and analyze spatial information has been greatly expanded. Consequently, landscapes analyzed in contemporary scientific literature can cover millions of hectares, expanding the geographic extent of what is considered a landscape.

Within a landscape, there may be numerous components such as forest, grassland, water bodies, houses, and roads. Or there may be one primary component divided into subclasses, such as forest divided into subclasses of young, mature, or old-growth forest. How to classify a landscape depends on the purpose of the study. For example, for an urban sprawl study, a landscape may be classified into different housing density classes; for a wildlife habitat study, a landscape may be classified into habitat, hospitable matrix, and inhospitable matrix; for a study of land cover change, a landscape may be classified into forest, pasture, cropland, and other.

A landscape is a place where natural and human forces interact. Both forces lead to landscape changes (succession) over large spatial extents and long temporal spans. These forces are usually referred to as landscape disturbances and investigated as landscape processes by scientific communities. In this entry, I discuss landscape succession, disturbances, landscape processes, and landscape modeling.

LANDSCAPE SUCCESSION

Succession is a series change from one stage to the next. As landscape components change over time landscape conditions change, which is often referred to as landscape succession. Landscape succession usually occurs slowly over decades or centuries and is driven by natural or anthropogenic forces or both. For example, in Changbai Mountains of Northeast China, early successional aspen and birch dominate the open lands resulted from volcanic activities, after about 40–50 years mid-successional tree species such as maple, oak, and basswood replace aspen and birch to become dominant. In about another next 40–50 years the maple, oak, and basswood are outcompeted by late successional Korean pine, which will reach mixed Korean pine hardwood climax status and will maintain the status for the next 300 years. In this example, young forests grow to become mature forests, mature forests grow to become old-growth forests, and old-growth forests gradually regenerate to start a new forest succession cycle. The whole cycle takes hundreds of years and the main drivers are natural forces.

Increase in human population and the associated need for natural resources drive expansion, creation, and re-creation of human communities worldwide, and infrastructure
developments also lead to more impervious surfaces. Through mapping historical impervious surface, researchers can reveal urban development for a region or state. For example, an urban sprawl study in the state of Missouri found that from 1980 to 2000, 129,853.2 ha of land was converted to impervious surface.[5] Although sprawl was very prominent on urban fringe during 1980s in major metropolitan areas, the trend shifted to the rural landscapes in the 1990s and 2000s. Sprawl in rural areas (also called rural sprawl) may have greater impact on ecosystems due to the low density of development and larger affected areas. Increase in population and the expansion of human society can eventually cause a natural landscape to be transformed into an urban landscape.

Landscape changes are measured from two perspectives: landscape composition and landscape configuration. The former quantifies the proportions of various components (classes), the evenness, dominance, and diversity of the study landscape. The latter characterizes spatial arrangement of various landscape components such as degree of fragmentation, aggregation, association, and connectivity. The common indices for measuring landscape composition include fraction or proportion, relative richness, Shannon’s Diversity index, and Shannon’s Evenness index. The common indices for measuring landscape configuration include contagion, aggregation index, connectivity, and proximity index. Most landscape indices can be found in FRAGSTATS, a software package developed by McGarigal et al.[9]

LANDSCAPE DISTURBANCE

Disturbances include environmental fluctuations and destructive events in an otherwise relatively stable system.[10] It is often characterized by a set of parameters, including distribution (spatial, geographic, topographic, environmental, and community gradients), frequency (mean number of events per time period), return interval (mean time needed to disturb an area equivalent to the study area), mean size (average area per event), intensity (physical force of the event per time such as rate of spread), and severity (impact on the organism, community, ecosystem, or landscape). Disturbance can have endogenous and exogenous causes, whereas in the former, change is driven by the biological properties of the system (e.g., insect susceptibility due to aging), whereas in the latter an outside driving force (e.g., extreme weather) is present. Disturbance can be either anthropogenic or natural, whereas the former is always exogenous and the latter is mostly endogenous.

Anthropogenic disturbances include forest harvesting, grazing, agriculture, or residential development. Their effects are gradual and cumulative, and are often profound on natural landscapes. Anthropogenic disturbances are found to be the main causes of landscape fragmentation, loss of species diversity, altered hydrological functions, or other types of natural resource degradation.

Natural disturbances include extreme weather, landslides, wildfires, insects, and diseases, which are forces that may cause abrupt changes in natural landscapes. They can change the path of landscape succession in many ways. For example, fire disturbance is an integral part of many forest ecosystems. In boreal forests (e.g., larch, spruce, fir forests), high-intensity crown fire can kill most of the trees where they occur and reset the successional stage to that of a newly regenerating forest.[11] In central hardwood forests (e.g., oak-pine forests), low-intensity ground fires can reduce understory density, increase herbaceous species diversity beneath a mature forest overstory, kill pathogens, and ultimately maintain a healthy condition for forest to grow and regenerate.[12] Many studies report that natural disturbances are crucial in maintaining landscape heterogeneity, which in turn determines biodiversity.

LANDSCAPE PROCESSES

Biological organizations occur in a hierarchical manner across a wide spectrum of spatiotemporal scales. At a given level of resolution, a biological system is composed of interacting components (i.e., lower-level entities) and is itself a component of a larger system (i.e., higher level entity).[13] An equally wide range of ecological processes is associated with ecological components at each hierarchical level. For example, stomata conductance is an ecophysiological process at individual leaf level; growth and aging is at an individual organism level; competition is at population level; inter-species competition is at community level; water and nutrient cycling is at ecosystem level; dispersal and fragmentation are at landscape level; and adaptation, speciation, and extinction are at biome level.[13] Processes at one scale often interact with processes at lower and higher scales.[14] Increasing level of organization leads to the increase in magnitude of both spatial and temporal scales. For example, at a single leaf scale, photosynthesis occurs in the order of minutes in a few square centimeters space, at a biome scale, species range distribution changes in response to climatic change, and species migration and extinction occur at a hundreds to thousands of years timeframe over a large region.[13]

In fact, any spatially continuous processes, including the above-mentioned natural and anthropogenic disturbances that are directly related to landscape position, spatial heterogeneity, and patch geometries and adjacencies are landscape processes.[15] These processes operate across a range of spatial extents ($10^3$–$10^6$ ha) and temporal span ($10^3$–$10^5$ year) and are often the main forces shaping the landscapes we have today.

LANDSCAPE MODELING

The challenges in predicting landscape change come from two fundamental aspects: the relevance of both long
temporal and broad spatial dimensions of landscape processes. Temporally, a landscape may take hundreds of years to undergo significant successional change. Processes that operate on such long time spans may go undetected by many field experiments, which are often based on relatively short observation periods that may not capture the full range of the events. Spatially, landscape change can be strongly affected by centuries by environment heterogeneity and the current spatial pattern resulted from past human land use and natural disturbances. The interaction of spatial and temporal factors across the landscape can be so complicated that it is beyond human comprehension. Thus, computer simulation modeling becomes a useful tool for understanding these large (10^5–10^7 ha), long-term, complex systems. With modeling techniques, it is possible to describe the modeled components and relationships mathematically and logically and deduce results that cannot otherwise be investigated.[16,17]

A specific definition of a landscape model is one that simulates spatiotemporal characteristics of at least one recurrent landscape process in a spatially interactive manner.[15] The term spatially interactive means that a simulated entity (e.g., a pixel or polygon) is a function of neighboring, or spatially related, entities. A landscape model under the specific definition has the following characteristics: 1) it is a simulation model, 2) it simulates one or more landscape processes repeatedly, and (c) it operates at a large spatial and temporal extent that is adequate to simulate the landscape process.

Landscape models applications generally fall in the three categories: (1) spatiotemporal patterns of landscape processes, (2) sensitivities of model object to input parameters, and (3) comparisons of model simulation scenarios.[15]

The direct outputs of landscape models are the spatiotemporal patterns of the model objects because the modeled spatial processes are stochastic and complex, and understanding their manifestations over space and time is necessary. Thus, the most effective method is to simulate spatiotemporal patterns of the model objects using built-in model relationships and parameters related to the model objects.

The lack of management experience at the landscape scales and the limited feasibility of conducting landscape-scale experiments have resulted in increasing use of scenario modeling to analyze the effects of different management actions on focal forests and wildlife species. Model scenarios are created by altering input parameters to reflect changes in climate, disturbance, fuel and harvest alternatives. The built-in model relationships remain unchanged. Comparing results from different model scenarios provides relative measurements regarding the direction and magnitude of changes within the simulated landscape.

**CONCLUSIONS**

Landscape will continue to be a unit in nature where natural and anthropogenic disturbances operate and interact. Such interactions may alter natural landscape succession, lead to landscape fragmentation, result in loss of species diversity, reduce hydrological functions, and cause other types of natural resource degradation. Because of the large spatiotemporal dimensions and numerous variables and processes involved in landscape succession, landscape modeling becomes a necessary tool in defining modeled components and relationships mathematically and logically and deducing results that cannot otherwise be derived. Landscape models will be increasingly used in predicting the future landscape change under various climate change and management scenarios.

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