LANDSCAPE DYNAMICS

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Keywords: agriculture, biodiversity, disturbance, fire, landscape pattern, land use, modeling, restoration, riverscape.

Contents

Summary

Change is one characteristic of landscapes; those changes are driven by and drive many ecological processes such as species movement, and physical flows. Moreover, human activities are important drivers of changes. Observation and understanding of changes are prerequisite to management of natural resources. Scale dependence is a remarkable feature of landscape dynamics and needs to be broadly defined.

Different analytical tools are used to detect changes: photos, census, and maps all bring in different type of information.

Understanding human activities requires interviews with land managers to decipher land use allocation decisions. These permit general rules to understanding and modeling of

changes. Land use constraints are general in agricultural landscapes and explain the fate of landscape structures. It also explains the interactions between the cultural and ecological parts of landscapes. Landscape dynamics can be used in ecological restoration as a mean of facilitating recolonization and creation of novel habitats.

Landscape modeling based on decision rules offers new perspectives in scenario building for both research and discussions with stakeholders and land managers.

1. Introduction

Landscapes change—they vary in space and time. No landscape remains static, though the time scales of changes vary from month to millennia. Those changes are interesting *per se* and are important as drivers of different aspects of ecological processes, including biodiversity. Thence acquiring knowledge on landscape changes and factors of those changes is an important question for the understanding and the management of our environment.

Spatial variations of landscapes are often related to change in the driving forces shaping them. Those driving forces act at many different scales from the global climatic scale to the very local harvest of a wheat field by a farmer. In between geological processes, public policies and socio-economic processes control landscapes. In landscape ecology the spatial extent of areas to be studied varies from one to several square kilometers. Within that extent, ecologically and human driven changes are the matter of concern.

In this chapter, a clear distinction is made between human-dominated and non-human dominated landscapes, and, within the first category between terrestrial and riparian/fluvial landscapes. The reader has to keep in mind that divisions are not so sharp. Global human-driven processes, such as climate changes, nitrogen deposition etc., influence all landscapes. Human-dominated landscapes are not free of ecological processes. Terrestrial and riparian landscapes form a continuum but, in practice, are analyzed separately.

As demonstrated elsewhere in EOLSS, landscapes patterns have an enormous impact of plant and animal populations, on colonization of new habitats, and so forth. Landscape dynamics change the flow of disturbances, the relationships between potential sources of seeds and suitable habitats, interactions among preys and predators, and most trophic flows. Examples are provided in the last section devoted to landscape ecological processes and ecological restoration.

If we study landscape dynamics rather than the dynamics of distinct parts, elements of landscapes, it is because of this importance of landscape structure. In other words, we must change the scale of observation for a better understanding of ecological processes. Biological and ecological heterogeneities over a range of scales interact to drive the fate of biodiversity or nutrient fluxes. Landscape dynamics, itself, like other landscape scale processes exhibit many phenomena of scale dependence, i.e. the observed values change according to the scale of measurement. Therefore, I present some references to scaling issues before entering the subject.

The objective is not to make a literature review, but rather, by using examples in different landscapes, to provide the reader with methods and general concepts on landscape dynamics.

1.1. Scaling issues

For two decades "scale" has been a keyword of growing importance in ecology (Allen and Starr 1982). This trend stems from both the recognition of space as a key component of ecological processes and from developments of hierarchy theory. These two aspects are often mixed as spatial patterns most often generate distinct levels of organization that should be treated separately. In fact, the levels of organization we distinguish are often a product of our own perspective rather than from biological or ecological processes. Due to the differences in size between species, some individuals of a species may contain communities of other (smaller) species, for instance lichen communities live on single trees.

To consider time and spatial scales we need to address the question "when designing restoration how does the outcome of the dynamics we initiate vary with site size, surrounding landscape, and its history? How does that affect the prediction on the outcome of the operation?" Imagine we restore a site that is totally autonomous, i.e. independent of its own geometric characteristics and of the surrounding landscape elements; only very local characteristics would affect ecological changes.

This has been the paradigm for decades in study of plant successions; they were supposed to be driven by internal factors, not by flows of propagules moving across landscapes. Within this framework, species composition at one point of time mostly depends on species composition from an earlier time, e.g. as in the concept of intitial floristic composition (Egler 1954). Thence changes leading to some type of equilibrium were supposed to be the outcome. This standpoint does not hold any more as the importance of surrounding landscape for plot dynamics has been demonstrated (Dale *et al* 2000). Scaling issues are thence crucial to understanding and managing ecosystems (Gordon *et al* 1997).

1.1.1 Definitions: scale and level of organization

This is a difficult point, as definitions seem to vary. "Small" and "large" scales have in geography and common sense opposite meanings. In geography, it is the ratio between the size in the real word (in nature) and the size on the map. Therefore, the scale on a 1/25 000 map is larger than on a map of 1/1 000 000, though the space represented on the map is smaller on the first map. In landscape ecology, "scale" also refers to the grain that is the resolution (sample size) of observations (every day/ every year, $1m^2$/ $1km^2$).

If the unit in space or time is small (one day vs. one year, one ha vs. one km^2) we say it is "fine grain", if the unit is large, it is "large" grain. The extent of observation also varies in space (a field, a region) and time (observations over a year, a decade). As a general rule, as in cartography, extent and grain are correlated. Observations on a small area are at a finer scale than over a large area, for instance on topographic or road maps, the area is smaller on a 1/25 000 maps than on a 1/100 000 maps, though there are exceptions.

According to Allen (1998) levels of organization are objects constructed by the observer beforehand. Objects such as “individual”, “population”, community”, “ecosystem” and “landscape” are such constructs, independent of observation scale. An individual may be of the size of a flea or an elephant. A lichen and a tree are both levels of organization. In practice, levels of organization are constructed so that individuals are parts of populations that are parts of communities. Other authors, such as Krummel *et al* (1987) pose that “levels of organization” emerge from scale dependencies. A change in the slope of the relationship “intensity of a phenomena/ grain” corresponds to a change of level of organization. Thence, when analyzing the vegetation of a small region, the humidity gradient may be the best predictor of the observed diversity. If the area of study is extended to the region, climate may become the best predictor. At a fine scale (smaller area) differences in grazing pressure may explain differences in vegetation.

1.1.2 The fields of ecological theory related to scaling issues

In the course of the development of ecology during the twentieth century, some authors have considered the spatial dimension of the processes they were studying. Watt (1947) was among the first to describe the life cycle of beech (*Fagus sylvaticus*) and heather (*Calluna vulgaris*) populations by demonstrating that the different stages form a mosaic. A full account of space was possible when MacArthur and Wilson (1967) set the theory of island biogeography to explain species richness differences between islands.

The theory predicts that large islands close to continents have more species than small islands far from mainland. When applying this theory to small woodlands, considered as “islands”, Forman *et al* (1976) gave a great impulse to the development of landscape ecology. Twenty years later this may be a too simplistic view of fragmentation, but it was an important milestone for the understanding of the spatial components of habitats. Regarding our theme of landscape dynamics, the point is that “fragmentation” as a state of landscape components became a process.

Hierarchy theory stems from research on complex systems. The broad predictions of this theory provide a schematic view: Complex systems can be described as a set of hierarchically nested entities. For entities at lower level, entities at higher level can 1) be a functional context, 2) exert a control on, 3) be a constraint on, 4) have a slower time constant, 5) have less high linkages among elements. We use these concepts latter.

2. Landscape changes in the wilderness

The understanding of changes in landscapes where human impact is at a minimum (no use of the land by people) is a way to analyze the role of disturbances that change landscapes. For instance, the study of the consequences of the grand fire of 1988 in Yellowstone National Park (USA) led to many surprises (Turner *et al* 2003). Thence, it is worthy to give an overview of that research.

Fires and storms are major events that drive landscape dynamics. There are also biological processes such as in beaver ponds (Figure 1) or insect outbreaks.

Figure 1. A succession of beaver ponds: in the forefront an active pond with a beaver hut, in the center, an abandoned pond. Algonquin Provincial Park, Ontario, Canada.

Figure 2. Elk grazing in post fire vegetation, Yellowstone National Park, August, 1994.

Research in the late 1970s on landscape dynamics in Yellowstone National Parks started to assess the importance of fire in landscape dynamics. Fire is an important driving force that occurs naturally (Figure 2). Though the policies to combat fire were somewhat less enforced than in other parks, human intervention had decreased its intensity after 1945. In 1988 a wildfire burnt a quarter of the Park area. Intensive studies of ecological changes were set up. Turner *et al* (2003) summarize the main results. From a landscape perspective, the main outcome is that fire increased landscape heterogeneity. Even if burning was intense, the most burnt areas were within 50 to 200 m of unburned or slightly burnt areas, a potential source of seeds for forest recovery. This heterogeneity is a source of biological diversity and of forest capacity to recover in keeping heterogeneous vegetation for maybe a century or so.

The recognition of the role of disturbances in the dynamics of natural landscapes is rather new (Pickett and White 1985). It has implication in terms of management, especially on the size of protected areas that should be large enough to encompass the size of major disturbing events.

3. Human driven changes

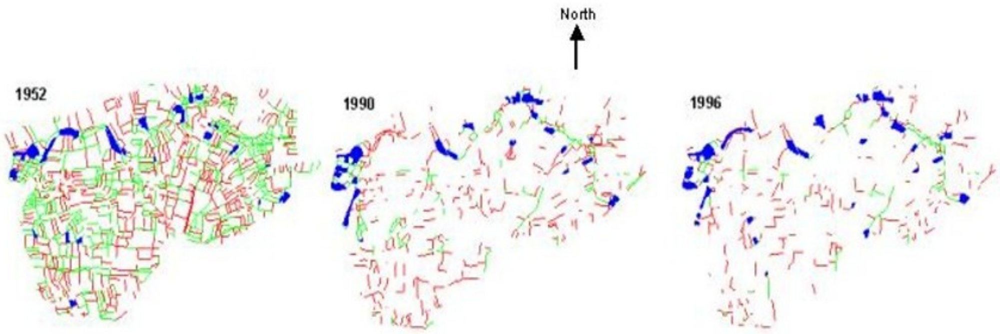
Crumley and Marquardt (1987), in their analysis of the dynamics of Burgundy (France) landscapes, define the relationships between landscape and society: "*people make their territories, houses, living spaces and work spaces, their own by consciously modifying them in terms of their effects on the senses, their utility, and their economic value. The landscape is the spatial manifestation of the relations between humans and their environment*". We take this as a definition of a cultural landscape, made and remade over centuries, changes to which we are very sensitive. Beyond the visual, the cultural and ecological values are important.Two questions must be addressed: how much do they change and why? We deal with the first question in the previous paragraphs. To the second question many answers pop up: agricultural intensification, economic development, etc. We must go beyond and seek the mechanisms of changes; this is what we attempt with agricultural landscapes.

3.1. Landscape change at multiple time scales

3.1.1 A visual approach

Let us start with a look at landscape photos and maps over different periods of time (scales). The first set of photos is the reconstruction of the aspects of a landscape based on air photos (Figure 3). The next (Figure 4) is a set of maps representing the changes in a hedgerow network landscape. It has the expected characteristics of diminishing hedgerow density, from 110 km to 26 km in less than 45 years in an area of about 5 km². The maps and the photos give two aspects (a visual one and a quantitative one) of the same phenomenon (hedgerow removal) in the same landscape. Then, Figure 5 presents a set of air photos and their translation into land use maps of a small area. Due to the process of crop rotation—a basis for good agricultural practices—the landscape changes from year to year. On the photos, one can also see part of the cycle of pruning and regrowth of hedgerow trees.

Figure 3. Photographic reconstitution of change sin a hedgerow network landscape of northern Brittany (France) between 1952 and 1995. Source: Centre National de documentation Pédagogique.



	1952	1966	1982	1990	1996
Hedgerows with continuous tree cover (km)	61,50	35,75	18,50	12,00	7,00
Hedgerows with non-continuous tree cover (km)	58,00	52,25	31,00	27,50	19,50
Woodland (ha)	15,25	15,50	19,50	15,25	18,25

Figure 4. Maps of changing hedgerow networks.
Source: Morant and Cotonnec 2003)

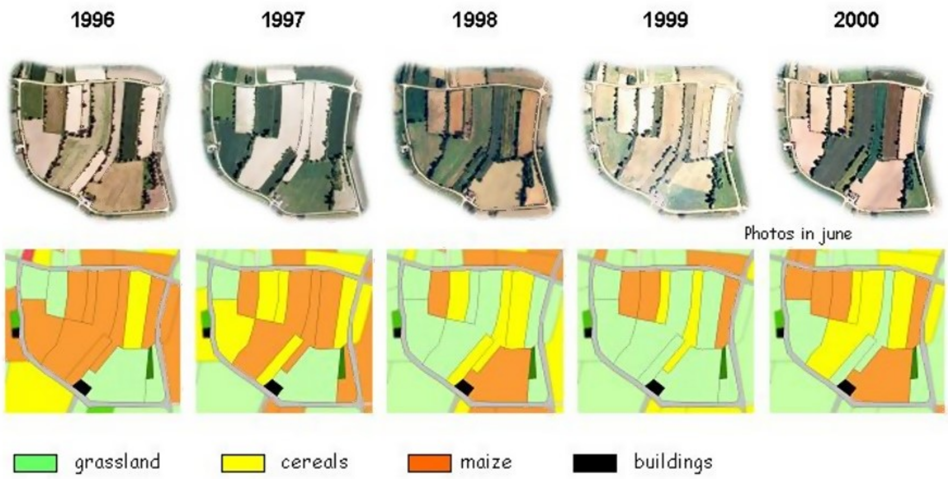


Figure 5. Air photos and mapping of crops over a five-year period in a Brittany landscape.
Source: M. Reboux, INRA, unpublished.

Figure 6. Photos of seasonal changes in a Brittany landscape. (Photos, Caren Y. Rantier)

The last set represents landscape changes within a year (see Figure 6). Drastic changes in ground cover and vegetation density become apparent. At these different time scales, changes in extent (from year to decades) and grain (month to decade) vary, creating different ecological conditions (standing biomass, type of cover, etc. Some conditions, e.g. seasonal variation from year to year or crop rotation, come back in a cyclic manner, while others change “definitively”, i.e. over a larger time scale (changes in crop type, hedgerow density etc.).From this introductory visual approach, one can expect scaling effects: at fine scale, changes are rapid, while those observed at a larger extent may be slower; if in a given part of a landscape, crops change from year to year, one would expect that if observed at on a larger area, the changes are slight, because farmers approximately need the same crops from year to year. Different fields have different crops in a given year and a different crop the year after, but the overall area of the different crops stays similar. Thence only changes in production systems will be detected.

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Biographical Sketch

Jacques Baudry is currently director of the SAD-Armorique, a research unit of the National Institute for Agronomic Research (INRA). The unit develops projects on the relationships between changes in farming activities, landscape dynamics and ecological processes.

An Engineer in Agronomy, and a doctor in ecology, he has worked as a consultant in rural management. He then completed a post-doctoral thesis with Richard Forman at Rutgers University (USA) and Michel Phipps at the University of Ottawa (Canada). There, he started his first work in landscape ecology in hedgerow networks and plant species movement and on the factors driving land use changes.

Once working for INRA, he studied connectivity, with species colonization of abandoned land as a model.

He has worked with Catherine Laurent, an economist, on the causes of land abandonment. Thence, he could develop research on the two aspects of landscape ecology: the ecological importance of landscape structures and drivers of changes of those structures. Methods and results are exposed in his book "Landscape Ecology", co-written with Françoise Burel and published by Sciences Publisher (USA).

Since 1993, he has been the coordinator of a long-term socio-ecological research (LTSER) project on bocage (landscapes characterized by hedgerows) the goal of which is to comprehend the role of human activities as driving factors of landscape and ecological changes. Ecologists, agronomists, geographers, hydrologists, archeologists, historians, psychologists, sociologists, and law scientists are involved in the various projects. He also coordinates national programs on biodiversity in agricultural landscapes for the Ministry of Environment.

He is a member of the scientific committees of several programs for the Ministry of Environment. He is also a member of the editorial board of Journal of Applied Ecology, Landscape Ecology, Journal of Land Use Systems and BMC-Ecology

His current interests are to formalize farming activities at various time scales as variables controlling ecological processes.