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Chapter 1. Forest landscape ecology and global change: an introduction

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Abstract

Forest landscape ecology examines broad-scale patterns and processes and their interactions in forested systems, and informs the management of these ecosystems. Beyond being among the richest and the most complex terrestrial ecosystems, forest landscapes serve society by providing an array of products and services, and if managed properly, can do so sustainably. In this chapter, we provide an overview of the field of

forest landscape ecology, including major historical and present topics of research, approaches, scales, and applications, particularly those concerning edges, fragmentation, connectivity, disturbance, and biodiversity. In addition, we discuss causes of change in forest landscapes, particularly land use and management changes, and the expected structural and functional consequences that may result from these drivers. This chapter is intended to set the context and provide an overview for the remainder of the book, and poses a broad set of questions related to forest landscape ecology and global change that need answers.

1. A brief history of forest landscape ecology

Before we can discuss landscape ecology, it is necessary to define what we mean by a *landscape*. Although this term has been given different interpretations by authors from different backgrounds, in the ecology literature, a landscape is most often considered to mean an area that is heterogeneous in at least one factor of interest (Turner et al. 2001). A landscape perceived by land and natural resources managers, for example, is usually a broad-scale mosaic of land-use and cover types that are strongly interconnected and are functioning as a single unit. Watersheds represent a good example of a landscape because, despite the diversity of ecosystems and land uses within any given watershed, all components of the watershed are interconnected, such that changes in one component affect all other components either directly, or indirectly for a change is transmitted through intermediate components.

Landscape ecology emerged in central Europe in the 1930s following the development of ecology as a separate branch of science. At the beginning of the 20th century, forests in Europe often consisted of fragments or remnant woodland patches in landscapes dominated by other land uses, typically agriculture and urban, but were nonetheless important in the functioning of ecosystems and the landscape, particularly in terms of water, soil, and wildlife conservation. Through recognition of these functions, forests became key units in land-use planning, which was one of the major applications of landscape ecology in Europe during the 20th century (Naveh and Lieberman 1994). Historically, the study of forests within a landscape context has also been addressed from the perspective of plant ecology in terms of plant communities with inherent temporal and spatial patterns (Turner 1989).

It was only in the 1980s that forests were addressed explicitly as landscape systems—as dynamic mosaics of interacting landscape units, patches, tree cohorts, or stands. Several factors contributed to this evolution. First, the establishment of a conceptual framework for the science of landscape ecology (Zonneveld 1990) provided the theoretical grounds for formally addressing and testing scientific hypotheses about landscapes, including forested landscapes. Second, the increasing availability of technology for data collection, storage, and analysis made it possible not just to process the large amounts of data associated with extensive and heterogeneous land areas, but also to incorporate spatially explicit methodological approaches, including spatial modeling of landscape structures and functions, into research (Mladenoff and Baker 1999b, Turner 1990). Third, many recent developments in landscape ecology occurred in regions where landscapes were predominantly forested, such as North America and Australia, which resulted in a high proportion of landscape ecology studies being conducted in forested landscapes (Perera et al. 2000). Fourth, forests are particularly interesting to ecologists because of their high spatial and vertical heterogeneity and the resulting complexity and high levels of species diversity they contain. They became particularly attractive for ecologists with an interest in the relationships between landscape patterns and biological diversity (Hunter 1990, Lindenmayer and Franklin 2002, With 2002).

Last, and particularly important in the context of anthropogenic landscapes, forests have a high social and economic value, both from a traditional timber-based economics perspective and from the more contemporary perspective of a sustainable, multifunctional ecosystem that provides crucial services for society. Globally, forests are now managed to ensure a sustainable production of commodities that combine conventional forest and non-forest products and ecosystem services. The landscape scale has become a required component of planning to address sustainable forest management, and forestry professionals started incorporating a landscape approach (Schlaepfer and Elliott 2000). As a reaction to this paradigm shift, a landscape perspective was also incorporated into silviculture by explicitly developing silviculture models and practices at this scale (Boyce 1995, Oliver and Larson 1996).

From 9366 publications selected by searching the Web of Science database (http://thomsonreuters.com/web-of-science/) in 2013, with all years included and with “landscape” and “ecology” as search terms, we found that 3290 (35% of all landscape ecology publications) dealt with forests. This proportion is only approximate, since publications dealing with landscape ecology or forest landscape ecology do not necessarily include these terms in the abstract or keywords, but it shows the relative importance of forests within the field of landscape ecology. In the journal *Landscape Ecology*, 46% of all the publications since 1987, the journal's first year of publication, included the term "forest" in the text. The number of forest landscape ecology publications has grown considerably over time, from 5 in 1988 to 316 in 2012. Around 15% of the publications are from a forestry perspective, with the remainder focused on ecology and conservation. In addition to publications in scientific journals, numerous books have been devoted to forest landscape ecology, including collections that resulted from forest landscape ecology conferences (Lafortezza et al. 2008, C. Li et al. 2011) and works dedicated to the ecology of forest landscapes, to the application of principles and methods of landscape ecology to the practice of forest planning, management, and conservation, and to a broad range of closely related theoretical and applied subjects (e.g., Hong et al. 2007; Kohm and Franklin 1997; Lindenmayer and Fischer 2006; Lindenmayer and Franklin 2002; Perera et al. 2000, 2004, 2006).

It appears that the majority of forest landscape ecology research has occurred in North America, since 58% of the publications stem from the United States and Canada. However, this field is rapidly expanding to new regions and new forest systems around the world, where it is contributing to a better understanding of landscapes and is supporting sounder forest management. This geographical shift creates challenges for the science of landscape ecology because it addresses the dynamics of highly complex and insufficiently understood systems and their responses to drivers of change. The new frontiers of forest landscape ecology include countries such as Brazil, Spain, and China. In Brazil, for example, the study of forest landscape ecology has grown rapidly in recent years, mainly within the fields of conservation biology (Lantschner et al. 2012, Tabarelli et al. 2004, Zanella et al. 2012), landscape dynamics (Freitas et al. 2010, Laurance et al. 1998, Lira et al. 2012), and forest management (Amaral et al. 2009, Brockerhoff et al. 2013).

2. A definition of forest landscape ecology

Despite the importance of forest landscapes in the development of landscape ecology and the emphasis on a landscape scale in research on forest conservation and management, forest landscape ecology has not become an independent field. For the most part, it is still mostly landscape ecology in a forest context, or a subset of landscape ecology that addresses relationships "in spatial geometry among forest elements" (King and Perera 2006) and how patterns and interactions affect forest processes and dynamics in heterogeneous forested areas. No major conceptual distinction is usually made between forest landscape ecology and the ecology of other types of landscapes, and the approaches, scales, and methods used are similar to those used in any other field of landscape ecology (e.g., Chen et al. 2008). Forest landscapes are also often defined in terms of conventional landscape ecology concepts, frameworks, and indicators, with an emphasis on the large extent of the landscape, the dominance of forest land cover types (despite the potential presence of non-forest elements), and high heterogeneity that produces a mosaic-like structure (King and Perera 2006, Perera et al. 2006, Perera and Euler 2000).

Although forest landscape ecology is part of the broader science of landscape ecology, it has a very well defined context and distinctive research issues and concerns. Forest landscape ecology has gained its own identity from the nature, type, and scales of the subjects of study and the issues and questions about the ecology of forest mosaics, within which management is a central component. One major element of this identity relates to the fact that landscapes with contiguous forest differ from landscapes where the forest cover exists only as patches in a matrix dominated by other types of land use or cover. Dynamics in contiguous landscapes, although preserving structural stability at the landscape scale, cause changes in ecosystems at the local scale. Patches and edges are, therefore, not spatially fixed structures in contiguous forest landscapes, since they change over time. As a result, fragmentation is often temporary, except when it is associated with a long-term trend of landscape change. This has caused the conceptual basis of forest landscape ecology to be supported by systems ecology, percolation theory, and disturbance or resilience perspectives more than in other fields of landscape ecology.

Most forests are managed, and for that reason, forest landscape ecology has commonly dealt with managed forests and management-related issues, with an emphasis on the causes and effects of management (Perera and Euler 2000). This is possibly one of the most distinctive aspects of forest landscape ecology. It is, therefore, not surprising that forest landscape ecology has gained attention outside of academic ecological circles, such as in the forest industry and in national and regional administration of forests.

Forest products companies address the landscape scale in forest management that is performed under sustainable forest management certification programs (Ferraz and Ferraz 2009). Federal and national agencies have incorporated the landscape scale in forest policy and management since the 1990s, following the emergence of novel management concepts such as ecosystem management and adaptive management (Rauscher 1999).

Many of the research issues in forest landscape ecology address either how management affects landscapes or how landscape-level patterns or processes affect forest management. The field can therefore provide a solid background to inform forest and landscape management based on landscape ecology principles (Gustafson and Diaz 2002). Management must also be accounted for in the context of other drivers of change that affect the structure, processes, and responses of the landscape at a variety of scales.

3. Major research topics in forest landscape ecology

Wu and Hobbs (2002) proposed the following as the top 10 research issues in landscape ecology: ecological flows in landscape mosaics; the causes, processes, and consequences of land- use and land cover change; nonlinear dynamics and landscape complexity; scaling; development of new methods; relating landscape metrics to ecological processes; integrating a description of humans and their activities into landscape ecology; optimizing landscape patterns; landscape sustainability; and data acquisition and accuracy assessment. These have all been addressed in forests as well as in other landscape types. In all journal publications concerning forest landscape ecology that have been published since 1987, the terms most frequently used are habitat (52% of publications), pattern (45%), scale (41%), management (38%), change (37%), conservation (36%) land use (28%), fragmentation (26%), patch (22%), disturbance (21%), edge (11%), heterogeneity (11%), and connectivity (8%). Of these, we consider edges, fragmentation, connectivity, disturbance, and biodiversity to be essential topics in forest landscape ecology, and in the rest of this section, we will briefly discuss why they are important and will provide links to the other chapters of the book, where relevant.

3.1. Edges

Edges have attracted more attention from forest landscape ecologists than from other ecologists (Donovan et al. 1997, Harper et al. 2005). Edges, created by disturbance and patterns in the distribution of resources, affect the physical environment (Chen et al.

1995), the composition and distribution of communities (Fraver 1994), and many ecological processes (Chalfoun et al. 2002) that function across adjacent patches. Although edge effects are local, they have cumulative effects through their influences on the abundance and spatial pattern of interior forest habitats and associated species (Gustafson and Crow 1996). In the literature, forest edges have been considered mostly from the perspective of biodiversity conservation based on their effects on the availability and quality of forest habitat and the spatial distribution of species (Ries et al. 2004).

Forest edges first became a relevant issue in the context of harvesting and management of pristine or other forests, particularly on the western coast of North America (Chen et al. 1992, Franklin and Forman 1987). This focus spread to other parts of the world (Alignier and Deconchat 2011, Tabarelli et al. 2004, Williams-Linera et al. 1998). The seminal paper of Franklin and Forman (1987) addressed how the size and pattern of harvesting units potentially affected landscape structure and key processes related to edge effects and biodiversity, and this remains an important field of research, as edges remain dominant features in managed landscapes. Knowledge generated since Franklin and Forman's paper was published has supported the development of management guidelines for forest landscapes (e.g., FSC 2010).

3.2. Fragmentation and connectivity

Fragmentation has shaped landscapes in many parts of the world for thousands of years due to the effects of land-use conversion and land degradation once humans became major drivers of landscape change. However, it is the ongoing fragmentation in forest landscapes in North and South America, Asia, and Oceania that raises concerns among scientists and conservation and management authorities, given the potential of this complex process to cause a loss of species and degradation or loss of key ecosystem functions (Hill et al. 2011, Laurance et al. 2011, Riitters et al. 2002, Saunders et al. 1991, Skole and Tucker 1993). As a subject of research, fragmentation has created a common ground for the integration of disciplines such as ecology, management, and social sciences within a common framework, in which the search for relationships between social and ecological patterns and processes at multiple scales has become a major goal.

Research on fragmentation is challenging given the multiple interactions among the structural components, such as habitat area, patch size, number, shape, perimeter–area ratio, edge abundance, distance or isolation, and connectivity in fragmented landscapes, as well as between these factors and ecological processes that are affected by the degree of fragmentation. On the other hand, this research provides fundamental support for efforts to halt fragmentation and to ensure that essential ecological functions are maintained in fragmented landscapes. Knowledge of fragmentation, in both structural and functional terms, is abundant and has solid theoretical support (Fahrig 2003, Forman 1995, Forman and Godron 1986, Lindenmayer and Fischer 2006).

Connectivity is a major goal in landscape systems, particularly when they are managed, as connectivity is necessary to provide pathways for movement between habitats for animal and plant species and to contribute to the maintenance of biodiversity at all scales (Lindenmayer and Fischer 2006). Connectivity is, therefore, a general component of sustainable landscapes (Forman 1995), and is now considered to be an essential target in forest management and conservation (Lindenmayer and Fischer 2006, Lindenmayer and Franklin 2002, Loyn et al. 2001). Connectivity has been traditionally considered from a structural perspective, although the concept was originally formalized as a process-oriented factor (With et al. 1997). The analysis of connectivity has evolved towards a more functional approach based on the traits of particular species of interest (Taylor et al. 2006). Attempts to combat the effects of fragmentation often rely on the creation or maintenance of structural connectivity between particular ecosystems in the landscape, usually through corridors, "stepping stones", or "green infrastructures" (Franklin et al. 1997, Lindenmayer and Franklin 2002, Zanella et al. 2012). In sustainable forestry, riparian management zones and wildlife corridors (for example) are used to provide habitat that permits movement of organisms among habitat patches and across landscapes driven by forest management. These features are fundamental for complying with sustainable forestry and certification programs (e.g., FSC 2010).

Connectivity research has been an important component of landscape ecology, and has produced a set of theoretical, methodological, and application tools for evaluating this attribute and testing hypotheses concerning its role in ecological processes (e.g., Saura 2008, Saura et al. 2011, With 2002). Fragmentation and connectivity and their effects on biodiversity are analyzed in detail in Chapter 7 of this book.

3.3. Disturbance

Given its significance in landscape dynamics and forest management, disturbance is another important factor in landscape ecology research. Forest management has been defined as “the management of disturbance and succession to achieve specific vegetation and ecological conditions that in turn support the products and benefits sought by the manager” (Gustafson and Diaz 2002). Management focuses on broad-scale processes based on the temporal and spatial dimensions of disturbance, which affect the configuration and functioning of the forest landscape. Much of forest landscape ecology research has dealt with disturbance, whether natural or anthropogenic in origin. Disturbance generated by natural causes (e.g., fire, hurricanes, pests) or by clearcutting and other silvicultural models (Z.H. Liu et al. 2012, Perera and Buse 2004) is a major source of patterns, processes, and dynamics in forest landscapes. Disturbance regimes or management plans determine the composition and configuration of forest landscapes (Mladenoff et al. 1993, Wallin et al. 1994) and affect the processes that shape the distribution of populations and communities, genetic flows, water yield, soil erosion, and productivity, among other factors, at stand and landscape levels (Burton 1997, Saura et al. 2011). On the other hand, the frequency, intensity and extent of disturbances are affected by the structure of the landscape (Cumming 2001).

Efforts to integrate natural disturbance patterns into forest planning and management include several approaches; Perera et al. (2004) and North and Keeton (2008) provide an overview of the roots, principles, methods, and applications of emulating natural disturbance. However, this approach is based on the idea that the spatial and temporal attributes of natural disturbance events can provide a template for forest management and can guide the definition of management strategies and practices. For example, in a forest management plan, clearcut size could be defined based on the statistical distribution of the size of burned areas, and rotation length could be combined with size based on a consideration of the fire recurrence interval. This would contribute to maintaining the structure and functioning in a managed forest landscape such that it resembles that of a natural landscape. This is assumed to result in a sustainable forest landscape. Chapter 3 in this book covers the specific case of fire at the landscape level.

3.4. Biodiversity

Biodiversity, whether in natural systems or in the context of forest management, has become a major component of forest landscape ecology (Fahrig 2003, Zavala and Zea 2004). Species diversity is a key component of ecological systems and is fundamental for providing most ecosystem services (see chapters 5 and 7). Ecosystem diversity is an important element of landscape structure and complexity and is one of the most commonly measured landscape attributes, usually through indices based on information theory. Principles, guidelines, frameworks, strategies, and practices proposed for the conservation of biodiversity in forests often are applied at the landscape scale (Gustafson and Diaz 2002, Hunter 1990, Lindenmayer and Franklin 2002, Lindenmayer et al. 2006, With 2002). In addition, the landscape level is a fundamental requisite for biodiversity conservation in the context of sustainable forest management programs (Montréal Process 1999) as well as in the context of land-use and climate change (Araujo et al. 2011).

4. Forest landscape ecology and change

Change is an intrinsic characteristic of landscapes, which is why change is part of the definition of landscape ecology (e.g., Forman and Godron 1986). Since both patterns and processes evolve over time, this dimension must be directly or indirectly considered in research methods and applications. Change has attracted additional interest in recent years due to the rapid transformations that many landscapes are exhibiting and to the consequences that these changes are expected to have on ecosystem services and human well-being (Hassan et al. 2005).

In forest ecology, change has been historically addressed mainly from an aspatial, community or stand, perspective and has been frequently based on the concepts and theories of ecological succession, climax communities, and disturbance. Although disciplines within geography and ecology, such as phytosociology and phytogeography, deal with the distribution and temporal patterns of plant communities at broad spatial scales (Turner et al. 2001), such changes in forest systems were not explicitly addressed until the 1980s (Bormann and Likens 1994, Mladenoff and Baker 1999a, Sprugel 1991, Turner et al. 1993). Since then, several methods and models that account for changes in forest landscapes have undergone rapid development (Mladenoff 2004, Xi et al. 2009), making possible not just the modeling of spatial patterns and processes but also the application of these tools in management-oriented simulations.

4.1. Landscape dynamics

All landscapes are dynamic, since both their structure and how they function change over time. However, under many natural conditions, these dynamics are relatively stable over time, with the landscape reaching and maintaining an equilibrium state. For instance, see the shifting mosaic steady-state concept of Bormann and Likens (1994) and the review by Turner et al. (1993). Increasingly often, however, forest landscape change is driven by anthropogenic disturbances such as harvesting (Gustafson and Diaz 2002), by human-mediated disturbances such as fire (Moreira et al. 2011), or even by land-use change through the expansion of agriculture or urban areas (Meyer 1995). These changes often push the landscape dynamics away from a more stable condition (equilibrium).

Whereas landscape dynamics occur mostly at a micro-scale (1 to 500 years; 1 to 10^6 m^2) in the conceptual temporal and spatial ecological framework of Delcourt et al. (1982), some landscape change events occur at a meso-scale (500 to 10 000 years; 10^6 to 10^{10} m^2). Meso-scale processes relevant for forest landscape change include long-term changes in vegetation cover, and are driven by anthropogenic factors and by climate change (e.g., land-cover changes throughout the Holocene). Major proximate drivers of forest landscape change have also acted at this scale, including historical land-use and cover change, habitat loss and degradation, and habitat fragmentation.

At the micro-scale, forest landscapes are affected both by physical environmental change, particularly through climate cycles (temperature and precipitation) or climate change (see Chapter 2), and by disturbance in the form of major proximate and anthropogenic drivers of forest landscape change (e.g., land-use and cover change, habitat loss, degradation, fragmentation, introduction of invasive species). Other major change events include disturbances such as fire (Turner et al. 1994), pest or pathogen outbreaks (Kelly et al. 2008), and windthrow or timber extraction (Bormann and Likens 1994, Delcourt et al. 1982).

Many of these processes are directly or indirectly driven by human activities. However, the ultimate driver of change in modern forest landscapes is human population growth (Groom et al. 2006, Meyer and Turner 1992). The world's population has grown from 1×10^9 inhabitants in 1800 to more than 7×10^9 today (UN 2011). Population will continue to increase in most regions of the world except Europe and Japan, where significant decreases are expected. The future population may be as high as 11×10^9 in 2050 and 16×10^9 in 2100 (UN 2011). Less-developed regions, which currently host 82% of the world's population, are growing at a much faster pace (UN 2011).

Landscapes of regions with fast population growth will likely suffer more drastic changes, mainly through land-use change, degradation or destruction of forest ecosystems, and increased forest fragmentation. These processes, combined with climate-driven change, may have disastrous consequences for a wide range of ecosystem services and, eventually, for human well-being (Leadley et al. 2010). Although there are many examples of changes in forest landscapes driven directly by recent population growth (Bradshaw 2012, Zhao et al. 2013), rural depopulation and the concentration of populations in cities may contribute more strongly to forest landscape change than was previously expected (DeFries et al. 2010).

4.2. Drivers and consequences of landscape change

Though most of the drivers discussed in this chapter affect landscapes at the micro-scale, long-term land-use change occurs at the meso-scale. Forest management simultaneously deals with the micro-scale (forest stands, planning units) and the meso-scale (forest estates, planning regions), but the majority of changes in forests, their causes, and their effects, are increasingly addressed at the latter scale. In particular, landscape-dynamics processes contribute to the long-term stability of landscapes; that is, they do not significantly affect landscape structure and functioning over time, at least in comparison with natural trends driven by large-scale factors such as climate. However, most processes that occur at multiple spatial and temporal scales drive change towards new states, with new patterns and functions, and this has implications for the services provided by forest landscapes. In this section, we will analyze two recent (or recently studied) factors that are both drivers of landscape change and major research and management challenges: land-use change and changes in forest management concepts and practices.

4.2.1. Land-use change

Driven by social, economic, or political factors and influenced by environmental constraints, land uses have been profoundly modified throughout history in most parts of the world. These changes are an ongoing process that is continuing to affect ecological processes (FAO 2012), making this topic of interest both generally and in landscape ecology (August et al. 2002). The study of land-use change is complex because of the many factors (drivers) and the interactions among them that operate at multiple temporal and spatial scales and because of the diversity of physical and biological factors that are affected by the changes (Lambin et al. 2003). In addition to the direct local effects of land-use change, large-scale effects on both patterns and processes are expected to occur at landscape, regional, and global scales. Moreover, the relationship between land-use change and changes in landscape patterns and processes is not linear. One of the consequences of this non-linearity is that changes in land use can have larger-than-expected effects on the structure, and concomitantly on the functioning, of forest landscapes. We will briefly discuss several land-use change processes that have affected forest landscapes in recent decades: agricultural expansion and intensification, agricultural abandonment, deforestation, and forestry intensification.

The expansion of agriculture has affected forest landscapes more strongly than just about any other factor during the last 10 000 years. The majority of agricultural land has been established on forest soils, leading to a decrease in forest area from 6×10^9 ha to the current level of 4×10^9 ha (FAO 2012). In Europe and parts of North America and Asia, this transition occurred in historical times and is largely finished, but the process continues in the rest of the world. Although the rate of expansion of agriculture is decreasing (FAO 2002), the pressure from agriculture on forest ecosystems remains high. Agricultural areas are expected to increase by 120×10^6 ha in developing countries by 2030, mostly due to the establishment or expansion of intensive cultivation of major food crops (FAO 2002). In regions such as East Asia, South Asia, the Near East, and North Africa that have already reached full use of their existing arable soil, agriculture will expand into forest landscapes that have survived previous expansion cycles. In the coming decades, the predicted expansion and intensification of agriculture is expected to affect the atmosphere, climate, soil, water, and biodiversity, and these effects may be cumulative.

The process of agricultural abandonment usually affects areas with low crop-production potential (e.g., low soil fertility, difficult topography, and climatic constraints) and low human density. Together with other drivers of change such as depopulation, incentives from markets, industrialization, poor adaptation of agricultural systems to local conditions, and land mismanagement, significant abandonment of agricultural activities has occurred in several regions in the world, but most frequently in Europe (Benayas et al. 2007). The effects of abandonment on the landscape structure depend on the matrix in which abandonment occurs and on the magnitude of the associated change. Abandonment in agriculture-dominated areas increases landscape heterogeneity by increasing landscape richness, diversity, evenness, and edge abundance and diversity, as well as increasing the variability in the sizes and shapes of landscape units. Functionally, landscape processes tend to be strongly influenced by the new systems that become established in the abandoned areas. Given that abandoned land generally becomes dominated by woody plants, agricultural landscapes often revert to forests within a few decades following abandonment. In landscapes where the matrix is mostly composed of natural or semi-natural cover types, agricultural abandonment leads to a loss of heterogeneity and the potential loss of local diversity (Navarro and Pereira 2012). Fire, which is usually absent from agriculture-dominated landscapes, is promoted in these more natural landscapes by local accumulation of fuel and increasing continuity of highly flammable units within the landscape (Moreira and Russo 2007).

Deforestation is another complex land-use change process associated with the conversion of forest to a different land-use or cover class. The annual net loss of forests during the last decade was nearly 5.2×10^{6} ha, which is the rate after accounting for the positive effects of afforestation (FAO 2010). Deforestation rates have been decreasing worldwide, but on different trajectories. Temperate regions reached their maximum deforestation rates prior to 1700, whereas tropical regions reached their maximum rate from 1950 to 1979 (FAO 2012). Although deforestation in temperate regions is currently balanced by reforestation, net deforestation remains high in tropical regions (FAO 2012).

Although agricultural expansion is a major cause of deforestation, there are many other causes, including unsustainable logging related to the demand for fiber and fuel, cattle grazing, infrastructure construction, urbanization, and interactions among these factors (FAO 2012). In addition, ancient agricultural systems such as slash-and-burn cultivation are still in use in many tropical regions. Deforestation is also associated with processes that act at multiple scales, such as urban growth, road construction, and climate change, in complex feedback loops, making the prediction of landscape change and its effects a difficult task (Freitas et al. 2010, Lambin et al. 2003). Deforestation can also result from habitat degradation. In this case, processes such as selective logging, insect pests and diseases, natural disasters, and invasive species affect the conservation of forest ecosystems (FAO 2010).

Deforestation is a typical landscape-level process. In addition to changing the vegetation composition, it affects other structural features of the landscape such as patch size (Bélanger and Grenier 2002); isolation, fragmentation, and connectivity (Lira et al. 2012, Riitters et al. 2002); edge dynamics (Laurance et al. 1998, Numata et al. 2009); and landscape stability (Metzger 2002). The ecological processes affected by deforestation include fire occurrence and intensity (Armenteras et al. 2013), species dynamics (Laurance et al. 1998), water yield (Sahin and Hall 1996), and ecosystem degradation and biodiversity loss (Bradshaw 2012, Brook et al. 2003).

In some parts of the world, forestry intensification is as significant as agricultural expansion and intensification in terms of its effects on forest landscapes. Whereas agricultural intensification requires good soil, weather, and terrain conditions, forestry, even when intensive, is less demanding. Thus, forests can grow over larger areas, including less-fertile soils and rough terrain, and intensification affects a diverse set of ecosystems, including native forests. Although planted forests represent just 7% of the world's forests, they are concentrated in East Asia, Europe, and North America (FAO 2010), where they affect landscapes strongly. The landscape-level effects of this process vary with the land-use history and the tree crop species. Plantations have been established under intensive management regimes based on exotic species such as *Eucalyptus* in South America and other regions of the world. When such plantations are established in close contact with native forests or instead of local forests (Cossalter and Pye-Smith 2003), their main effects are land-use change and the creation of edge effects. Bamboo plantations in Africa or Central America and rubber plantations in South and Southeast Asia and West Africa are crops with a potential effect on native forests. The established plantations are ecologically simpler and are managed to maintain that structural and functional simplicity; they therefore cannot support rich plant and animal communities, leading to impoverishment of local and eventually regional diversity. Under certain circumstances, however, plantations, can provide habitat connectivity at the landscape level, despite their poor habitat quality, and thereby help to maintain population processes and diversity (Barlow et al. 2007).

In some regions, forest plantations are established in degraded areas, usually after previous deforestation and intensive agriculture or in areas where forest cover has been historically replaced as a result of land-use and cover change. In each case, the landscape prior to afforestation was dominated by non-forest land uses. Degraded land is particularly common in tropical regions with impoverished soils that are fragile and have poor resistance to disturbance, and in semi-arid and arid areas, such as much of northern China, that are also highly vulnerable to degradation. In such cases, even intensive forestry based on exotic species can have positive impacts in terms of organic matter inputs, energy and nutrient cycling, and providing habitat, and these changes can influence broader areas than just the local direct effects of the plantations. For example, see the thorough review of ecosystem functions and services associated with plantations in Brazil and elsewhere by Brockerhoff et al. (2013). Restoration of these areas based on the establishment of forest plantations, including landscape-scale measures, has been proposed (Lamb et al. 2005). However, afforestation programs in degraded areas have also been associated with negative ecological and socioeconomic effects (Cao et al. 2011).

Historical land-use and cover change has been particularly common in Europe and North America. In Europe, forests account for 34% of the land area, compared to 80% around 2000 years ago (FAO 2012). This relatively high coverage is only because of afforestation campaigns conducted during the last 100 to 150 years. Many of these planted forests are managed in relatively intensive ways, such as *Eucalyptus* plantations in Spain and Portugal, poplar (*Populus* spp.) plantations in Italy, or willow (*Salix* spp.) coppices managed for energy production in Sweden. As in Europe, the rapid deforestation that took place in North America during the 19th century was rapidly followed by reforestation or natural regeneration of abandoned agricultural land. For example, the United States and Canada have planted an annual average of 371 000 ha of forest since 2000, (FAO 2010).

4.2.2. Changes in forest management

Forest planning, management paradigms, and forestry practices have changed dramatically during the 20th century, not just in terms of the concepts and objectives (e.g., the move from sustained timber yield to ecosystem management) but also in terms of the scale at which forest management is addressed, which expanded from the cohort or stand to large-scale heterogeneous landscapes (Brunet et al. 2000). This shift in scale was influenced by the development of landscape ecology in the 1980s, which provided the conditions and a theoretical framework for the application of forest landscape ecology within forestry. Landscape-level sustainability criteria and indicators are used today to support decisionmaking in forest management to ensure the sustainable provision of forest products and the maintenance of ecological functions. Clearcut size, the abundance of edges, connectivity, and the presence of corridors, among others, are important landscape-level variables that are relevant in today's forest management because of their relationship with ecological processes. Forest landscape ecology informs management not only by supplying knowledge of the interactions between patterns and functions in forest landscapes, but also by providing conceptual and methodological tools to support planning and management.

The expansion of emerging concepts such as sustainable management, ecosystem management, multifunctionality, and adaptive management in forestry during the late 20th century has resulted from changing public perspectives towards forests and natural resources and increased scientific knowledge. These novel approaches have affected decisionmaking, forest management, and forest product markets, as well as the structure and functioning of forest landscapes.

Sustainability has become the most important goal in planning and management of forests. Emerging from the “Statement of Forest Principles” and the “Convention on Biodiversity” that were agreed to at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992, the concept rapidly became the background for major international initiatives directed at defining principles and practices for sustainable forestry as well as for certification programs. Schlaepfer and Elliott (2000) and Burley (2001) provide a detailed history of sustainable forestry.

Broad scales are required to address sustainability in natural and managed systems in the fields of land planning, nature conservation, and land management, including forest management (Cary et al. 2009, Christensen et al. 1996, Forman 1995, Lubchenco et al. 1991). Sustainable forestry initiatives and certification programmes address landscape patterns and processes in several ways. Many of the criteria and indicators of the Montréal Process (1999) and the Pan European Forest Certification (http://www.pefc.org/) require that large scales be defined and applied. Criteria such as water conservation, habitat and species conservation, maintenance and encouragement of the productive functions of forests, and maintenance of ecosystem health or integrity rely strongly on a consideration of the spatial attributes of ecosystems at broad scales. At the national level, the program’s guidelines also require a landscape-scale approach, which includes the establishment and management of riparian buffer zones and wildlife corridors, defines the size of harvested areas, and prescribes adjacency rules. In addition, compliance with sustainable forestry programs involves the application of landscape ecology concepts and methods (e.g., FSC 2010). In the Sustainable Forestry Initiative in the United States, for example, several biodiversity- and water-related processes, criteria, and indicators can only be addressed from a landscape perspective (Azevedo et al. 2008).

Ecosystem management is the designation of the management policy adopted by the USDA Forest Service and other federal agencies of the United States in the 1990s based on the application of ecological principles in forest management (Rauscher 1999, Schlaepfer and Elliott 2000). Despite the numerous interpretations of the concept, it deals with many complex ecological and management themes, including holism and a consideration of cross-scale interactions among a system's components, defining the ecological boundaries of systems at multiple scales, maintaining diversity of patterns and processes at all scales, research, managing and using existing data, monitoring, adaptive management, and accounting for interactions between ecosystems and humans (Christensen et al. 1996, Franklin 1993, Grumbine 1994, Szaro et al. 1998). Its ecological foundations and the prerequisite for addressing large temporal and spatial scales make this approach intimately related to forest landscape ecology (Crow 1997, Franklin 1993). A full range of applications in forestry is provided by Kohm and Franklin (1997).

Multifunctionality in forestry refers to the delivery of multiple outputs from the process of forest management that are obtained by taking appropriate measures to optimize their production (i.e., multifunctional management). Although multifunctionality is related to the concept of multiple-use, and may have evolved from the Multiple Use–Sustained Yield Act of 1960 in the United States to simultaneously address timber, range, water, recreation, and wildlife values, the term has been expanded to encompass a broader range of ecological functions and services. Multifunctional management also overlaps considerably with the concept of sustainable management, as defined by Farrell et al. (2000), since the objectives of sustainable forest management consider multiple roles, functions, and outputs of forest systems, and the terms are often used interchangeably. Spatial multifunctionality is an extension of the concept to the landscape level, by considering multiple outputs from the diverse land-use and cover types present within a given landscape (Carvalho-Ribeiro et al. 2010). Landscapes, by their intrinsic heterogeneity and complexity, are consequently seen as multifunctional systems (Willemen et al. 2010).

Ecosystem services are not, in a strict sense, inherently a management concept, but their impact on the management of ecosystems and landscapes will nonetheless be massive in the coming years. The use of the ecosystem services concept in management provides a quantitative and objective methodological framework to support decisionmaking in complex systems that are being managed, simultaneously, for multiple targets and objectives. This is particularly relevant in defining management strategies and technical solutions for the application of philosophies such as multifunctionality or sustainability in forestry. It is also relevant for landscape ecology, since many of the ecosystem services usually associated with forests are actually landscape services, including water-related services (e.g., yield and quality regulation), disturbance regulation services (e.g., fire, flooding), or cultural services (e.g., esthetics).

Although the ecosystem services framework is based on human needs, it is a long-term, ecologically based approach to management because it relies on a holistic perspective that requires the maintenance of fundamental ecosystem patterns and processes, including biodiversity. Chapter 5 provides a thorough discussion of ecosystem services and their valuation in forest systems.

Adaptive management is the process of adjusting management practices as more knowledge is gathered through research, monitoring, or experience and as the system's behavior changes in response to management (Holling 1978). The concept has been developed and adapted to the management of natural resources, where predictability is low and uncertainty is high, particularly when available knowledge is limited, and falls within the scope of sustainability (Walters 1986). Adaptive management is a growing component of strategies to adapt natural resources to climate change. It has been addressed in silviculture as an operational null hypothesis for the management of unstudied forest systems (Oliver and Larson 1996) and in ecosystem management as a way of dealing with complex unknown and changing systems (Kessler et al. 1992). Most proposals for the application of this concept, however, come from the field of forest biodiversity conservation (Lindenmayer and Franklin 2002, Lindenmayer et al. 2006).

Our discussion in this section indicates that forest management has changed significantly during the past century, both conceptually and in practice, and it is likely that these changes will increasingly affect the patterns and processes of forest landscapes. Previous evaluations of these concepts have included the changes observed in the structure of forested landscapes that have undergone different management practices (e.g., Crow et al. 1999, Spies et al. 1994) or the use of modeling and simulation to predict changes in structure as a function of management practices such as the choice of regeneration method, harvest and regeneration scheduling, and the spatial pattern of harvested areas (e.g., Baskent 1999, Crow et al. 1999, Franklin and Forman 1987, Gustafson and Crow 1996, Radeloff et al. 2006, Shifley et al. 2000, Spies et al. 1994). The effects of forest policy and management objectives on spatial patterns have also been analyzed through simulations (Cissel et al. 1998, Gustafson and Loehle 2008, Hagan and Boone 1997). The effect of management-caused changes in structure on landscape functioning has been addressed through modeling and simulation for wildlife habitat suitability (Hansen et al. 1992, Larson et al. 2004, H.B. Li et al. 2000, Shifley et al. 2006), plant succession and disturbance (He et al. 2002, Kurz et al. 2000), metapopulation dynamics (Akcakaya et al. 2004), and hydrological processes (Azevedo et al. 2005).

Despite these advances, the application of landscape ecology approaches or methods to real-world forest management, particularly by the forest industry and the private sector, has been limited. Although the forest industry tends to consider landscape issues in management, mostly due to the desire to achieve certification, the implementation of a forest landscape approach has mostly been superficial. The management of *Eucalyptus* plantations by some forestry companies in Brazil is a possible exception. These companies have applied sustainable forestry principles and methods using GIS-based software that was developed to assess and monitor landscape diversity (with stands defined in terms of clone and age), water balance, and the size, edges, core areas, proximity, vegetation diversity, and value of conservation areas based on conventional and customized landscape metrics (Ferraz and Ferraz 2009). Insufficient implementation of forest landscape ecology in forestry practices is discussed in detail by King and Perera (2006), and will be addressed in the final chapter of this book.

5. Trends and roles of forest landscape ecology in the context of change

5.1. Why is forest landscape ecology essential within the framework of global change?

Given the current trends for the major drivers of change discussed earlier in this chapter, land-use change in forest landscapes creates forest expansion or forest fragmentation, which are particularly relevant processes that require further attention from forest landscape ecologists, particularly to support forest management. Forest cover is expected to keep increasing in some parts of the world, such as Europe and North and South America. The expansion of planted and naturally established forests associated with rural abandonment and the intensification of forestry is causing fast changes in the landscapes of the southern and eastern parts of Europe (Benayas et al. 2007, Keenleyside and Tucker 2010, Navarro and Pereira 2012, Proença et al. 2012). The prospects for further forest expansion in the coming decades are high given the availability of abandoned farmland (Keenleyside and Tucker 2010). Trends include forest intensification (south), multifunctional forestry (in other areas), and the transition of previously rural landscapes back to wilderness (Navarro and Pereira 2012). In other parts of the world, abandonment of agricultural land (North America) and re-establishment of forest in previously degraded land (South America and China) is also expected to expand forest cover.

In each of these cases, a landscape perspective, and the associated theory, methods, and tools, are required in any attempt to manage forest landscapes that are undergoing development (or a return to previous forested states) to ensure multifunctionality or sustainability or just to ensure a smooth transition between "system states". Particularly relevant is the management of landscapes for the sustained provision of ecosystem services, as this is only possible at landscape scale. Landscapes that became dominated by forest develop different processes. In most areas where forest expansion is occurring, fire is a major disturbance and might become a major driver in subsequent change; therefore, a landscape's fire regime is an important reference for both landscape and stand management.

In contrast, many forest landscapes around the world are expected to experience habitat loss and fragmentation in the future. These processes attract attention from society in general, since they will affect some of the world's most biodiverse regions and will have significant effects on global biological diversity and ecosystem services. Forest fragmentation is one of the most serious threats to biodiversity, but fortunately, it is also one of the major research subjects covered in landscape ecology, and particularly in forest landscape ecology.

In addition, all forest landscapes are being influenced by climate change. Since many processes affected by this type of change occur at the landscape scale or are affected by other processes that occur at this scale, forest landscape ecology has an increasingly relevant role in the context of global change. Through changes in the temporal and geographic patterns of temperature and precipitation and changes in their uncertainty (e.g., interannual variability, the frequency of extreme events), climate change will affect species distribution and ecosystem productivity, disturbance regimes, biological invasions, and resilience (Hansen et al. 2001), and, most importantly, will affect the role of ecosystems as service providers (Schroter et al. 2005). In some cases, these effects have already been detected (see review in Hannah 2011). In return, landscape changes will affect climate, both locally and globally, through changes in albedo, evapotranspiration, and emissions of greenhouse gases through complex feedback processes. Interactions among climate change, land-use and cover change, management, and large-scale disturbance (e.g., fire) will be complex and difficult to forecast (Dale et al. 2001).

Changes in an ecosystem's species composition due to extinction or shifts in distribution ranges may influence forest ecosystem function and the survival of numerous plant and animal species, with subsequent effects on landscape-level systems. (For example, see Chapter 2 of this book.) In terms of conservation, measures adopted since the 19th century, such as the establishment of protected areas and conservation networks, will need to be adjusted to account for the expected changes in species distribution during the present century (Araujo et al. 2011, Hannah et al. 2007). For example, see Chapter 2 for a discussion of the need for "assisted migration" of species in response to climate change. On the other hand, current landscapes play a fundamental role in species redistribution in response to climate change through the effect of landscape structure (and the key role of connectivity) on the spread of organisms. Changes in the distribution of vegetation types are also occurring. In Europe, climate change will increase the dominance of forest landscapes in the near future, thereby positively influencing ecosystem services such as productivity and esthetics but negatively influencing water availability and vulnerability to forest fires or the ability to sustain high-quality timber production (Hanewinkel et al. 2013, Schroter et al. 2005). In other parts of the world, such as North America (Bachelet et al. 2001) and Asia (Weng and Zhou 2006), the trend is also an expansion of forest systems, but the effects remain unknown. Pest outbreaks and changes in fire regimes will become active drivers in landscapes affected by climate change. Increasing frequency or severity of pest outbreaks and disease epidemics or of forest fires are predicted in response to changes in climate that affect the composition of forest ecosystems and the landscape pattern (Dale et al. 2001, Westerling et al. 2006). Climate change will therefore affect both processes that occur at the landscape scale and management of the ecosystems and landscapes affected by these processes, and this will require the integration of climate change into future planning and management of forests. Approaches to deal with climate change will be increasingly based on concepts such as adaptation and resilience, which are being studied more intensely from both theoretical and applied perspectives and from a landscape perspective (Heller and Zavaleta 2009, Opdam et al. 2009).

5.2. Roles of forest landscape ecology in contemporary forest science and management

Based on what we have discussed thus far, forest landscape ecology has contributed and will continue to contribute to helping researchers and managers to deal with change and its complexity. The major goal of forest landscape ecology is to minimize the risks and the effects of change on ecological sustainability and human well-being by providing a better understanding and description of change and its effects from a theoretical perspective while, as an applied science, simultaneously informing the management and planning of forest landscapes.

From a scientific perspective, landscape ecology offers the foundations (theory, approach, scale, research methods and tools, knowledge) to provide: (1) a full understanding of the drivers of change and their nature, scale, complexity, and interactions; (2) full understanding of the effects of change on patterns, processes, and services; and (3) full availability of methodological and practical tools to monitor landscape change. Understanding the drivers, processes, and effects of change is a rather difficult task considering the inherent complexity of the systems under analysis, and the difficulty is increased by the complexity of change, particularly when that change results from interactions at multiple scales. For this reason, monitoring of landscape change; isolating the weight, scale, and mechanisms of different drivers of change; and understanding of interactions at multiple scales are of utmost importance in the development of this field.

From a management perspective, the potential roles of forest landscape ecology are to: (1) inform the planning, management, and design of forest landscape systems under changing conditions; (2) support the multifunctionality and sustainability of forest landscapes under changing conditions; (3) integrate change into the disturbance regimes that result from management and planning; (4) ensure sustained provision of ecosystem services, particularly those related to biodiversity conservation; and (5) support the definition of adaptation strategies, approaches, and outcomes. Forest landscape ecology must, therefore, provide the foundations, the methods, and the tools to deal with change in a management context. It must also support the incorporation of generally accepted concepts such as sustainability, multifunctionality, ecosystem services, and adaptive management into more conventional management approaches. It should also provide support for changes in management in order to adjust forest landscapes and the management methods to, for example, account for changes in disturbance regimes (e.g., fire, pests, storms), biological invasions, drought, human pressures, and other change processes. Given the potentially high species extinction rate that will occur under the projected fast environmental change and the irreplaceability of biodiversity in sustaining ecosystem structure and functioning, biodiversity conservation planning at broad scales under future land, climate, and disturbance conditions should be our top priority.

5.3. How this book addresses forest landscape ecology and change

In this book, we have addressed change in forest landscapes from both theoretical and practical perspectives. Based on the existing management traditions in forest landscape ecology and the need to contribute more and better solutions to deal with change and its effects in real-world situations, we developed the book outline by simultaneously considering the underlying processes of change (climate, human activities, disturbance regimes), the effects of change on ecosystem and landscape processes (carbon, biodiversity, disturbance), the methods to monitor and assess change (landscape monitoring), approaches to deal with changes in management (ecosystem services), and the integration of knowledge in forest management at the stand and landscape scales (forest management and change).

After our introduction, in which we discuss the analysis of change in forest landscapes and the role of forest landscape ecology in a changing context (Chapter 1), Louis Iverson and his colleagues provide a detailed analysis of the consequences of climate change on the distribution of tree species and on the interactions of plants, populations, and ecosystem processes with landscape patterns (Chapter 2). Next is a discussion of the processes that simultaneously drive change and are the result of other drivers, and the complex interactions among them. Francisco Rego and Joaquim Silva explore the case of fire as an agent of disturbance based on the Portuguese experience (Chapter 3) and Juliana Farinaci and her colleagues explore the transition from deforestation to forest restoration in São Paulo, Brazil, and Indiana, United States, emphasizing their causes and consequences (Chapter 4). Chapter 5, by Cristina Marta-Pedroso and her colleagues, is directed towards changes in socioeconomic perspectives related to ecological and social processes and functions, and explores the application of the ecosystem services concept and related methodologies in forestry decisionmaking. In Chapter 6, Jiquan Chen and his colleagues analyze the processes of carbon sequestration and storage and their dynamics in forest ecosystems and landscapes, as well as their interaction with climate change. Chapter 7, by Santiago Saura and his colleagues, is dedicated to the major effects of landscape change on biodiversity at multiple scales, with an emphasis on habitat amount, quality, fragmentation, connectivity, and heterogeneity. Chapter 8, by Valentín Gómez-Sanz and his colleagues, is dedicated to the theoretical and technical aspects of procedures for monitoring and assessing changing landscapes. The implications of changes in forest management approaches and methods are discussed in detail by Robert N. Coulson and his colleagues in Chapter 9, which explores the author's contributions towards better management of forest landscapes in response to the several sources of change that are currently affecting forest landscapes, or that will affect them in the future. Common to most of the chapters in this book is the objective of providing knowledge transfer from the scientific sphere to the sphere of real-world management (e.g., monitoring techniques, adaptation to fire regimes, adaptation to climate change, biodiversity conservation, carbon sequestration and storage, and valuation and evaluation of human values and ecosystem services). We conclude by summarizing the main achievements in this book, discussing the challenges that forest landscape ecology faces in the future, and describing the next steps that are required to advance this field (Chapter 10).

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