PART I

Introduction and concepts

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Coupling landscape ecology with natural resource management: Paradigm shifts and new approaches

1.1 Introduction

Global human population has now exceeded 6 billion people and this rapidly increasing population has significant implications for natural resources. On the one hand, demands for natural resources have dramatically increased and will continue to increase (FAO, 1997). On the other hand, natural resources have been reduced in both quantity and quality as extraction has become more intensive and extensive than ever before (Vitousek *et al.,* 1997). As a result, much of the world's biodiversity has been lost (Ehrlich, 1988; Myers, 1990; Pimm and Gittleman, 1992), and many species have become threatened and endangered (Wilson, 1988; Rutledge *et al*., 2001). Other ecological consequences include degradation of ecosystem goods and services (Costanza *et al*., 1997; Daily, 1997), landscape fragmentation (Harris, 1984), and unsustainable use of natural resources (World Commission on Environment and Development, 1987; Lubchenco *et al*., 1991). Furthermore, the management of natural resources has become more constrained and complex due to the interactions among ecological, political, socioeconomic, demographic, and behavioral factors (Thrupp, 1990; Cairns and Lackey, 1992; FEMAT, 1993; Liu, 2001; McCool and Guthrie, 2001; Chapter 19, this book). In order to address these great challenges in natural resource management and to achieve sustainability of natural resources in the future (Speth, 1992; MacDonald, 1998; Rogers and Feiss, 1998; Kates *et al*., 2001), resource managers need insightful guidance and new perspectives from emerging disciplines such as landscape ecology (Sharitz *et al.,* 1992; Swanson and Franklin, 1992; Noss, 1983; Dale *et al*., 2000).

Landscape ecology is an interdisciplinary field that studies landscape structure, function, and change (Forman and Godron, 1986; Hobbs, 1995). Although the term was coined by the German biogeographer Carl Troll in 1939 (Turner, 1989), landscape ecology did not draw much attention outside of

Europe until the early 1980s. During the last two decades, the field of landscape ecology has been rapidly advancing (Naveh and Lieberman, 1984; Risser *et al.*, 1984; Zonneveld and Forman, 1990; Forman 1995a; Pickett and Cadenasso, 1995; Wiens and Moss, 1999). Such rapid advancement is evidenced by the formation of the International Association for Landscape Ecology (IALE) in 1982 and its regional chapters (e.g., US-IALE, Europe-IALE, China-IALE), a large number of national and international conferences, creation of the international journal *Landscape Ecology* in 1987 (Golley, 1987, 1995), the proposition of a large number of landscape ecology concepts (e.g., Urban *et al.*, 1987; Pulliam, 1988; Turner, 1989; Levin, 1992; Wiens, 1992; Hobbs, 1995), the formulation of many principles (e.g., Risser *et al.*, 1984; Forman and Godron, 1986; Forman, 1995a,b), and the development of numerous methods and techniques (e.g., Turner and Gardner, 1991; Pulliam *et al.*, 1992; Klopatek and Gardner, 1999).

Although landscape ecology provides a spatial systems perspective and has great relevance to natural resource management (Hobbs, 1995), the application of landscape ecology in natural resource management has been lagging (Forman, 1986; Aspinall and Pearson, 2000; Chapter 18, this book). Likewise, natural resource management actions have not been fully utilized for the advancement of landscape ecology, even though they provide excellent opportunities for further landscape ecology development (e.g., Chapters 13 and 18, this book). Given these needs and potential benefits, the main goal of this book is to identify links and ways of bridging the gaps between landscape ecology and natural resource management. In this chapter, we briefly introduce a number of fundamental concepts, principles, and methods in landscape ecology; discuss how natural resource management paradigms can be modified to fit into a landscape ecology perspective; and provide an overview of this book.

1.2. A brief introduction to landscape ecology: Concepts, principles, and methods

In this section, we briefly introduce some fundamental concepts, principles, and methods in landscape ecology. More details can be found in other chapters of this book and many publications cited throughout this book.

1.2.1 Landscape structure, function, change, and integrity

Although the exact definition of a landscape can vary greatly, most landscape ecologists agree that a landscape is a heterogeneous land area (e.g., Turner, 1989; Forman, 1995a) (Fig. 1.1) that is often hierarchically structured. The basic unit in a landscape is a patch, which is a relatively homogeneous area.

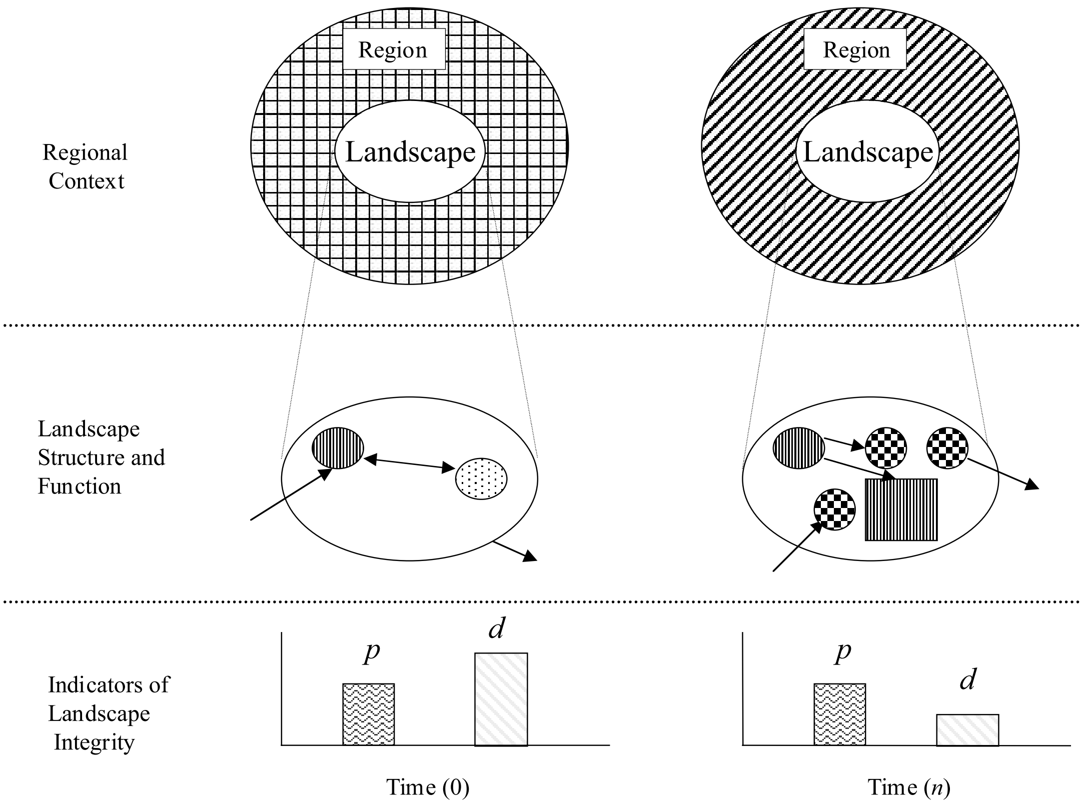

FIGURE 1.1
A diagram of regional context (top row), landscape structure and function (middle row), and landscape integrity (bottom row). Landscape changes are illustrated at two time steps: time 0 (left column) and time *n* (right column). The top row illustrates that a landscape (white ellipse) is embedded in a region (shaded ellipse). A landscape (middle row) consists of patches with different sizes and shapes. Arrows refer to landscape function (flows of energy, matter, and organisms) within and between patches and landscapes. Landscape integrity (bottom row) can be represented by different indicators such as productivity (*p*) and diversity of native species (*d*). In this example, changes in landscape structure and function as well as regional context (different shadings) cause a reduction in diversity of native species but no significant change in productivity.

The size (extent or spatial dimension) of a landscape is dependent on research and management objectives and varies with the perception of the organisms (Pearson *et al.*, 1996). Because different organisms view the same landscape differently, a landscape could range from square meters (from a small insect's perspective; Wiens and Milne, 1989) to thousands of square kilometers or larger (from humans' perspective; Forman and Godron, 1986).

Patches and landscapes are not isolated entities, but embedded in local, regional, and global contexts (Forman, 1995a; Liu and Ashton, 1999) (Fig. 1.1). A landscape is an open system with flows across landscape boundaries and interactions with other landscapes. For instance, nutrients and pollutants may follow hydrologic flows from uplands to aquatic systems (Carpenter *et al.*, 1998). Landscape functions (or processes) include matter flows, energy flows, and organism flows such as migration and dispersal among patches (Forman, 1995a) (Fig. 1.1). Through these various flows, patches and landscapes connect with and influence each other (Fig. 1.1).

Both landscape structure and landscape function change over time and across space due to natural and anthropogenic disturbances (Pickett and White, 1985; Turner *et al.*, 1997; Dale *et al.*, 1998) (Fig. 1.1). Landscapes change in a variety of ways. For instance, a contiguous large landscape may be fragmented into smaller pieces or some landscape elements may be lost (Forman, 1995a). Conversely, small landscapes or patches may coalesce into larger ones. Rates of change can be differential across a landscape (Liu *et al.*, 2001). Depending on the intensity and frequency of disturbances, some changes are very dramatic, while other changes are gradual or less obvious (Turner, 1987; Baker, 1992; Swanson *et al.,* 1998; Foster *et al.*, 1999).

While landscape structure, function, and change have been extensively studied, landscape integrity is a subject relatively unexplored. The concept of landscape integrity is different from but related to ecosystem integrity (Woodley *et al.*, 1993; De Leo and Levin, 1997), ecological integrity (Crossley, 1996; Pimentel *et al.*, 2000), and biological (or biotic) integrity (Karr, 1981; Hunter, 1999). The major difference lies in that landscape integrity is a health measurement at the landscape level (Fig. 1.1), while other integrity concepts indicate the health status of ecosystems or communities. Landscape integrity may result from complex interactions among ecosystems in the landscape and is unlikely to be a simple summation of ecosystem integrity. Landscape integrity can be measured by indicators such as productivity and diversity of native species at the landscape scale. The exact relationships between landscape integrity and landscape structure and function are unknown but are likely to be nonlinear. Changes in landscape structure and function may or may not lead to significant changes in landscape integrity (Fig. 1.1). For example, modifications of some patches in a landscape may not affect its integrity due to elasticity or compensation of other patches in the landscape. Given its importance and lack of knowledge about it, we suggest that landscape integrity should be on the priority list of research by the landscape ecology community.

1.2.2 Principles

Like other disciplines, a set of principles has emerged in landscape ecology. According to Forman (1995b), a general principle integrates various sources of knowledge, addresses important questions, has a wide range of applications, has predictive ability, is established in theory, and has direct supporting evidence. Based on these criteria, Forman (1995b) lists 12 principles of landscape ecology. One of the principles states that spatial arrangement of patches is a major determinant of functional movement across the landscape. Additional principles have been proposed by others, such as Risser *et al.* (1984), Urban *et al.* (1987), Turner (1989), Ahern (1999), Ludwig (1999), and Farina (2000). These include the principle that local ecological conditions (e.g., organism abundance and species diversity) are affected by landscape context or attributes of the surrounding landscape (Dale *et al.*, 2000). For example, Pearson (1993) reported that bird species richness within a stand is largely affected by the vegetation structure in the surrounding areas. Likewise, Liu *et al.* (1999) found that food in oil palm plantations supports higher levels of wild pigs that, in turn, significantly reduce tree seedling regeneration and tree species richness in stands adjacent to the plantations.

1.2.3 Methods

Research methods in landscape ecology have progressed remarkably fast over the last two decades (e.g., Turner and Gardner, 1991; Klopatek and Gardner, 1999; Farina, 2000). These methods include approaches and tools for collection, analysis, and integration of both spatial and non-spatial data. In terms of data collection, methods like sampling (Cochran, 1977; Chapters 3 and 11, this book) and observations (Hanski, 1991; Grossman *et al.*, 1995) are routinely used in landscape ecology. Experimentation is also becoming popular (Lovejoy *et al.*, 1986; Robinson *et al.*, 1992; Wiens *et al.*, 1995; Ims, 1999), even though it is frequently faced with challenges in identifying suitable replicates (Hargrove and Pickering, 1992; Chapters 3 and 13, this book) because landscape-level experiments often must use large, yet heterogeneous areas. While sampling and experimentation usually require researchers to be physically in the field, remote sensing techniques collect information about an object without direct physical contact and have become an essential tool for obtaining large-scale spatial data in the forms of satellite imagery and aerial photography (Lillesand and Kiefer, 1994; Jensen, 1996; Chapter 16, this book). In addition, global positioning systems (GPS, satellite-based georeferencing systems) are frequently used to gather spatial data, especially for purposes of ground truthing (Liu *et al.*, 2001).

Tools for data analysis and integration include geographic information systems (GIS), spatial statistics, and modeling. Geographic information systems (Maguire *et al.*, 1991) are arguably the most important tool for storing, manipulating, analyzing, and integrating both spatial and non-spatial data. Spatial statistics or geostatistics (e.g., spatial autocorrelation, kriging, spectral analysis, trend surface analysis) are useful tools for analyzing landscape patterns (O'Neill *et al.*, 1988; Legendre and Fortin, 1989; Turner and Gardner, 1991; Li and Reynolds, 1993; Gustafson, 1998), along with specifically designed software, such as FRAGSTATS (McGarigal and Marks, 1994) and Patch Analyst (http://flash.lakeheadu.ca/~rrempel/patch/). Because landscape structure and management practices often vary across space, spatially explicit models are especially useful (Pulliam *et al.,* 1992; Liu, 1993; McKelvey *et al.*, 1993; Dunning *et al.*, 1995; Turner *et al.*, 1995). Spatially explicit models are computer-based models that account for the ecological and socioeconomic differences among different locations in landscapes and allow efficient analysis of spatial interactions (Liu *et al.*, 1994; Dunning *et al.*, 1995; Verboom and Wamelink, 1999). Combining remote sensing and GIS data, these models offer great promise to natural resource managers, because the arrangement of landscape elements differs in space and time, and the visual display makes the comparisons of management alternatives and their ecological consequences much easier (Franklin and Forman, 1987; Liu *et al.*, 1995; Turner *et al.*, 1995; Gustafson and Crow, 1996).

1.3 Shifts in paradigms of natural resource management

While traditional natural resource management has met numerous societal needs, it has also caused a host of problems (Christensen *et al.*, 1996; Kohm and Franklin, 1997), such as conflicts between management for short-term and long-term benefits, between management at small scales and large scales, and between management of different natural resources (Liu, 1995; Scott *et al.*, 1995; Dale *et al.*, 2000; McShea and Rappole, 2000). To overcome the shortcomings of traditional management, it is necessary to facilitate shifts in management paradigms using a landscape perspective. Specifically, it is essential to tie landscape structure with multi-scale management; to link landscape function with cross-boundary management; to connect landscape change with adaptive management; and to use integrated management by incorporating multi-scale, cross-boundary, and adaptive management to achieve sustainable landscape integrity (Fig. 1.2).

From single-scale management to multi-scale management

Traditional management has usually taken place at a single spatial scale. In forestry, for example, management often occurred at the stand level (Crow, 1999). Because a landscape is usually heterogeneous and ecological consequences are often scale-dependent (Toman and Ashton, 1996; Chapter 2, this book), management must be similarly carried out at multiple scales such as patch, patch group, and landscape. If no patches are the same, it may be neces-

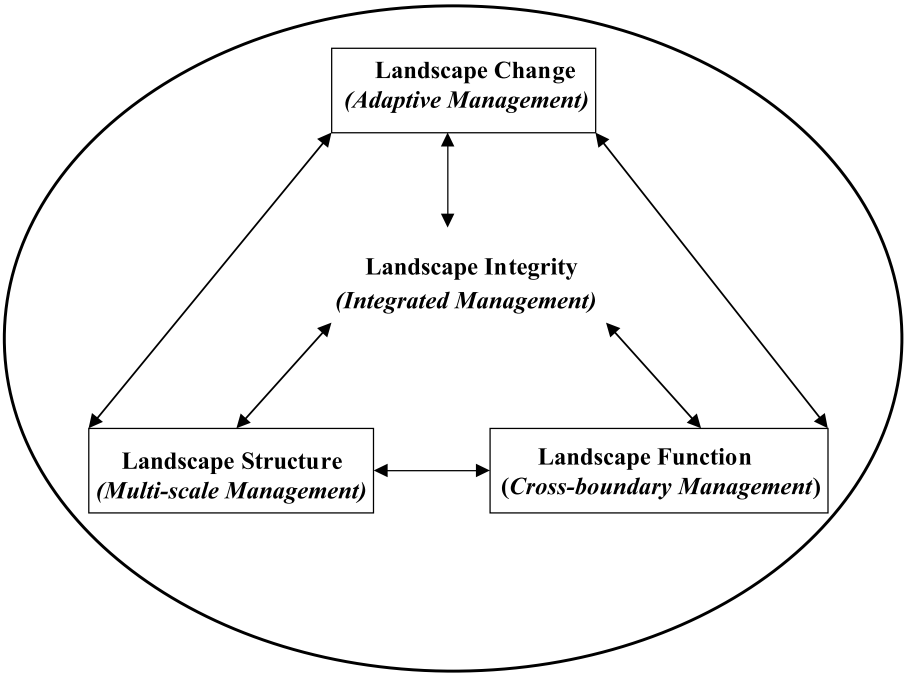

FIGURE 1.2
Relationships among the four major aspects of a landscape and the four management paradigms. Each box refers to a specific linkage between landscape ecology and natural resource management: landscape structure and multi-scale management, landscape function and cross-boundary management, and landscape change and adaptive management. Because landscape integrity and integrated management encompass all three linkages, they are represented by the entire ellipse.

sary to undertake different management activities in different patches to accommodate landscape heterogeneity. If two or more patches share the same characteristics, these patches can be grouped and be managed in the same way. For example, in an agricultural landscape with three patches (A, B, C), patch A has low soil fertility while B and C have high fertility, patches A and B have high density of pests whereas pest density in patch C is low, and all three patches have low soil moisture. In order to increase productivity and reduce costs, a multi-scale approach would be to enhance fertility (e.g., through applying organic manure) in patch A, to control pests (e.g., through integrated pest management) in patches A and B (as a patch group), and to improve water conditions (e.g., through irrigation) across the landscape (all three patches). Thus, individual patches or patch clusters need to be assessed and managed in the context of a landscape where management activities can be coordinated to achieve the overall performance of designed management plans at the landscape level.

From within-boundary management to cross-boundary management.
Conventional management was often conducted within the boundary of land ownership or within the same patch or landscape, without taking account of the interactions between the focal patch/landscape and other patches/landscapes (Reid, 1996). A cross-boundary management approach is thus needed to incorporate landscape functions (i.e., flows of energy, matter, and organisms) because landscape functions may not recognize political, management, ownership, and natural boundaries, and because management within a patch or landscape may have tremendous effects beyond the boundaries (Knight and Landres, 1998; Liu, 2001). The cross-boundary management paradigm considers the impacts of management within a focal system (patch or landscape) on other systems, as well as incorporating the impacts of management in other systems on the focal system (e.g., Chapter 7, this book). Also, it is important to study ecological and socioeconomic factors affecting landscape functions so that the functions can be enhanced or suppressed as appropriate (e.g., to create barriers for the dispersal of invasive species and to remove barriers to the movement of endangered species; Chapter 9, this book).

From static management to adaptive management
In the past, many management practices remained the same, even though significant changes had taken place on the landscape. For example, fire suppression in many regions of the US continued despite accumulation in the amount of fuel (Baker, 1994; Miller and Urban, 2000). Similarly, fishing pressures remained high despite a sharp decline in fish stocks and degradation in fish habitat (Rothschild *et al.,* 1994; Larkin, 1996). Because landscapes are constantly changing due to natural and anthropogenic disturbances (including management practices), management practices suitable for a previous condition are not always appropriate for new conditions. Thus, management strategies need to be changed accordingly. Adaptive management (Holling, 1978; Walters, 1986; Lee, 1993) has become an increasingly popular approach for addressing such dynamic and uncertain issues. The purpose of adaptive management is to accumulate knowledge and, thus, reduce uncertainty about the system. To achieve this purpose, adaptive management uses management alternatives as experiments with testable hypotheses. Furthermore, it is an iterative process that can adjust to new information, new management goals, and landscape changes over broad spatial and temporal scales.

From isolated management to integrated management
Past resource management practices often had single objectives (Scott *et al.*, 1995), which caused many unexpected negative results and varying degrees of socioeconomic and ecological conflicts (Kohm and Franklin, 1997). For

example, the goal of forest management was usually to produce as much timber as possible. However, timber harvesting had secondary effects of improving habitat for white-tailed deer by creating an abundant supply of accessible forage (Waller and Alverson, 1997). Improved habitat increased deer numbers to the point that forest regeneration in many areas had been almost completely eliminated and, thus, timber production could not be sustained (Alverson *et al.*, 1988). Additionally, overabundant deer populations caused crop damage and traffic accidents (Xie *et al.,* 2001). Furthermore, these consequences vary at multiple scales over time. This example illustrates the need for simultaneously and holistically managing deer, timber, and other natural resources in the landscape. To eliminate or minimize such conflicts and maintain high landscape integrity, it is important to take an integrated approach that incorporates multi-scale, cross-boundary, and adaptive management. It is crucial that different types of natural resource management be coordinated in both space and time. Integrated management shares many features with widely discussed ecosystem management (e.g., Grumbine, 1994; Christensen *et al.*, 1996), but integrated management also takes a landscape perspective by dynamically incorporating spatial interactions across heterogeneous landscapes to achieve sustainable landscape integrity.

1.4 Linking landscape ecology with natural resource management

The main objective of this book is to link landscape ecology with natural resource management. The linkages are discussed in six sections, comprising 20 chapters. The first section is introductory and contains this chapter, while the last section offers syntheses (Chapter 18) and perspectives (Chapters 19–20) regarding opportunities and challenges in integrating natural resource management with landscape ecology. The middle four sections (Parts II through V) link four different aspects of landscapes (structure, function, change, and integrity) with four corresponding management paradigms (multi-scale, cross-boundary, adaptive, and integrated management). Part II emphasizes multi-scale management based on landscape structure. Part III discusses the relationships between landscape function (e.g., flows of energy, matter, and species) and cross-boundary management (i.e., management across natural boundaries, ownership boundaries, political boundaries, and/or management boundaries). Part IV ties adaptive management with landscape change. Part V links landscape integrity with integrated management. We should point out that while each of Parts II–V has a particular emphasis, a certain degree of overlap is inevitable, as the four landscape aspects and the four management paradigms are interrelated. Furthermore, each of the 16 chapters in Parts II–V provides background information regarding numerous natural resource