Chapter 9
Forest landscape management in response to change: the practicality

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Abstract In this chapter, we examined forest landscape management from a pragmatic (practical as opposed to idealistic) perspective. The discussion was framed in the context of the landscape: a spatially explicit geographic area consisting of recognizable and characteristic component ecosystems. This perspective provided two opportunities for management: the individual component ecosystems and the mosaic of ecosystems that form the landscape per se. A point of emphasis was that forest management is not a generic concept and requires specification of the purpose of management, the spatial unit(s) being managed, the type of forest being managed, and the projected desired outcome of management. Given these constraints, we considered how the principal drivers of landscape change (disturbances, climate, and domestication) influence forest management practices. We concluded with an examination of the concept of designed forest landscapes to provide human-valued goods and services and identified constraints to achieving this end.

9.1 Introduction

Forest landscapes exist in a variety of forms and are managed for multiple purposes. In this chapter, our goal is to examine forest landscape management from a pragmatic (practical as opposed to idealistic) perspective. The discussion is framed within the context of the principal drivers of forest landscape change: human intervention through domestication, natural disturbances, and climate. This approach is taken with the full recognition of contemporary and pervasive literature that deals with topics such as sustainability science (Wu 2013), landscape sustainability (Weins 2013), landscape services (Potschin and Haines-Young 2013, Termorshuizen

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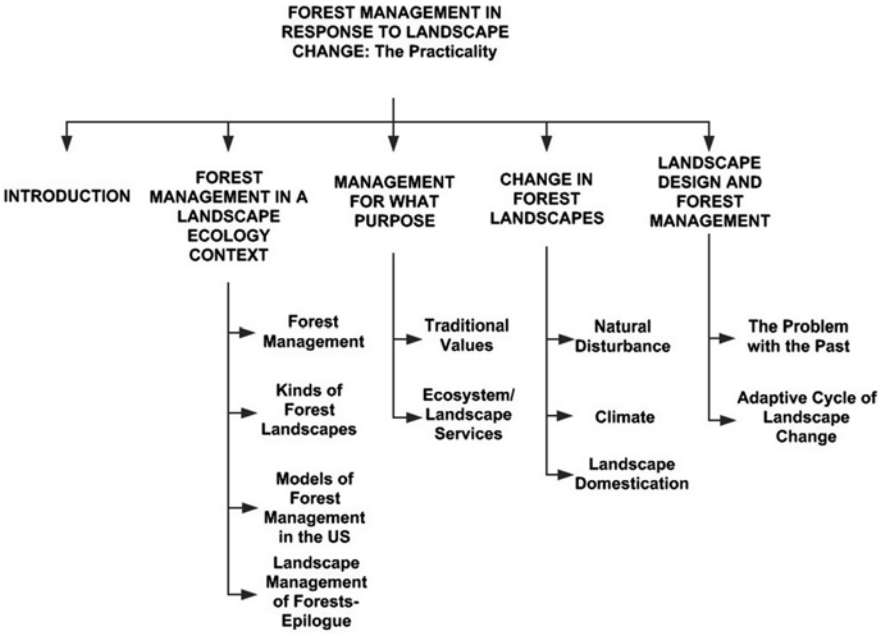

Figure 9.1 Summary of the topics considered in "Forest management in response to landscape change: the practicality"

and Opdam 2009), and designed landscapes (Musacchio 2009, Nassauer and Opdam 2008). Each of these subjects has relevance to forest landscape management in response to change, and in the following sections, we introduce concepts from this literature pertinent to the focus of the chapter. In particular we examine (1) forest management in a landscape ecology context, (2) management for what purpose, (3) change in forest landscapes, and (4) landscape design (Fig. 9.1). This investigation draws from domain knowledge associated with *landscape ecology*, which is the science that embraces the agenda of ecology in a spatially explicit manner (Coulson and Tchakerian 2010).

9.2 Forest management in a landscape ecology context

To *manage* is to take charge of or care of. As our focus centers on forest landscapes, how we define the spatial and temporal dimensions and the composition (structure) of the management arena, i.e., landscape, is of paramount importance. For our purposes, a *landscape* is defined to be a spatially explicit geographic area, i.e., an area defined by coordinates, consisting of recognizable and characteristic component

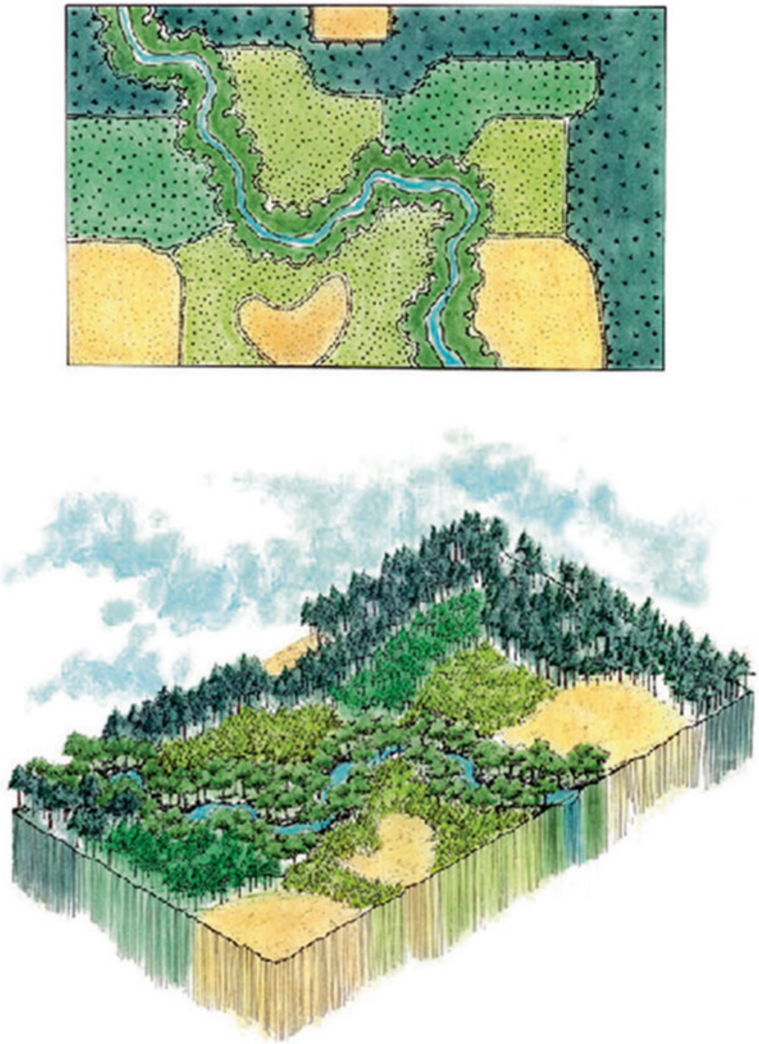

Figure 9.2 Overhead and plan views of a forest landscape, illustrating the component ecosystems and the mosaic pattern. *Source*: Coulson and Tchakerian (2010). Used with the permission of KEL Partners Inc.

ecosystems (Fig. 9.2) (Coulson and Tchakerian 2010). Given this definition, there are two opportunities for management: the individual component ecosystems and the mosaic of ecosystems that together form the landscape per se. Each of these management units is examined in the following sections.

9.2.1 Ecosystems as building blocks of landscapes and management units

The scientific literature dealing with ecosystems is inherently vague on spatial dimensions. Likens (1992) provided the first definition of ecosystem that included boundary as a component: "a spatially explicit unit of the Earth that includes all of the organisms, along with components of the abiotic environment within its boundaries". However, the issue of boundary and ecological functionality was recognized and dealt with in the European literature (reviewed by Zonneveld 1989) beginning in the 1930s through the concept of an *ecotope*, i.e., the smallest ecologically distinct landscape feature associated with a landscape mapping and classification system. Ecotopes are bounded ecosystems. The term *ecotope* is also synonymous with *site*, proposed by Bailey (1996).

Bounded ecosystems have historically been the fundamental unit of management in forestry and agriculture. The basic ecosystem processes (primary production, consumption, decomposition, and abiotic storage) are the targets for management. For example, gross primary production in forest ecosystems has been greatly increased by genetic selection, i.e., "tree breeding." For some forest tree species, the breeding programs have greatly altered the ratio of bole length to crown size and thereby increased merchantable biomass. Net primary production can be greatly increased by integrated pest management tactics that reduce herbivore consumption by pest species. Pesticide applications represent a common tactic in both forest and agricultural ecosystems. Decomposition in forest ecosystems is influenced by different types of site preparation practices: debris removal, furrowing, windrowing, etc. These practices also reduce export of nutrients by fluvial- and aeolian-mediated erosion and, along with fertilizer inputs, influence abiotic storage (Coulson and Tchakerian 2010). Finally, bounded ecosystems are generally the unit of harvest in commercial forests and therefore represent the source for one type of final ecosystem service: wood fiber for use by humans in building construction, paper production, and as fuel.

In summary, we define *forest ecosystem management* to be the orchestrated modification or manipulation of the basic ecosystem processes (primary production, consumption, decomposition, and abiotic storage) for desired human-defined ends. In traditional forestry, management centers initially on forest vegetation, and it is the domain of *silviculture*. The term *silviculture* is simply defined as the theory and practice of controlling forest establishment, composition, and growth. When practiced, this anthropocentric activity is place based, with the bounded ecosystem serving as the management unit. The knowledge base dealing with silviculture of many commercially important tree species is rich and extensive. This knowledge base is in part founded on a fundamental understanding of plant population and community dynamics and the tacit experience of forestry practitioners. Examination of how human intervention, climate change, and natural disturbance affect forest management practices begins with the component ecosystems that form the landscape.

9.2.2 Forest landscapes as management units

We are representing a landscape to be composed of multiple bounded ecosystems that together form a mosaic that is typically characterized by heterogeneity. The exchange of matter, energy, and information within the landscape is influenced by the kinds of ecosystems present and their spatial arrangement, i.e., the content and context of the building blocks. The ecosystems that characterize a specific forest landscape are defined fundamentally by topographic, climatic, and edaphic variables superimposed on an underlying geomorphology. As the climatic and edaphic variables change, so do the component ecosystems and their characteristic flora and fauna. By aggregating the component ecosystems that form a landscape, we have changed and expanded the basic management unit to include the mosaic. This landscape unit is considerably more complex than the ecosystem, and the management approaches and end points are much different.

Forest landscape management is the orchestrated modification or manipulation of landscape structure (components of the landscape and their linkages and configurations), function (the flux of energy, matter, and information within and among the component ecosystems), and rate of change (alteration in the structure and function of the ecological mosaic over time) to create dynamic mosaic patterns that provide human-valued goods and services. Again, landscape management is a place-based activity involving discrete human activities enacted within a spatially explicit land area organized as a mosaic of component ecosystems (Coulson and Tchakerian 2010). The *dynamic* feature of the definition implies that the mosaic patterns of forest landscapes develop and cycle through time in a predictable and sustainable way. However, there is no compelling evidence to suggest that forest landscape succession proceeded in this manner prior to the Anthropocene or that forestry practices today could be used to mimic the process if it did exist. The fundamental contemporary question is then how the drivers of change alter the processes that result in *observed* patterns of forest landscapes through time, i.e., the reverse of the pattern/process paradigm. The answers to this question represent the research, development, and applications agenda for landscape ecology and forest science for the foreseeable future. Musacchio (2009), Termorshuizen and Opdam (2009), Kates (2011), Turner et al. (2013), and Wu (2013) all provide lists of topics that identify different aspects of this agenda.

9.2.3 Kinds of forest landscapes

To this point, we have represented a forest landscape in a generic manner to be a mosaic consisting of multiple interacting ecosystems and management to be an anthropocentric activity directed to provision of goods and services. However, forests are also commonly classified to reflect specific management goals, structural complexity, spatial extent, different levels of human intervention, and ownership.

For discussion purposes, we recognize six different types of forests: conservation forests, extensively managed forests, intensively managed forests, specialized forestry settings, agroforests, and urban/suburban (*peri-urban*) forests. This classification differs modestly from that used by FAO (2011). The following is a brief description of the forest types.

The *conservation forest* is considered to be the natural or nominal condition. These forests are not managed for the production of goods and services, but, rather, are left to develop through natural processes of ecological succession. These forests are generally protected because of unique physical attributes and scenic beauty. Within the United States National Forest System, the USDA Forest Service sets aside conservation forests. These forests are designated as wilderness areas. Direct human intervention is minimal. Natural disturbances are left to follow their normal course. The biotic response to climate change is based on natural history traits that include inherent tolerance (or intolerance) to extreme and cyclic conditions. Persistence of conservation forests, given little human intervention, is often a function of their spatial extent. The cumulative impact of the disturbance regime has to be smaller than the area protected.

In *extensively managed forests*, human use of multiple resources (timber production, fish and wildlife, hydrology, recreation, grazing, etc.) is recognized. Extensively managed forests are often isolated from large human population centers, e.g., boreal forests of Canada, Alaska, and Russia. As such, these forests are used for the production of goods and services but, because of their remote locations, are modestly managed. Natural disturbances (such as wildfire and insect outbreaks), along with human intervention through harvesting, play important roles in shaping the structure and composition of extensively managed forests (Berg et al. 2006, Williams and Birdsey 2003). Again, climate change adds or extracts species as dictated by their tolerances.

Intensively managed forests are the focus of much of the commercial forestry practiced worldwide. The fundamental unit of silviculture is the bounded ecosystem (as defined above). Management practices often involve clear felling (cutting of all trees from a site), site preparation, fertilization, replanting with genetically selected species, etc. Landscape heterogeneity is reduced by single-species plantings. Age-class distribution is a function of harvest schedules. Human intervention is extreme. The forest landscape is highly modified relative to the nominal state. Management also includes efforts to reduce the impact of natural disturbances, e.g., fire control and suppression of insect and disease outbreaks.

Specialized forestry settings include nurseries (for the production of seedlings and ornamental plants), seed orchards (for the production of genetically selected seeds for reforestation), Christmas tree plantations, etc. The specialized settings require considerable care and maintenance and management activities resemble agriculture more than typical forestry practice, i.e., the emphasis is on cultivation rather than silviculture. Again, the fundamental unit of management is the bounded ecosystem.

An *agroforest* consists of a blend of agricultural crops and forest trees. *Agroforestry* deals with using trees on farms. There are two categories of the practice: simultaneous (trees, crops, and/or animals are grown together at the same time on the same parcel of land) and sequential (crops and trees take turns in occupying most of the same space, e.g., slash and burn agriculture). Agroforestry is an ancient practice primarily associated with tropical environments. It results in the production of both foodstuffs as well as forest products. Agroforests share some characteristics of natural forests in that they generally consist of multiple strata, contain large and mature trees, and have a shade-tolerant understory.

The *urban/suburban* (*peri-urban*) *forest* is a broad designation that includes a variety of settings, e.g., residential neighborhoods, parks, trees along city streets, etc. Urban/suburban forests can be remnants from commercial forests that have been encroached upon through development, they can be the result of plantings, or they can represent a combination of both native and introduced plant species. Their principal purposes are for esthetic enjoyment and as buffers to weather. Urban/suburban forests are highly modified by humans and are often created and designed to provide an illusion of the natural state. However, they can also serve to provide goods and services, e.g., refuges of biodiversity, habitat for wildlife, food (e.g., nuts and fruits), etc.

The point of this discussion of the different forest types is to emphasize that the ecological, economic, social, and political impact of the drivers of change is different for each landscape. Regardless of whether the forests are valued using traditional measures (timber production, water, hydrology, recreation, grazing, etc.) or ecosystem (landscape) services, the differences remain. In some instances, forest management can influence the degree of impact. For example, in intensively managed forest landscapes, natural disturbances such as wildfire and insect outbreaks can often be suppressed using remedial tactics. Human-mediated change, such as the introduction of invasive plant species, can be addressed through vegetation management practices. Response to climate change by conversion to another plant species or management approach at the ecoregion scale is generally not a viable solution for intensively managed forest landscapes. Guldin (2013) provides a compelling example illustrating factors associated with converting naturally regenerated pine (*Pinus* spp.) stands to intensively managed plantations in the southern United States. The conclusion was that a “climate-change conversion program” would be prohibitive given the cost, acreage involved, and public and nonindustrial private forest land ownership. However, for urban/suburban landscapes, species replacement is a viable approach. For example, Dutch elm disease (*Ophiostoma ulmi* and *O. novo-ulmi*) eliminated American elm (*Ulmus americana*) as a prominent landscape tree in urban and suburban northeast and north central United States. Over a period of several decades, American elm was replaced with a variety of hardwood species that reestablished many of the functional roles this tree once provided. Ironically, ash (*Fraxinus* spp.) was one of the recommended replacement species, and this genus is now host for the emerald ash borer (*Agrilus planipennis*). This introduced invasive species is a significant mortality agent for ash species throughout much of their range in the United States, and it is having an impact on urban and suburban forest landscapes comparable to that of the Dutch elm disease several decades earlier.

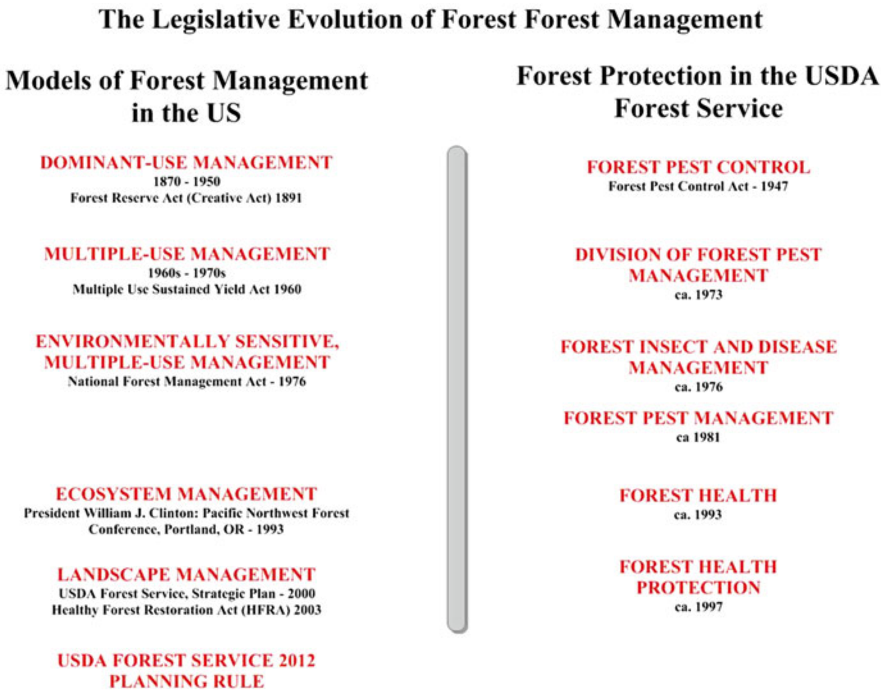

Figure 9.3 The history of forest management models employed by the USDA Forest Service in National Forests in the United States

9.2.4 Models of forest management

In the United States, several different models have been used in the past to guide forest management practice on public lands. Each model represented the prevailing thought of the time on how forests should be managed for the public good. Authorization came from legislative mandates and, in turn, each model was implemented throughout the National Forest System. Figure 9.3 summarizes the legislative history of forest management in the United States, as well as the response by the extension arm of the USDA Forest Service, Forest Health Protection, to the different models. Beginning in 1870, six different models have been used: dominant-use management; multiple-use management; environmentally sensitive, multiple-use management; ecosystem management; landscape management; and the forest plan. Coulson and Stephen (2006) examine the basic features of each model in detail, and here we simply identify the point of emphasis and the reaction of the Forest Health Protection agency. The purpose of the following commentary on the different models of forest management is to provide perspective for the prevailing view of forest management.

The first model of forest management in the United States was known as *dominant-use management*. This model followed from the Forest Reserve Act

(Creative Act of 1891) and persisted into the 1950s. The approach emphasized production of economically valuable species. Typically the goal was to maximize production. Protecting the means of production was also a goal, and this activity included fire control and insect suppression. In recognition of the complexity of forest protection, the Forest Pest Control Act of 1947 established the extension arm of the USDA Forest Service, and this agency was first named *Forest Pest Control* (Fig. 9.3).

The second model of forest management was known as *multiple-use management*. This model was authorized by the Multiple-Use Sustained Yield Act of 1960. The principal new feature centered on the recognition that forests provided a variety of goods and services that were valued by humans, in addition to timber production. The goal of multiple-use management was to maximize utilization of different resource values and do so on a sustainable basis. The term *sustainability*, in this context, meant continuous production of desired outputs, e.g., a non-declining and even flow in the case of wood fiber. No single resource was to be valued more than any other. This model provided the legal basis for management of United States National Forests in the 1960s and 1970s. In response to the broader management charge, the extension arm of the USDA Forest Service was renamed the *Division of Forest Pest Management* in 1973.

The third model was referred to as *environmentally sensitive*, *multiple-use management*. This model was authorized through the National Forest Management Act of 1976. The model represented forests as systems with interacting biotic and abiotic components and recognized that production was subject to ecological and environmental constraints. Important management concepts included sustained yield, minimizing negative environmental impacts, and protecting species diversity. This model recognized that different management approaches were possible, included a means to obtain input from stakeholder groups, and provided for the creation of a "Committee of Scientists" (to advise the Secretary of Agriculture on forest management issues). To accommodate the new model, the forest protection enterprise was renamed *Forest Insect and Disease Management* in 1976 and later changed to *Forest Pest Management* in 1981. The model was an abject failure but led to the next chapter, ecosystem management.

The fourth model was referred to as *ecosystem management*. This model followed from the Pacific Northwest Forest Conference in 1993, convened in response to controversy over forest management on public lands in the Pacific Northwest, United States. In contrast to the previous anthropocentric concepts of forest management, ecosystem management was a biocentric (biologically centered) concept. The goal was to maximize ecological integrity or "health", subject to the need to allow for sustainable human use. Ecosystem protection was the first priority and human-valued goods and services the second. Ecosystem management represented a significant departure from the production-driven models described above that emphasized forest resources. Although laudable in intent, ecosystem management was an elusive concept for both ecologists and foresters. Nevertheless, in 1993 the forest protection enterprise was renamed *Forest Health* and changed again in 1997 to *Forest Health Protection*.

The fifth model was referred to as *landscape management*. Authorization came from two sources: the Forest Service Strategic Plan of 2000 and the Healthy Forest

Restoration Act of 2003. In this model, the basic management unit was the landscape (as defined above). Emphasis was placed on the functional interconnections among landscape components as well as the production of human-valued goods and services. This integrative perspective resulted in an ecocentric management concept that combined both the anthropocentric and biocentric views of previous models. Implementation of the landscape management concept, again, proved to be problematic. However, the Healthy Forest Restoration Act did provide a set of guidelines for directed actions that were intended to adjust the landscape environment to approximate previous states, which were presumed to be better than the existing conditions.

The current view of forest management on public lands in the United States is defined by the National Forest System land management *planning rule*. The planning rule was implemented in 2012 and now serves as the guideline for USDA Forest Service management of the National Forest System. The intent of the planning rule is "to ensure that (management) plans provide for the sustainability of ecosystems and resources; meet the need for forest restoration and conservation, watershed protection, and species diversity and conservation; and assist the Agency in providing a sustainable flow of benefits, services and uses of National Forest System lands that provide jobs and contribute to the economic and social sustainability of communities."

The point of this discussion of the different models used in management of public forest lands in the United States is to emphasize the dramatic change in philosophy and practice that has occurred over a brief period of about 150 years. Because management of public lands in the United States is enacted through a legislative process and implementation is charged to a governmental agency (the USDA Forest Service), tracing changes in the model was straightforward and tractable. Other countries with a legacy of governmental management of public forest lands likely have undergone dramatic changes in approach as well. Why the models of forest management changed is subject to speculation. The following are five plausible reasons: (1) perceived deficiencies or inadequacies in the approach or outcome of management, (2) accommodation of advances in technical information and tacit knowledge of forest management, (3) expansion of the values for which forests are managed, (4) the perceived need to protect and preserve forest lands in perpetuity, and (5) recognition of the contribution forest lands provide in regulating global atmospheric processes.

9.2.5 Landscape management of forests: epilogue

In the preceding subsections, the goal was to frame forest management in an explicit manner. To this end, we addressed three issues. First, we specified and defined the actual spatial units of forests that are amenable to human intervention and that are directly affected by the drivers of change (ecosystems and landscapes). Second, we identified different kinds of forests and emphasized that each had specific management goals and objectives, constraints on the degree of management that is possible or desirable, and unique valuation systems for scoring the impacts of change. Third, we examined six different models of forest management employed in the United States (implemented over a period of less than 150 years) and identified that there has been an evolution in philosophy ranging from resource mining to an emphasis on a science-based approach for understanding the relation of the forest environment and the production of human-valued goods and services. The point of emphasis is that forest management is not a generic concept and requires specification that includes the purpose of management, the spatial unit(s) being managed, the type of forest being managed, and the projected desired outcome of management. The anthropocentric models of management were appealing for their simplicity, i.e., an emphasis on the production of human-valued goods and services. The models of forest management became intractable with the presumption that there was a well-defined scientific recipe (with ingredients from ecology) that could be applied to guide the enterprise.

9.3 Purpose of forest management

Forest management is a purpose-driven business. The specific values for which forests are managed can be summarized categorically (which is the traditional approach) or by the concept of ecosystem services (which is a contemporary view). Following, we examine each and also consider the relation between the two approaches.

9.3.1 Traditional values

The traditional purposes for forest management have been summarized categorically as "values". The basic categories of management initially centered on timber production, hydrology, fish and wildlife, recreation, and grazing; and this list was later expanded to include real estate, biodiversity, endangered species, cultural resources, and non-wood forest products. Each of these categories represents a multifaceted subject domain, and all include as an endpoint something of value to humans. The value can usually be expressed in monetary terms, which facilitates a place-based calculation of the impact of the drivers of change. All of the constraints identified (forest type, location, spatial and temporal scale, management objective, etc.) come into play in the valuation process.

9.3.2 Ecosystem services

An alternative approach to forest valuation is summarized in the concept of ecosystem services. Simply defined, *ecosystem services* are "the benefits of nature to households, communities, and economies" (Boyd and Banzhaf 2007). The concept grew from an interest in a science-based approach to managing the environment to enhance human welfare. Scientific and social interest in the subject of ecosystem services followed from the publication of the *Millennium Ecosystem Assessment* (MEA 2005) and the topic has since received considerable commentary in the landscape ecological science and environmental economic literature, e.g., Boyd and Banzhaf (2007), Termorshuizen and Opdam (2009), Mace et al. (2012), Turner et al. (2013), Wu (2013), Marta-Pedroso et al. (2014), etc.

Given our focus on the purposes of forest management in relation to drivers of change, there are three features of the concept of ecosystem services that are relevant: the economic component, the relation between scientific and social perspectives, and the landscape context. Each of these topics is examined below.

9.3.2.1 The economic perspective on ecosystem services

There is an economic component of the concept of ecosystem services that is closely tied to interests in systems for environmental accounting and performance assessment. "Services" are the units these systems track and measure. The economic perspective is particularly useful for defining what constitutes an ecosystem service, given that there are several taxonomies. To be useful in environmental accounting systems, ecosystem services must be defined by quantity (units) and price. This constraint requires a precise definition of ecosystem services. To address this critical requirement, Boyd and Banzhaf (2007) distinguish between final and intermediate ecosystem services. *Final ecosystem services* are components of nature directly enjoyed, consumed, or used to yield human well-being, e.g., wood fiber, clean water, scenic beauty, etc. Final ecosystem services are end-products of nature. *Intermediate ecosystem services* are the biological, physical, and chemical processes that lead to the end-products. Nutrient cycling is an example of an intermediate ecosystem service. The value of intermediate services is in the provision of final ecosystem services. The *Millennium Ecosystem Assessment* (MEA 2005) defined ecosystem services as supporting, regulating, provisioning, and cultural. The first and second categories are examples of intermediate services, and the third and fourth are final services. Furthermore, there is a fundamental distinction between the quantity (or physical measure) of ecosystem services and the value of those services. The social value of ecosystem services is spatially explicit, i.e., ecosystem services are not spatially fungible or subject to spatial arbitrage (Coulson and Tchakerian 2010). The categorical forest management values identified above are examples of final ecosystem services in that they can be characterized by quantity and price.

9.3.2.2 The relation of scientific and social perspectives of ecosystem services

We have represented a landscape in a scientific context to be an eco-physical entity, i.e., an integration of the biotic and abiotic components within a spatially explicit boundary. An alternative perception considers the landscape to be a cultural unit (Nassauer 1997; Wu 2011, 2013). In this view a “landscape is… a heterogeneous mosaic of ecosystems that is constantly being adapted by humans to increase its perceived value” (Nassauer and Opdam 2008). The bridge between the ecological and cultural views of a landscape is through the structure–function–value chain (Termorshuizen and Opdam 2009). The ecological concept of landscape centers on the structure–function portion of the chain and deals specifically with processes. The processes are the intermediate ecosystem services, as defined in the previous section. From a management perspective, the basic question is how the drivers of change affect the governing processes of the structure–function (pattern/process) relationship that result in a desired forest landscape mosaic. The answers to this question are clearly the domain of scientific inquiry. The cultural concept of landscape centers on the function–value portion of the chain and deals with end-products of management. The end-products are final ecosystem services, as defined in the previous section. The basic forest management question is how the drivers of change affect the values placed on the end-products. The answers to this question still involve scientific inquiry but also require economic and social assessment (Termorshuizen and Opdam 2009).

9.3.2.3 Landscape context of ecosystem services

The acknowledgment that forest landscape management includes consideration of both eco-physical and cultural perspectives (linked through the structure–function–value chain) leads to an expanded view of the concept of ecosystem services. Final ecosystem services are often associated with a component ecosystem that is an element of the landscape mosaic, e.g., fish harvested from a lake. However, the clean water and habitat structure that provided the environment for the fish resulted from processes (intermediate services) associated with adjacent ecosystems, e.g., filtration, nutrient inputs, etc. Furthermore, in some cases the final ecosystem service is the result of an ensemble of interacting ecosystems, e.g., a scenic vista. In this case, the final ecosystem service, esthetic enjoyment of a viewshed, results from a unique placement of different ecosystems in the mosaic. Both ecosystem services can be managed for, e.g., protecting the intermediate services and regulating harvest, in the case of the fish in the lake; and preservation of the viewshed by excluding intrusions (e.g., roads, built structures, etc.), in the case of the scenic vista. So, in addition to the eco-physical/cultural perspective, landscape heterogeneity must also be included in any discussion of management for ecosystem services.

The concept of ecosystem services is evolving. Synonyms include terms such as natural capital, environmental services, green services, and landscape services. All emphasize a connection between the eco-physical environment (ecosystem and landscapes) and human values (Termorshuizen and Opdam 2009).

9.4 Change in forest landscapes

Landscape change deals with the alteration of the structure and function of the landscape environment in space and through time. Following, we examine three principal drivers of change in forest landscapes: natural disturbance, climate, and domestication. Coulson and Tchakerian (2010) provide an expanded discussion of the topic focused on landscape-cover change, landscape-use change, effects of landscape change on living organisms, and development of pattern in mosaic landscapes.

9.4.1 Natural disturbance in forest landscapes

The concept of *disturbance* is fundamental to a discussion of change in forest landscapes. The term is used interchangeably with *perturbation* and *stress*. Although variously defined in the literature, for our purpose, a *disturbance* is an initiating cause (a physical force, a process, or an event) that produces an effect (consequence) that is greater than average, normal, or expected. This definition requires a reference state (i.e., a mean condition bounded by a range in variation), as well as specification of spatial and temporal boundaries. The utility of a rigorous definition of disturbance is to separate circumstances where an initiating cause → consequence relationship is considered to be a disturbance in contrast to a normal or expected event. For example, when does a fire in a fire-climax forest (e.g., chamise chaparral, *Adenostoma fasciculatum*) cease to be a normal or expected event and become a disturbance (Coulson and Tchakerian 2010)?

A disturbance event can be characterized in a variety of ways: e.g., it can be biotic or abiotic in origin; it can be distributed, targeted, diffuse, or patchy in space; it can be frequent, rare, or periodic in occurrence; etc. The scope of the concept of ecological disturbance in forests is immense. However, there are several recurrent themes that center on the effects of disturbance on forest landscape transformation processes, primary production, nutrient cycling, biodiversity, endangered and threatened species, and population dynamics of selected species. The impacts can be assessed from ecological, economic, social, and political perspectives and also evaluated in the context of ecosystem services (Coulson and Tchakerian 2010).

Evaluating the consequences of disturbance events for a forest landscape requires observation over an extended time frame. Five human generations or approximately 100 years (20 to 25 years × 5) is often used as a reasonable temporal boundary.

The ensemble of disturbance types associated with a specific landscape is referred to as a *disturbance regime*, and impact evaluation involves an assessment of the aggregate regime.

9.4.2 Climate and forest landscape change

For our purposes, *climate change* is "a departure from the expected average weather patterns ('climate normals')" (NOAA 2013) for a specified forest landscape. As a driver of change, we are particularly interested in how variation in the expected state of the atmosphere (as defined by variables such as temperature, precipitation, wind speed, etc.) affects the biotic communities associated with forest landscapes. Effects on the biota are a function of tolerances to changes in the weather parameters (e.g., in means, extremes, variability, and seasonality) and adaptability to increased frequency and intensity of atmospheric-initiated disturbance events (floods, droughts, storms, fire, pestilence, etc.) (Bellard et al. 2012, Iverson et al. 2014).

The effects of climate change on a forest landscape are manifested in several ways: species can be eliminated, the timing of species life cycle events can be altered, the distributional range and extent of species can be expanded or reduced, trophic structure can be disconnected, and biotic regulation of ecosystem processes can be disrupted or eliminated. Within an ecological time frame, the living organisms have limited options to accommodate new climatic conditions: response in space through various dispersal mechanisms and response in time through adjusting life history strategies (e.g., phenology, diurnal rhythms, etc.). Forest management options in response to climate change are limited and again constrained by the purpose of management, the spatial unit(s) being managed, the type of forest being managed, the projected desired outcome of management, and the market value of final ecosystem services.

Forest trees are generally long-lived species, and they move twice in their life cycle, once as a seed and again as a pollen grain. Natural regeneration of forest landscapes is a function of the success of this movement and is constrained, as defined above, by space and time. Replacing species that are poorly adapted to a changing climate regime is feasible in agroforests, specialized forestry settings, and urban/suburban landscapes, but problematic in intensively and extensively managed forests. Certainly, forest managers have the option to substitute species at replanting following harvest or after a broadscale natural disturbance (e.g., from *Pinus* to *Eucalyptus*). However, the landscape ecological consequences of this action are speculative, and markets may not exist for the products of the substitute species. For the reasons outlined by Guldin (2013), orchestrated substitution of species at the ecoregion scale is not economically feasible.

Biotic responses to modest changes in weather parameters can have a profound effect on forest landscapes. Bark beetle herbivory in coniferous forests provides a good example. Small increases in temperature can trigger outbreaks through two different mechanisms: accelerated insect development time (reflected in voltinism, the number of generations the insect passes through each year) and range expansion that exposes greater numbers of hosts or uncommon host species. Berg et al. (2006) attributed in part the massive outbreaks of the spruce beetle (*Dendroctonus rufipennis*) in spruce forests (*Picea* spp.) of Alaska (United States) and the Yukon Territory (Canada) in the 1990s to elevated temperature that reduced winter mortality and increased insect development time from a 2-year life cycle to a 1-year cycle. Logan et al. (2010) documented persistent outbreaks of the mountain pine beetle (*D. ponderosae*) in whitebark pine (*Pinus albicaulis*) in high-elevation forests in Yellowstone National Park (United States). Generally, whitebark pine forests are inaccessible to the insect because the lower temperature regimes are unsuitable for its development. This insect has also been responsible for the massive outbreak in lodgepole pine (*Pinus contorta*) throughout the Pacific Northwest of the United States (U.S.) and Canada.

9.4.3 Domestication and forest landscape change

The term *landscape domestication* is defined as the activities of humans that structurally shape and functionally modify landscapes to satisfy basic human needs. With some concession to simplification, the basic human needs include adequate food, water, housing, energy, health, and cultural cohesion. In the context of forests, management actions associated with domestication are initiating causes that produce predictable changes in the forest landscape use. The management intent is for the changes to provide ecosystem services that directly translate to human needs, as defined above (Coulson and Tchakerian 2010). The subject of humans as agents of change in forest landscapes has been examined in detail by Farinaci et al. (2014) and is by far the most significant driver.

Climate, edaphic characteristics, and topographic features (surface geometry and landform) delineate logical physical boundaries for landscape-use change as directed to forest management. The different kinds of forest landscapes (described above) are largely defined by these structuring variables. The social boundaries for landscape-use change are rooted in issues associated with demographics, economic systems, sociopolitical policy, and technical and scientific developments (Farinaci et al. 2014).

9.5 Landscape design and forest management

Previously, we defined *forest landscape management* to be the orchestrated modification or manipulation of landscape structure, function, and rate of change to create dynamic mosaic patterns that provide human-valued goods and services in perpetuity. Landscape management was also described as a purpose-driven and place-based activity involving discrete human activities enacted on a spatially explicit land area organized as a mosaic of component ecosystems. This concept of management is perhaps praiseworthy in intent, but could it be implemented? In the following we consider the practicality of a science-based approach to forest landscape design for management purposes.

9.5.1 The premise of forest landscape design for the sustainable production of goods and services

The recognition that forest landscapes are structured as a mosaic of interacting ecosystems and that this ensemble forms a template that could be modified and manipulated in prescribed ways for the production of human-valued goods and services logically lead to consideration of the use of design concepts for optimization purposes. Nassauer and Opdam (2008) and Musacchio (2009) advocated the use of a science-based approach to landscape design for management purposes. The concept is defined as follows: "… design [is] an intentional change of landscape pattern, for the purpose of sustainably providing ecosystem services while recognizably meeting societal needs and respecting societal values. Design is both a *product*, landscape pattern changed by intention, and the *activity* of deciding what that pattern could be" (Nassauer and Opdam 2008). A fundamental component of this definition is the notion of sustainability, which is a term also subject to broad-based interpretation. Wu (2013) defined the concept as follows: "landscape sustainability is the capacity of a landscape to consistently provide long-term landscape-specific services essential for maintaining and improving human well-being". Wu (2013) further advocated the utility of a scientific enterprise based on the concept: landscape sustainability science ("a place-based use-inspired science of understanding and improving the dynamic relationship between ecosystem services and human well-being in changing landscapes under uncertainties arising from internal feedbacks and external disturbances"). Further commentary on this subject is provided by Kates (2011). The concepts of scientific design of landscapes, landscape sustainability, and landscape sustainability science are certainly laudable and, in part, represent visions that have accompanied the maturation of the discipline of landscape ecology. However, there are significant obstacles to their application in practical forest management.

9.5.2 The practicality of landscape design in forest management

The practical issues associated with implementation of design concepts that lead to the sustainable production of ecosystem services resulting from forest management center on the disutility of past experiences for predicting future events and the absence of a conceptual model of how change mechanisms influence mosaic pattern in space and time. These subjects are discussed below.

9.5.2.1 The problem with the past: interaction of the drivers

By definition, managed forest landscapes have been modified or manipulated through human intervention. Landscapes where climatic, edaphic, and topographic conditions are favorable for forest production have been utilized for similar purposes for many generations, although there is interplay among agriculture landscape use, forest landscape use, and landscape domestication. In the case of intensively managed forest landscapes, agroforests, specialized forest settings, and urban forests, the modifications and manipulations may have occurred multiple times. For example, the forest region of the Southern United States has undergone massive and multiple changes following European settlement. Initially, much of the native forested land was converted to cotton agriculture, and the revenue generated from this enterprise provided the financial resources that fueled the development of the United States economy. However, following depletion of soil fertility, cotton agriculture was abandoned and converted (or reconverted) to pine (*Pinus* spp.) production. The conventional forestry practice was to reestablish the forests, following harvest, through natural regeneration, and this approach was subsequently replaced by planting genetically selected pine seedlings. This practice has now been utilized through four to six forest generations in the Southern United States. Furthermore, modern agricultural practices and the competing values of cotton fiber vs. wood fiber have resulted in extensive plantings re-devoted to cotton production. The point of this example is to illustrate the fact that managed landscapes today often do not resemble the past state. Additionally, much of this chapter has addressed how the drivers of change (climate, disturbances, and domestication) create new conditional states. We have addressed each driver independently, but it is important to recognize that their influences on forest landscapes are complementary and the consequences of the interactions are unknown. In the context of forest management, how the drivers of change interact, coupled with multiple historical landscape uses, challenges the utility of past experience for predicting future events.

9.5.2.2 Adaptive cycle of landscape change

Using established design concepts to configure forest landscapes for management purposes is not a new concept. One of the first efforts in this regard was provided by Diaz and Apostol (1992) who defined a systematic approach for incorporating emerging concepts of landscape ecology into forest management planning. This approach was referred to as forest landscape analysis and design, and it featured a landscape analysis component (with five steps [landscape elements, landscape flows, relation between landscape structure and flows, process of landscape change, and linkages]) and a landscape design component (with three steps [landscape patterns from GIS databases, landscape pattern objectives, and forest landscape design]). The culmination of the process was a design plan tied to a spatially explicit forest landscape. This approach remains a useful planning tool today. The penultimate step in the process called for the definition of a landscape pattern that would lead to the production of specific ecosystem services in the future. This juncture is where current knowledge of landscape ecology, forest management, and cultural geography is inadequate.

The fundamental problem in using design concepts in forest landscape management is that we do not have a conceptual model (metaphor) that addresses spatially explicit dynamic development and change in landscape mosaics in space and time. An analogous situation exists in the computer science discipline of artificial intelligence (AI). One branch of this discipline, expert systems, has been useful in mimicking human problem solving in practical situations. It is possible to develop computer code that can process the logic associated with "if–then" rules and, with the addition of fuzzy mathematics (to deal with uncertainty), mimic successfully a problem solving approach used by humans. The branch of AI that deals with pattern matching did not fare as well. Humans see and recognize patterns very well, but how we accomplish this task is without a conceptual model. So, it has not been possible to write computer code that even remotely mimics the capabilities of humans in pattern identification.

The adaptive cycle (Holling 1992) and panarchy (Gunderson and Holling 2002) have been useful organizing constructs for conceptualizing change and the development of complex ecological and economic systems. Landscape ecology has not provided a conceptual model for the succession of mosaic pattern in natural (or managed) landscapes. Does mosaic pattern in landscapes follow the conservation, release, reorganization, and exploitation sequence of Holling's adaptive cycle, and how would this scheme play out in a spatially explicit forest landscape?

Simulation modeling for forest landscape dynamics is an active component of landscape ecology research, and the utility and limitations of this approach for studying forest landscape dynamics have been examined by Gustafson (2013). Forest landscape modeling was compartmentalized into two basic methodologies: phenomenological (empirical or statistical) models and mechanistic (process-based) models. Emphasis was placed on the limited utility of phenomenological models based on retrospective examination of past conditions. Process modeling, based on "first principles" (an approach advocated by P.J.H. Sharpe in the early 1970s), perhaps provides a means for understanding the complex behavior of forest landscape dynamics. However, the current state of understanding of forest management does not provide design principles that allow for the projection of the production of sustainable ecosystem services.

9.6 Epilogue

In this chapter, we examined forest landscape management from a pragmatic (practical as opposed to idealistic) perspective. The discussion was framed within the context of the principal drivers of forest landscape change. Four components of forest management were examined and are briefly summarized below: management in a landscape ecology context, management for what purpose, change in forest landscapes, and landscape design.

1. The discussion of forest management was considered in the context of the landscape: a spatially explicit geographic area consisting of recognizable and characteristic component ecosystems. This perspective provided two opportunities for management: the individual component ecosystems and the mosaic of ecosystems that form the landscape per se. Traditionally, silviculture has guided management of the forest ecosystem unit. Management of the mosaic pattern to produce human-valued goods and services is a study in progress. This study is complicated by the existence of different types of forest landscapes, each with unique management goals. Six different forest management settings were examined. Additionally, the philosophical basis for how to manage forests is unsettled, and we illustrated this issue by an examination of the approaches implemented on the National Forest System in the United States over a 150-year period. The conclusion was that forest management is not a generic concept and requires specification that includes the purpose of management, the spatial unit(s) being managed, the type of forest being managed, and the projected desired outcome of management.
2. As the purpose of forest management is of paramount importance, we next examined this subject from two perspectives: traditional values and ecosystem (landscape) services. Ecosystem services were defined to consist of intermediate services (processes) and final services (products). We emphasized that the purposes of forest landscape management included consideration of both eco-physical and cultural perspectives. The bridge for the eco-physical and cultural perspectives of landscape was through the structure–function–value chain. The eco-physical concept of landscape centered on the structure–function portion of the chain and dealt specifically with processes (intermediate services). The cultural concept of landscape centered on the function–value portion of the chain and dealt with the end-products of nature. The basic forest management question was posited as how the drivers of change affect the values placed on the end-products of management.
3. Landscape change was defined to be the alteration of structure and function of the landscape environment through space and time. The principal drivers of change included natural disturbances, climate, and landscape domestication. A *disturbance* was defined to be an initiating cause that produces an effect that is greater than average, normal, or expected. Disturbance characteristics and impacts on landscapes were examined. Climate change was defined as a departure from the expected average weather patterns for a specified forest landscape. Effects of climate change on forest landscapes and biotic responses were examined. The relations between climate change and disturbance were illustrated through examples of elevated herbivory triggered by a modest change in temperature. *Landscape domestication* was defined as the activities of humans that structurally shape and functionally modify landscapes to satisfy basic human needs. Landscape domestication was identified to be the most significant driver of change.

4. We concluded with an examination of the plausibility of using design concepts as a means of modifying and manipulating landscape mosaics for the production of human-valued goods and service. This “design-in-science” concept was considered in the context of the pervasive themes in landscape ecology that deal with sustainable landscapes and sustainability science. Practical issues associated with implementation of landscape design concepts were examined in the context of the disutility of past experiences for predicting future events and the absence of a conceptual model for how change mechanisms influence mosaic pattern in space and time.

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