Chapter 2
Fundamental Concepts in Ecology

Guy McPherson

Abstract Even though exurban development claims millions of acres of privately owned wildlands, most Americans have a limited grasp of the ecological impacts that development brings. This chapter bridges the knowledge gap in two ways. First, it explains the role of ecology in understanding wildland ecosystems. Issues covered include the scope and objectives of ecology, its history and background, and the potential for introducing a land ethic in exurban land development. Second, it describes basic terms, concepts, and ecological processes that appear in subsequent chapters. This provides readers with a richer understanding of the in-depth material provided in these chapters. The chapter also discusses natural science disciplines that play a role in the science of land development beyond the metropolitan fringe.

Introduction

This chapter provides justification for an ecologically based approach to land development beyond the metropolitan fringe. It begins by describing the historical role of humans in land development and then describes a role for ecology in the near future. An overview of terms, concepts, and processes that apply generally to ecological systems is used to introduce subsequent chapters, and therefore avoid overlap and redundancy among those chapters. This approach is intended to enable contributors to discuss selected topics at a relatively high level of understanding. The chapter concludes with a scenario for the future of development beyond the metropolitan fringe.

The human role in extinction of species and degradation of ecosystems is well documented. Since European settlement in North America, and especially after the beginning of the Industrial Revolution, we have witnessed a substantial decline

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in biological diversity of native taxa and profound changes in assemblages of the remaining species. We have ripped minerals from the Earth, often bringing down mountains in the process; we have harvested nearly all the old-growth timber on the continent, replacing 1000-year-old trees with neatly ordered plantations of small trees; we have hunted species to the point of extinction; we have driven livestock across almost every acre of the continent, baring hillsides and facilitating massive erosion; we have plowed large landscapes, transforming fertile soil into sterile, lifeless dirt; we have burned ecosystems and, perhaps more importantly, we have extinguished naturally occurring fires; we have spewed pollution and dumped garbage, thereby dirtying our air, fouling our water, and contributing greatly to the warming of the planet; we have paved thousands of acres to facilitate our movement and, in the process, have disrupted the movements of thousands of species. One could argue that a fundamental problem is not that the road to hell is paved with good intentions, but that the road to hell is *paved*. We have, to the maximum possible extent allowed by our intellect and never-ending desire, consumed the planet. In the wake of these endless insults to our only home, perhaps the biggest surprise is that so many native species have persisted, thus allowing our continued use and enjoyment.

If we accept that humans played a pivotal role in loss of species and degradation of ecosystems, we face a daunting moral question: How do we reverse these trends?

Aldo Leopold simultaneously recognized human transgressions against other species while also providing inspiration for improving our behavior in his famous book, *A Sand County Almanac*: (1949, p. viii): "We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect." Leopold's vaunted "land ethic" provides a goal toward which we can strive.

Maintenance of biological diversity is important because present and future generations of humans depend on a rich diversity of life to maintain our civilization and ultimately our survival. As architects of the extinction crisis currently facing planet Earth, we have a responsibility to future *Homo sapiens* and to nonhuman species to retain as much biological diversity as possible. We must embrace our capacity and capability to sustain and enhance the diversity and complexity of our landscapes. The substantial economic cost of maintaining high levels of biological diversity will pale in comparison to the costs of failing to do so.

Reintroducing ecological processes with which species evolved, and eliminating processes detrimental to native species, underlies the ability to maintain species diversity. Specifically, the management of wildland ecosystems should be based on maintenance and restoration of ecological processes, rather than on structural components such as species composition or maintenance of habitat for high-profile rare species. In fact, a focus on the latter goals—a fine-filter approach—may clog the coarse filter necessary for landscape-scale management of many species and ecosystems. For example, attempting to retain a particular native species by planting and tending individuals of the species in developed environments fails to account for the diverse array of processes necessary for the continued existence of the species. These processes include, for example, pollination, herbivory, seed dispersal, and competition between co-occurring species. By focusing on structural rather than functional elements, the species is retained in the short term, as if in a garden or zoo, while conditions necessary for its long-term persistence continually erode over time. We can plant long-lived species and, with proper care, some individuals will survive. But sustaining populations of these species over long periods of time will require retention of myriad processes that have developed in concert with species' evolution.

A Role for Ecology?

Ecology is the scientific study of the interactions that determine the distribution and abundance of organisms (Krebs 1972). Implicit in this definition is the need to understand the movements of water, nutrients, and energy as a basis for predicting effects of human activities on natural systems (McPherson and DeStefano 2003). Predicting and maintaining or altering the distribution and abundance of various organisms are the primary goals of natural resource management, hence effective management of natural ecosystems depends on ecological knowledge. Paradoxically, management of ecosystems often ignores relevant ecological theory and many ecological investigations are pursued without appropriate consideration of management implications. This paradox has been recognized by several agencies and institutions (e.g., National Science Foundation, US Forest Service, US Fish and Wildlife Service, Bureau of Land Management, Environmental Protection Agency) (Grumbine 1994; Alpert 1995; Keiter 1995; Brunner and Clark 1997) and entire journals are dedicated to the marriage of ecology and management (e.g., *Journal of Applied Ecology*, *Conservation Biology*, *Ecological Applications*). Nonetheless, underlying causes of this ambiguity have not been determined and no clear prescriptions have been offered to resolve the paradox (McPherson and DeStefano 2003). Ecological principles can and should serve as a primary basis for management of human-built environments adjacent to, or surrounded by, wildland ecosystems. Thus far, however, such principles have been invoked rarely as development projects are planned and implemented.

Considerable ecological research has investigated the structure and function of ecosystems. This research has been instrumental in determining the biogeographical, biogeochemical, environmental, and physiological patterns that characterize these ecosystems. In addition, research has elucidated some of the underlying mechanisms that control patterns of species distribution and abundance. Finally, researchers have identified many tentative explanations (i.e., hypotheses) for observed ecological phenomena. Many of these hypotheses have not been tested explicitly, which has limited the ability of ecology, as a discipline, to foresee or help solve managerial problems (Underwood 1995). The application of ecology is further constrained by the lack of conceptual unity within ecology and the disparity in goals of science and management.

The unique characteristics of each ecosystem impose significant constraints on the development of parsimonious concepts, principles, and theories. Lack of conceptual unity is widely recognized in ecology (Keddy 1989; Peters 1991; Pickett, Kolasa and Jones 1994; Likens 1998) and natural resource management (Underwood 1995; Hobbs 1998). The paucity of unifying principles imposes an important dichotomy on science and management: general concepts, which science should strive to attain, have little utility for site-specific management or site-specific development, whereas detailed understanding of a particular site or system, which is required for effective management, makes little contribution to ecological theory. This disparity in goals poses a significant obstacle to relevant discourse between science and management.

In addition, scaling issues may constrain the utility of some scientific approaches (Peterson and Parker 1998). For example, it might be infeasible to evaluate the response to exurban development of rare or wide-ranging species; in fact, it might be impossible to evaluate such responses with strong inference (sensu Platt 1964). In contrast, common species with small home ranges are abundant at restricted spatial and temporal scales and are therefore amenable to description and experimentation; unfortunately, these types of species rarely receive the interest, much less the empathy, of land developers and homeowners. Issues of temporal scale similarly interfere with the integration of science and management. For example, the myriad consequences of land development rarely can be accurately determined, much less predicted, beyond a few years' time. Such information is crucial to managers and policy makers interested in weighing all benefits and costs associated with land development, and the absence of this information often tilts the balance in favor of short-term interests and therefore in favor of developers and the developments they propose. Tack on the positive discount rate fundamental to neoclassical economics, which further favors short-term benefits at the expense of long-term costs, and it seems all the cards are stacked in favor of land development.

Given these many and varied constraints on the application of ecology, it is reasonable to question the role of ecology in any human enterprise, much less an enterprise as invasive and disruptive as a home-construction project (or development of entire subdivisions). Is there a role for ecology as human populations push into wildland ecosystems? Or should ecologists simply get out of the way as the bulldozer transforms the countryside into suitable habitat for civilized humans?

This chapter argues that ecology has the potential to play two roles at the interface between urban and wildland areas: (1) with its understanding of the natural history of species, ecology can mitigate impacts of development and (2) the relatively standardized terminology of ecology can be used to describe the impacts of the transformation of wildlands to exurbs and suburbs (i.e., ecologists are analogous to war correspondents, able to describe the horrors of war in a fair and balanced manner). Thus far, the latter role has been employed far more commonly than the former.

Ecological Concepts

The discipline of ecology is more than a century old, which is an adequate time to develop a firm foundation. Ecology has emerged as the primary source of principles, theories, and concepts for solving environmental problems during the last four decades (e.g., Odum 1971; Ricklefs and Miller 2000). Fueled by Charles Darwin's dangerous ideas about ecology and evolution (see especially Darwin 1859) and an increasingly scientific approach to the study of natural history, ecology rose to prominence as a scientific discipline in the late nineteenth century (McIntosh 1985). The rapid and enthusiastic development of ecology in the late nineteenth and early twentieth centuries was particularly evident in the United States, where naturalists, botanists, and zoologists such as Stephen A. Forbes, Henry Cowles, Frederick E. Clements, Charles C. Adams, Victor Shelford, and Charles Elton pursued ecology as an intellectual endeavor. Despite important contributions by these scientists, particularly to our understanding of the distribution and abundance of species, ecology remained relatively unknown to the general public until the middle of the twentieth century.

Seminal contributions to the study of ecology during the 1930s and 1940s were overshadowed by the Second World War. During this period, ecology was formalized as a quantitative science that illustrated the interconnected nature of organisms within ecosystems. Particularly influential was the work of Raymond L. Lindeman, whose 1942 paper on energy flows through ecosystems became the basis for subsequent work. More importantly in terms of environmental protection, the naturalist and forester Aldo Leopold came to believe that ecology was the basis for understanding and managing planetary resources. Leopold's personal transformation from carnivore-hunting representative of resource-extraction industries to ecologically oriented philosopher and conservationist led the way to a shift in consciousness. Through his writing, Leopold became a primary proponent and contributor to this shift in consciousness that finally reached critical mass in the public arena a quarter-century after his death in 1948.

Ecology entered the public consciousness during the 1960s and 1970s when the roots of many societal problems—pollution, overpopulation, and allocation of resources—were recognized as issues to which ecologists had something important to say. Rachel Carson's 1962 book, *Silent Spring*, found an attentive audience. Among the outcomes of public awareness was a watershed of federal legislation targeted as environmental protection, from the Wilderness Act and the Endangered Species Act to the Clean Air Act and the Clean Water Act. Although much of this legislation reflected confusion in the public arena about the boundaries between the science of ecology and the practice of environmental protection (and in some cases, Druid-like spiritualism), ecology became a touchstone for protection of the natural world.

Ecological concepts relevant to the topic of development beyond the metropolitan fringe are summarized in this section from the author's own experience and descriptions provided by Spellerberg (2002) and Forman et al. (2003). They include water and water flows; vegetation and biological diversity; populations, particularly populations of animals; and interconnections at the landscape scale, particularly fragmentation of habitats (Table 2.1; Fig. 2.1).

Hydrology refers to the quantity of water present in, or flowing through, a system (Dunne and Leopold 1978). Hydrological processes are discussed in Chapter 11. Hydrologic flows are driven primarily by gravity. *Groundwater* fills the spaces

Table 2.1 Ecological consequences of development beyond the metropolitan fringe

Attribute	Impact
Aesthetic	Undesirable relative to natural vegetation
Soil	Infiltration decreases Sediment moved offsite Erosion increases, thus reducing productivity
Hydrology	Watercourses altered Water quality altered Quarrying and transport of materials alter water courses far beyond developed area
Plant community	Nonnative species introduced Native species removed Runoff favors some species at expense of others Chemical pollutants destroy habitat Altered microclimate, especially temperature extremes
Animal community	Habitat "generalists" favored over habitat "specialists" Road kill increases Movements altered or terminated for many species Anthropogenic noise impacts communication among animals

between soil particles, and the upper surface of saturated soil is termed the water table. Groundwater beneath the surface is called an *aquifer*, whereas a water table that persists at or above the soil surface forms a body of water such as a *wetland*, stream, river, pond, or lake. Extensive pumping of groundwater to satisfy human needs for potable water has led to substantial declines in groundwater depth in most urban and suburban areas, and exurban areas are similarly threatened. The

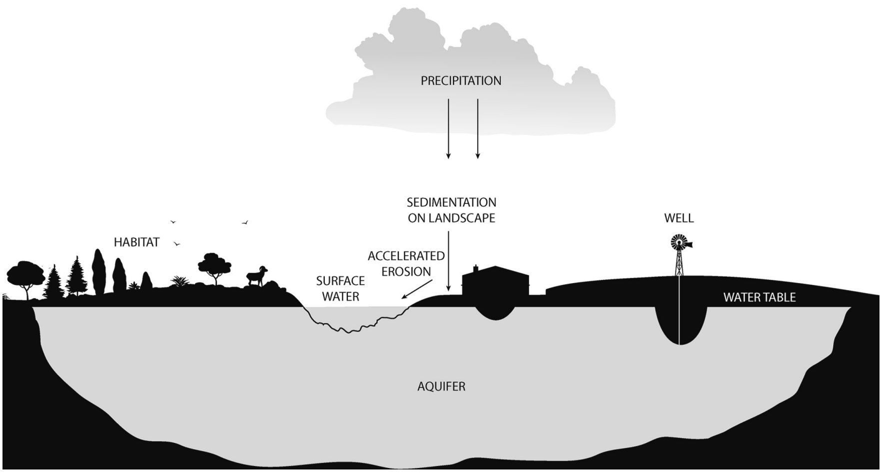

Fig. 2.1 Ecological systems in exurbia. Source: Guy McPherson

subsequent depletion of aquifers causes associated surface waters to dry up, thereby reducing surface waters such as streams and lakes. Habitat for plants and animals that live in well-watered areas is threatened when these features are reduced or eliminated by groundwater pumping.

Upon falling onto the surface of the Earth, precipitation follows one of three routes: *infiltration*, *evaporation*, or *runoff* (Dunne and Leopold 1978). Some water infiltrates into the soil; eventually, some of this water percolates down into a water body or into groundwater via *subsurface flow*. A portion of the water that infiltrates is taken up by plants and pumped back into the atmosphere via *transpiration*. However, much of the precipitation does not infiltrate the soil if it falls onto developed areas (i.e., roads, parking lots, sidewalks, rooftops). This precipitation either ponds on the surface and evaporates directly into the atmosphere or runs off. Considerable effort has focused on mitigating *surface runoff* from urban, suburban, and exurban developments because such runoff, especially during heavy rains, causes *erosion*. From gullies and small channels to streams and rivers, running waters have the potential to carry soil particles and numerous chemicals. The resultant movement of sediment from one place to another on the landscape is problematic in many ways, as described in Chapter 9.

Water quality describes the physical, chemical, and biological characteristics of water (Wetzel and Likens 1991). Physical attributes include temperature, velocity, and turbidity (amount of sediment in solution); chemical attributes include pH and proportions of nitrogen, phosphorous, oxygen, and organic substances; and biological attributes include concentrations of algae, insects, fish, and other organisms. In general, asphalt, compacted soil, and altered distribution of plants and channels resulting from exurban development generate profound changes in water quality.

Vegetation refers to the kinds and numbers of plants in an area. Vegetation serves as *habitat* for animals. The variety of life forms is called *biological diversity* or *biodiversity*. The dominant measures of biodiversity are *species diversity* or *species richness*, terms that refer to the number and abundance of species in an area. *Non-native species* are species that have become established beyond their native ranges. These concepts are detailed in Chapters 4, 5, 7, 8, and 12.

All the individuals of a species that live in a particular place are called a *population*. Most Americans are concerned about populations of species that are colorful (e.g., birds, butterflies) or similar in appearance to humans (e.g., large mammals). Concern is especially apparent for these species when their existence is threatened from a local area (*extirpation*) or from the planet (*extinction*). Causes and consequences of population-level phenomena are described in Chapters 4, 5, 6, 7, and 8. *Fragmentation* of habitats and *corridors* for animal species receive particular attention in Chapters 4, 5, and 6. Finally, mitigation for exurban development in the form of parks, preserves, and regional planning is described in Chapters 10, 12, and 13.

Such mitigation must account for ongoing and likely future changes in global, and therefore regional, climates (see Chapter 3 for a discussion of global climate change). As Earth warms and precipitation regimes change, habitat for all species is being altered. Some species are capable of the rapid movement necessary to keep up with changes in climate, but many others move and reproduce too slowly to adapt.

Thus, the geographical distribution of species and ecological communities likely will change dramatically in the years ahead. Although planning and accounting for these "new" mixtures of species pose a significant threat to biological diversity, our responsibility to future *H. sapiens* and to nonhuman species dictates we must take up this daunting challenge.

Expertise and Opportunities Beyond the Fringe

Although an integrated scientific approach to land development beyond the metropolitan fringe is lacking, scientists and practitioners from many disciplines can inform decision making. Conservation biology and ecology clearly play a role, with their emphases, respectively, on conserving Earth's bounty of life and describing the distribution and abundance of organisms. Both endeavors rely on many other disciplines, if only because no single discipline is sufficient to understand the movements of water, nutrients, and energy as a basis for predicting effects of human activities on natural systems. Because predicting and then maintaining or altering the distribution and abundance of various organisms are the primary goals of natural resource management, managers also play a significant role in land development.

Although ecology is the obvious integrative discipline that could be used to inform land development beyond the metropolitan fringe, the science hardly exists in a vacuum. Rather, ecology is informed by the "applied" sciences of soil science, forestry, wildlife biology, fisheries biology, and range science and also by the "basic" sciences of evolution, genetics, geology, hydrology, and climatology. Soil scientists, geologists, hydrologists, and climatologists describe and quantify physical constraints on development and also describe consequences of development on redistribution of soils and water downstream from developments. Wildlife and fisheries biologists describe and quantify implications of land development for animal populations. Ideally, foresters and range scientists play a similar role with respect to plant populations. In practice, however, foresters and range scientists typically focus on production of trees and livestock, respectively, to the virtual exclusion of all other products and attributes, which limits their credibility and effectiveness.

The sciences of genetics and, more broadly, evolutionary biology indicate that most native species are poorly adapted to land development. By interrupting natural processes to which native species have evolved, land development threatens the survival of native species. For example, interruption of fire regimes, fragmentation of habitat, alteration of hydrological cycles such as floods and runoff, and introduction of nonnative species are among the many anthropogenic activities that pose serious threats to the continued persistence of thousands of native species. Conservation biologists and ecologists continue to tally the losses of species, but no serious effort has been made to stem the rising tide of species extinctions because doing so would require a reduction in economic growth (Czech 2000). Americans, and the politicians who represent us, will tolerate many inconveniences, but we will not willingly abandon economic growth.

As if relations among scientific disciplines and also between science and its application were not sufficiently complex, land tenure further dirties the turbid waters. The rapidly increasing human population and explosion of financial wealth that underlie land development beyond the metropolitan fringe clash with the hodgepodge of mostly conservative land owners and land managers occupying the lands under, or adjacent to, development. Federal lands are managed by the Department of Defense (e.g., military installations, testing grounds, bombing ranges), the Forest Service, which is housed within the Department of Agriculture, and also by several agencies in the Department of Interior. Major players in the latter department include the Bureau of Land Management, National Park Service, Fish & Wildlife Service, and Bureau of Indian Affairs. The sovereign nations known as Indian reservations comprise up to a fifth of lands in some western states. Further adding to the complexity of land tenure, particularly in western states, state land departments manage a significant proportion of lands, often under a peculiar mandate: statehood was granted to western states conditional upon their management of lands in a manner that provides maximum benefit to the state's educational trust fund. The typical interpretation of this mandate is that state "trust" lands should be managed to maximize revenue in support of public education. As a consequence, state land departments typically act as the most aggressive and powerful land developers in western states, auctioning parcels to large land developers in a manner that maximizes revenue for the state trust fund (thereby committing those lands to economic development with minimal protective constraints for resident populations of nonhuman organisms). Private lands, which are intermixed within a patchwork of federal, national, and state lands, typically fall beyond the purview of legislative or regulatory agencies, and therefore are subject to economic development with minimal protection for any attribute except the financial bottom line. One result of the varied missions and goals of federal land-management organizations is general, systemic neglect of nonhuman species, integrated approaches to land development, and, in a broad sense, the common good.

Conclusion

Urbanization and the associated transportation infrastructure have divided formerly large, contiguous landscapes into fragmented pieces. Fires that formerly covered large areas are constrained by fragmentation, and hydrological regimes have been altered in a similar manner. Animals that necessarily range over large areas, such as mountain lions, bison, and grizzly bears, have suffered expectedly and noticeably. Exchange of genetic material among populations of smaller organisms, or those that range over smaller distances, undoubtedly has been reduced as well, although these changes have not been documented and are not readily apparent. Fragmentation of landscapes has been particularly pronounced since the Second World War, largely as a result of government subsidies that have promoted growth of the human population and development of suburbs and exurbs. Suburban development in particular represents perhaps the greatest misallocation of resources in the history of planet Earth. The suburbs are designed for people to live far from their places of work, far from manufactured goods, and far from places to recreate. As a consequence, Americans make several daily trips in their cars, thus burning the planetary endowment of oil and exhausting the myriad resources used to manufacture automobiles.

These trends will be reversed in the coming years because the Oil Age is drawing to a close. The inability to obtain inexpensive fuel, or any fuel at all, spells the demise of development beyond the metropolitan fringe. Indeed, the inability to obtain expensive oil dictates the end of economic growth upon which western civilization is built. Ecologists have long recognized the importance of limits to growth, and it seems increasingly obvious that the end of the Oil Age, hence the end of the age of fossil fuels, represents a fundamental limit on growth (thus persistence) of western civilization. Unfortunately, our near-term inability to burn fossil fuels on a large scale probably will come too late to save many of the planet's species from the effects of runaway greenhouse, perhaps including even our own (Lovelock 2006; Hansen et al. 2007).

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