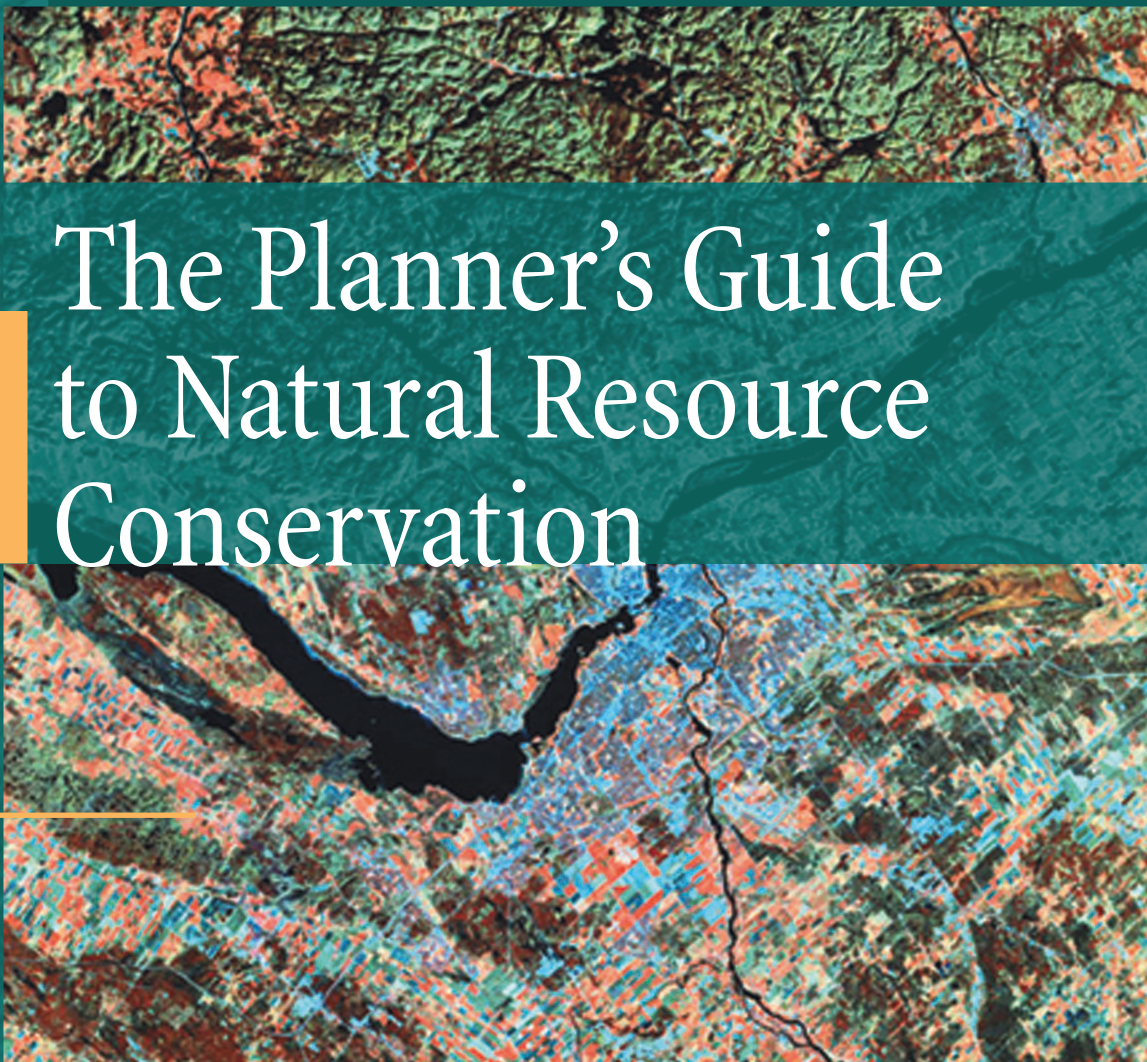
Adrian X. Esparza • Guy McPherson
Editors



The Planner's Guide to Natural Resource Conservation

The Science of Land Development Beyond the Metropolitan Fringe

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Editors
Adrian X. Esparza
School of Natural Resources
University of Arizona
Tucson AZ 85721
USA
axe@email.arizona.edu

Guy McPherson
School of Natural Resources
University of Arizona
Tucson AZ 85721
USA
grm@ag.arizona.edu

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Preface

Venture outward from the city, beyond the roar of automobiles and the rows of manicured suburban lawns, and you will find exurbia. It is a collage of housing types and residential densities (typically 1–40 acre parcels) located in what we once called the rural countryside. More than anything, exurbanization embodies the nation's affinity for open space and diverse natural amenities. Homes nestled in Arizona's Sonoran desert are as desirable as condominiums (seasonal homes) perched in the remote mountains of Idaho and Maine, or hobby farms and horse properties in Iowa, Texas, or Florida. The allure of nature largely explains the popularity of exurban living. About 37% of the country's population now lives in exurbia, and estimates indicate that a growing number of Americans will follow suit in the years ahead (Glennon and Kretser 2005; Theobald 2005).

It is widely understood that land development disrupts environmental systems. On the one hand, planners, landscape architects, and civil engineers work tirelessly to mitigate these impacts in urban areas. On the other hand, foresters, wildlife biologists, and range managers attempt to thwart the impact of developments that abut forest, park, and preserve boundaries. But exurban land is the "middle ground" that lies between cities and federal and state lands held in the public trust (Knight 2002). As such, exurbia is a unique blend of urban and rural that stands apart from cities and natural environments. For this reason alone, exurban land deserves special treatment.

Other reasons demonstrate the need to single out the environmental impacts of exurban land development. First, exurbanization fuels the conversion of productive farm and ranchland and promotes encroachment on near-pristine wildlands (forests, native grasslands, deserts). The loss of agricultural land is widely documented and has been targeted by farm and ranch conservationists (Merenlender et al. 2005; American Farmland Trust 2007). But the impacts of development in exurban wildlands have largely been neglected and gained a foothold in research agendas and policy arenas only in recent years. Thus, we know far less about the environmental impacts of exurban residential development.

Second, exurban lands are privately owned which means that, with the exception of a few federal policies (e.g., the Endangered Species Act), development regulations and approval fall on the shoulders of regional (county) planners and local elected officials – boards of supervisors or county commissioners. While planners often (but not always) champion the environment, their ability to conserve exurban wildlands is limited by two factors. First, surveys of environmental planning programs find that faculty favor the teaching of environmental law, policy, and applied skills over natural science-based education (White and Mayo, 2004, 2005). This clearly varies by institution, but by and large, regional planners do not know enough about the science of land development beyond the metropolitan fringe. Second, the planning profession has long struggled with the absence of a well-defined "ethic" that guides the treatment of land (Beatley 1994). This is not to say that planners lack ethical guidelines. Quite the contrary; like all professions, planners are guided by a code of ethics and professional standards. Yet there is no philosophical or ideological basis – a land ethic – to inform land-use decisions.

Finally, from an environmental perspective, the private ownership of exurban land is troublesome in itself. Thompson (2004, p. 142) notes that "...more than 90 percent of threatened or endangered species rely on private land to some degree for their habitat." He continues by indicating that "[t]he fragmentation of the landscape into millions of private lots has also had a devastating cumulative impact...and much of this destruction has taken place on private lands" (Thompson 2004, p. 143). Regretfully, private property owners and land developers are largely unaware of the ways in which exurbanization impacts wildland environments. This, coupled with the lack of science-based education among planners and civic leaders, signals the need for an approachable, science-based text on exurban land development.

The Planner's Guide to Natural Resource Conservation responds to the environmental consequences of exurban land development in two ways. First, the book's 13 chapters explain the environmental consequences of exurban land development. The aim is to provide a working, science-based understanding of ecological processes and the impacts of land development while avoiding the more technical material found in specialized journals and science textbooks. Contributors are all well-established environmental scientists and regional planners with years of teaching and research experience in the fields of zoology, ecology, conservation biology, restoration ecology, wildlife biology, hydrology, forestry, civil engineering, and regional planning. In sum, contributors open the door to the science of land development beyond the metropolitan fringe. Second, the book provides guidance on how to minimize the impacts of exurban land development. Contributors weigh in on land development schemes (i.e., scattered site versus clustered housing, road improvements, water catchment) and suggest ways to minimize or avoid ecological damage. Thus, the book describes ecological processes, explains how development infringes on them, then suggests ways to sidestep or mitigate potentially harmful outcomes.

The book is geared to a broad audience of land-use professionals and the public at large. Foremost, it supplements the educational needs of environmental and regional planners. Those working in allied land development professions – landscape architects, civil engineers, geologists, hydrologists, land managers – will find the book equally valuable because of its integrative and hands-on approach. The public at large has much to gain from the book as well. Civic leaders, elected officials, environmental organizations, activists, and concerned citizens will find that the book complements their interest in conservation and wise land stewardship. In sum, the book has much to offer in the classroom, office, home, and in the field.

While the book leans heavily toward applied learning and practice, it also seeks to advance a land ethic that guides the use of privately owned exurban land. Like Aldo Leopold (1949), who urged adoption of a land ethic 60 years ago, we believe that ecology, which is embedded in Leopold's human–land community, is the building block for such an ethic. This is reflected in Leopold's comment, "…a land ethic changes the role of *Homo sapiens* from conqueror of the land-community to plain member and citizen of it. It implies respect for his fellow-members, and also respect for the community as such" (Leopold 1949, p. 204). The human–land community positions all biota on equal terms and downplays the perception of land as merely a commodity that yields value through "development." Leopold did not eschew the use of land for societal purposes. Rather, he understood that land was needed to support human populations but argued for an approach to land-use and resource exploitation that respects the aesthetic value of nature and the fragile balance of ecological systems (Newton 2006). His land ethic, and the human–land community in particular, embodies this perspective.

In the years since Leopold's seminal writings, scholars from numerous disciplines have debated the nuances and implications of the land ethic. Some have questioned whether a single or unified land ethic is viable (Norton 2000; Davidson 2007; Evanoff 2007), others have challenged it as an ecofascist ideology (Horn 2005), while still others attempt to place the land ethic within the sphere of environmental ethics and philosophy (Callicott 1989; Taylor 2001; Brennan 2007; Hadley 2007; Starkey 2007). More recent efforts draw upon Leopold's writings to build new perspectives on environmentalism, namely deep ecology, ecofeminism, and radical environmentalism (Salleh 1995; Sessions 1995; Banerjee and Bell 2007; Vanderheiden 2008). This book does not weigh in on these debates, although we acknowledge their importance in shaping environmental thought and consciousness. Instead, we seek to promote the land ethic by providing a solid yet approachable understanding of ecology as it applies to the exurban realm. We acknowledge that education alone is not enough to alter perspectives and the treatment of land. Nevertheless, we are also aware that a fundamental knowledge of how and why land development affects exurban lands is pivotal to understanding and promoting Leopold's land ethic. The book is written with this spirit in mind.

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Contents

Contributors

Ann Audrey Environmental Projects Coordinator, City of Tucson Office of Conservation and Sustainable Development, 345 S. Toole, Tucson, AZ 85726-7210,USA, ann.audrey@tucsonaz.gov

Carl E. Bock E.E. Biology Department, Box 334, University of Colorado-Boulder, Boulder, CO 80309, USA, carl.bock@colorado.edu

Jane H. Bock E.E. Biology Department, Box 334, University of Colorado-Boulder, Boulder, CO 80309, USA, jane.bock@colorado.edu

Mark Briggs World Wildlife Fund, Chihuahuan Desert Program, 100 E. Hadley Avenue, Las Cruces, NM 88001, USA, mkbriggs@msn.com

Joel R. Brown USDA NRCS, Jornada Experimental Range, MSC 3JER, Las Cruces, NM 88003-8001, USA, joelbrow@nmsu.edu

Evan Canfield Chief Hydrologist, Planning and Development Division, Pima County Regional Flood Control District, 97 E. Congress St., Tucson, AZ 85701, USA, evan.canfield@rfcd.pima.gov

Stephen DeStefano USGS Massachusetts Cooperative Fish and Wildlife Research Unit, Holdsworth NRC, 160 Holdsworth Way, University of Massachusetts, Amherst, MA 01003, USA, sdestef@nrc.umass.edu

Adrian X. Esparza School of Natural Resources, Biological Sciences East, 209, University of Arizona, Tucson, AZ 85721, USA, axe@email.arizona.edu

Paul Fromer RECON Environmental, Inc., 1927 Fifth Avenue, San Diego, California 92101, CA, USA, pfromer@recon-us.com

Richard H. Hawkins School of Natural Resources, Biological Sciences East, 207, University of Arizona, Tucson, AZ 85721, USA, rhawkins@ag.arizona.edu

Lynn Huntsinger Environmental Science, Policy, and Management, 137 Mulford Hall, MC 3114, University of California, Berkeley, Berkeley, CA 94720-3114, USA, huntsinger@calmail.berkeley.edu

Kendall Kroesen Tucson Audubon Society, Habitat Restoration, 300 E. University Blvd, #120, Tucson AZ 85705, USA, kkroesen@tucsonaudubon.org

Kathleen A. Lohse School of Natural Resources, Biological Sciences East 126, University of Arizona, Tucson, AZ 85721, USA, klohse@email.arizona.edu

R. William Mannan School of Natural Resources, Biological Sciences East 312, University of Arizona, Tucson, AZ 85721, USA, mannan@ag.arizona.edu

David W. Marcouiller Urban and Regional Planning, 101 Old Music Hall, 925 Bascom Mall, University of Wisconsin-Madison, Madison, WI 53706, USA, dwmarcou@wisc.edu

Rachel McCaffrey School of Natural Resources, Biological Sciences East, University of Arizona, Tucson, AZ 85721, USA, rachmcc@email.arizona.edu

Guy McPherson School of Natural Resources, Biological Sciences East 226D, University of Arizona, Tucson, AZ 85721, USA, grm@ag.arizona.edu

Adina M. Merenlender Department of Environmental Science, Policy and Management, College of Natural Resources, University of California, Berkeley 137 Mulford Hall, Berkeley, CA 94720, USA, adina@nature.berkeley.edu

William W. Shaw School of Natural Resources, Biological Sciences East 216, University of Arizona, Tucson, AZ 85721, USA, wshaw@ag.arizona.edu

Robert J. Steidl School of Natural Resources, Biological Sciences East 312, University of Arizona, Tucson, AZ 85721, USA, steidl@ag.arizona.edu

David Tremble Sauk County Planning and Zoning Department, West Square Building, Room 248, 505 Broadway, Baraboo, WI 53913, USA, DTremble@co.sauk.wi.us

Contributor Biographical Sketches

Ann Audrey joined the City of Tucson's Office of Conservation and Sustainable Development (OCSD) in September 2006. Her focus areas at the city are developing guidance documents and strategies for riparian habitat preservation and restoration, working with developers to minimize impacts to riparian areas while allowing for well-planned growth, and working with staff, technical advisors and consultants to develop the city's Habitat Conservation Plans for projected growth areas. Prior to joining the city, Audrey was the restoration projects manager for Tucson Audubon Society, where she developed the restoration program and was involved in all facets of design, implementation, maintenance, monitoring, funding, and long-term stewardship. Audrey has also worked in the fields of water resources planning and environmental consulting. She has a master's degree in water resources administration and advanced training in permaculture design.

Carl E. Bock is professor emeritus of ecology and evolutionary biology at the University of Colorado, Boulder. He received his Ph.D. in zoology from the University of California at Berkeley in 1968 and then joined the faculty of the University of Colorado, where he has remained for the entirety of his academic career. He is an ecologist and vertebrate zoologist, whose field work has centered on western North America. He is the author of over 100 articles and book chapters, mostly focused on the impacts of livestock grazing, fire, exotic species, and exurban–suburban development on the plants and animals of western grassland and savanna ecosystems. With his wife and colleague, Dr. Jane H. Bock, he is the co-author of *The View from Bald Hill, Thirty Years in an Arizona Grassland* (University of California Press, 2000) and *Sonoita Plain: Views of a Southwestern Grassland* (University of Arizona Press, 2005).

Jane H. Bock is professor emerita of ecology and evolutionary biology at the University of Colorado, Boulder. She received her Ph.D. in botany from the University of California at Berkeley in 1966 and then joined the faculty at the University of Colorado in 1968, where she has remained. She is a plant evolutionary ecologist whose fieldwork has centered in the western United States and the alpine of the Central Rocky Mountains and the Central Caucasus. She is also a pioneer in the field of forensic botany. She has published over 80 papers and book chapters and two books, mostly in collaboration with Dr. Carl E. Bock. In addition she has edited a book, *Evolutionary Ecology of Plants*, with Dr. Yan Linhart and co-authored a book on forensic botany with Drs. Meredith Lane and David Norris.

Mark Briggs, M.S., is a restoration ecologist with the World Wildlife Fund's Chihuahuan Desert Program. His focus is on river restoration in the southwestern United States and northern Mexico, and he is currently working as part of a binational team to bring back the Rio Grande near Big Bend. Over the last 15 years, he has been involved in a variety of river conservation efforts in wildland, exurban, and urban settings. Although the specific objectives of these projects often vary with location, the general thrust involves understanding the causes of ecological decline, developing strategies to improve bottomland ecological conditions, and implementing monitoring programs to both gauge the effectiveness of restoration efforts and understand how and why ecological conditions are changing. Briggs also conducts workshops on river restoration in both Mexico and the United States. He has published widely on restoration, monitoring, and natural resource research and sits on the editorial board of the international journal *Restoration Ecology*. He is currently working on a special edition of the journal that focuses on issues related to the spread of salt cedar – an exotic, invasive plant that is affecting bottomland ecosystems in many parts of the arid western United States and northern Mexico.

Joel R. Brown is a rangeland ecologist at the Jornada Experimental Range. He is assigned to the USDA Natural Resources Conservation Service, National Soil Survey Center in Lincoln, NE. His research interests include agricultural systems response to climate change, applications of ecology to land management, and technology transfer in extensively managed agroecosystems. He has refereed more than 60 journal publications and book chapters in the areas of ecology and land management. His professional experience includes 5 years as an NRCS field and area range conservationist in Kansas, 5 years as California NRCS state rangeland specialist, 5 years as CSIRO (Australia) project leader and senior principal research scientist, and 8 years as NRCS global change leader and cooperating scientist with the ARS Jornada Experimental Range. His formal education includes a bachelor of science degree in agriculture/botany from Fort Hays State University (KS), a master's degree in grazing ecology from Texas A&M University, and a Ph.D. in shrubland ecology from Texas A&M University.

Evan Canfield is a chief hydrologist in the planning and development division of the Pima County Regional Flood Control District in Tucson, Arizona, and adjunct faculty in the Watershed Sciences Program in the School of Natural Resources at the University of Arizona. Dr. Canfield holds a B.S. in geology from the University of Iowa, an M.S. in geology from the University of Wisconsin-Madison, and received his Ph.D. in agricultural engineering from the University of Arizona. He is also a registered professional civil engineer and a certified floodplain manager. He uses computer models to understand the impacts of development on flood peaks and flooded areas and is also involved in basin management plans, which hope to preserve open space and accommodate the rapid growth in Southern Arizona.

Stephen DeStefano is the leader of the USGS Massachusetts Cooperative Fish and Wildlife Research Unit, and a research professor in the department of natural resources conservation at the University of Massachusetts-Amherst. His research focuses on suburban wildlife and human–wildlife interactions. Current projects include demography and landscape pattern use of abundant species such as beavers, deer, moose, and carnivores in mixed suburban and rural landscapes. He leads the suburban ecology working group, a collaboration of university, state, and federal entities in Massachusetts, was named a Fellow of the Wildlife Society in 2005, and is a member of TWS' Urban Wildlife Working Group.

Adrian X. Esparza is an associate professor in the School of Natural Resources at the University of Arizona. He received his Ph.D. in regional science from the University of Illinois-Urbana in 1987. Prior to joining the School of Natural Resources, he held a faculty position in the School of Planning, College of Architecture at the University of Arizona where he taught courses in land-use planning and housing. His research focuses on exurban land development in the southwest United States and urbanization in the United States–Mexico border region. He has published numerous articles in planning journals, recently authored a book on poverty in the United States–Mexico border region, and has received awards from the Association of Collegiate Schools of Planning (ACSP) and the North American Regional Science Council.

Paul Fromer is vice president at RECON Environmental, Inc., a San Diego, California-based environmental consulting firm specializing in species and habitat conservation. He is a behavioral ecologist by training with 28 years at RECON. He has overseen the development of regional-scale conservation programs for individual endangered species including least Bells vireo, Stephens' kangaroo rat, Mojave desert tortoise, northern spotted owl, and Delmarva fox squirrel. His more recent work has focused on ecosystem-based regional conservation programs covering multiple species in the Mojave and Sonoran deserts, coastal southern California scrublands, and central Texas aquifer and karst communities.

Richard H. Hawkins is professor of watershed hydrology in the School of Natural Resources at the University of Arizona. Dr. Hawkins holds B.S. degrees from the University of Missouri in both forestry and in civil engineering, and an M.S. and Ph.D. in watershed management from Colorado State University. He is a registered professional civil engineer (New York) and certified professional hydrologist. At Arizona since 1988, he previously served on the faculties of Utah State University, Colorado State University, and State University of New York. He has had professional experience with the California Department of Water Resources, the US Forest Service, and the US Environmental Protection Agency. He is the author or co-author of over 150 scientific and professional papers and project and consulting reports. In 1993 Dr. Hawkins received the Arid Lands Hydraulic Engineering Award from the American Society of Civil Engineers. His specialty areas are surface water hydrology, rainfall runoff, water quality, and land-use effects.

Lynn Huntsinger is a professor in the Department of Environmental Science, Policy, and Management, University of California, Berkeley. Dr. Huntsinger is a rangeland ecologist whose work focuses on the conservation and management of rangelands. She has published on numerous topics including working landscapes, grazing ecology, ecosystem services, and the conservation history of Californian and Spanish oak woodlands and forests. She focuses on the interaction of social and ecological systems. Recently she has become an investigator in a multiagency adaptive management project for fire hazard management in the Sierra Nevada. Dr. Huntsinger is a certified rangeland manager in the state of California.

Kendall Kroesen is restoration program manager for Tucson Audubon Society. He came to environmental work and riparian restoration after receiving a Ph.D. in cultural anthropology in 1997. As restoration program manager he oversees the design, implementation, maintenance, and monitoring of multiple large riparian restoration projects along the Santa Cruz River and in other locations. Kendall works with city, county, and private landowners to develop site-specific strategies for protecting and restoring disappearing riparian wildlife resources. He has an interest in the ecological and cultural context in which society addresses and solves problems of sustainability and in which it reconciles human settlements with the needs of wildlife.

Kathleen A. Lohse is an ecosystem scientist who joined the faculty of the School of Natural Resources at the University of Arizona in January 2007. She received her Ph.D. from the University of California, Berkeley, in 2002 in soil science with an emphasis in ecosystem science and B.S. and B.A. in 1993 in Urban and Regional Studies and Biology from Cornell University. She works at the interface of ecology, earth system science, and land-use planning studying the processes shaping watersheds and their responses to anthropogenic changes. Her primary research interests include examining the effects of human activities such as nitrogen (N) deposition and land-use changes on soil properties and hydrologic transfer of nutrients and sediments to downstream ecosystems, determining the environmental consequences of these alterations for river–riparian ecosystems, exploring the interactive controls of vegetation change, management practices, and fire on ecosystem and geomorphological processes, and coupling spatially explicit biophysical models with land-use change models to predict cumulative watershed effects.

R. William Mannan is a professor of wildlife ecology in the School of Natural Resources (SNR), University of Arizona. He received his B.A. degree in biology from Hanover College, Hanover, Indiana, in 1974, and his M.S. and Ph.D. degrees in wildlife ecology from Oregon State University, Corvallis, in 1977 and 1982, respectively. He teaches both undergraduate and graduate courses in the School of Natural Resources, and his research interests focus on the relationships between animals and their habitats in urban and forest environments and animal behavior as it relates to habitat use.

David W. Marcouiller is a professor of urban and regional planning at the University of Wisconsin-Madison and is currently on sabbatical leave with the Høgskolen i Nord Trøndelag in Steinkjer, Norway. A resource economist by training, his work focuses on the linkages between natural resources and community economic development with a particular interest in multifunctional rural landscapes and the production of natural amenities. He has published over 150 manuscripts in a variety of outlets including *Tourism Economics*, the *Annals of Tourism Research*, *Forest Policy and Economics*, *Forest Science*, the *Canadian Journal of Forest Research, Wood and Fiber Science*, the *Northern Journal of Applied Forestry*, the *Journal of Planning Literature*, *Society and Natural Resources*, *Land Economics*, *Economic Development Quarterly*, *Growth and Change*, the *Review of Regional Studies*, the *Review of Urban and Regional Studies*, and the *American Journal of Agricultural Economics*. At the end of 2008, he concluded a 10-year term as editor of the *Journal of Regional Analysis and Policy*.

Rachel McCaffrey is a Ph.D. candidate in the School of Natural Resources at the University of Arizona. Prior to arriving in Arizona, Rachel received her B.S. in biology from Rice University and her M.S. in wildlife science from Texas Tech University, where she studied how prairie dog management impacts other organisms associated with prairie dog colonies. Rachel has served as director of the Tucson Bird Count, a citywide citizen science project designed to monitor urban birds, since 2003. Her current research focuses on investigating how birds respond to human-influenced habitat factors at different scales.

Guy McPherson is a professor emeritus in the School of Natural Resources at the University of Arizona (Ph.D. 1987, Texas Tech University). He also worked for the University of Georgia, Texas A&M University, University of California, Berkeley, and The Nature Conservancy. His research focuses on development and application of ecological knowledge. His scholarly efforts have produced dozens of journal articles and eight previous books.

Adina M. Merenlender is a conservation biologist on the faculty at the University of California at Berkeley Department of Environmental Science, Policy, and Management. She is interested in the forces that influence loss of biodiversity at all hierarchical levels from genes to ecosystems. Her research program covers a diverse suite of projects that involve mapping, monitoring, and modeling land-use change and the natural resources that are impacted by these changes. These include integrating economic and physical data to forecast land-use change, target conservation priorities, and address the cumulative effects on California′s coastal watersheds. Ultimately, her research and extension efforts are helping to shift the working paradigm of salmon restoration in central California from site-specific restoration treatments to large-scale changes in water management to restore summer stream flows. Ongoing field studies explore the influence of exurban development and other land-use types on biodiversity and habitat connectivity in California′s north coast oak woodlands. Over 60 scientific papers are published describing research done in her lab and she recently co-authored *Corridor Ecology: The Science and Practice of Linking Landscapes for Biodiversity Conservation*.

William W. Shaw is professor of wildlife and fisheries science in the School of Natural Resources, University of Arizona, where he has worked since 1974. He has degrees from the University of California at Berkeley (Ecological Science), Utah State (Wildlife Management), and the University of Michigan (Natural Resources). His research interests encompass topics that combine biology and the sociopolitical dimensions of wildlife conservation. He has published widely on topics that deal with the effects of urbanization on wildlife resources. He has also worked on studies involving relationships between protected areas and local people in many countries throughout the world. In 1988, he received the Daniel Leedy award for Urban Wildlife Conservation. This award is given to one person each year in recognition of efforts to integrate conservation with urban planning and design. Since 1999 he has served as a scientific advisor to Pima County, Arizona, and as chair of the Science and Technical Advisory Team for the Sonoran Desert Conservation Plan. This is a comprehensive land-use plan and multispecies habitat conservation plan for a region comprising over 9,000 square miles in southern Arizona.

Robert J. Steidl is an associate professor of wildlife and fisheries science, University of Arizona (Ph.D. 1995, Oregon State University). He is a vertebrate population ecologist whose research interests focus on conservation biology and applied quantitative ecology. His research focuses on issues of quantifying the effects of human activities on wildlife populations, especially rare and endangered vertebrates, and on developing reliable approaches for long-term monitoring of vertebrate populations. He serves on the recovery teams for several endangered species and is co-chair of the Science and Technical Advisory Team for the Sonoran Desert Conservation Plan.

David Tremble has served as a planner and land protection specialist for the Sauk County Department of Planning and Zoning since 2000. He lives in Prairie du Sac, Wisconsin. As Sauk County's Land Preservation Specialist/Planner, Dave has primary responsibility for the management of Sauk County's *Baraboo Range Protection Program*, a conservation easement program designed to provide permanent protection of the unique natural values of the Baraboo Range. His work also includes public process design and group facilitation for community development and natural resource protection planning efforts. David spent 15 years as a facility planner and construction project manager with the University of Wisconsin-Madison and as a public school teacher prior to that. He graduated in 1977 from the University of Northern Iowa and completed a master's in urban and regional planning from UW-Madison in 1997.

Part I
History and Fundamental Ecological Concepts

Chapter 1
Exurbanization and Aldo Leopold's Human–Land Community

Adrian X. Esparza

Abstract Exurbanization occurs on privately owned lands that are found beyond the metropolitan fringe and outside the jurisdiction of federal and state lands held in the public trust. This chapter describes exurban land development from the perspective of Aldo Leopold's human–land community. It uses a historical approach to explain why Leopold's human–land community never materialized and how this framed the country's relationship with land from its founding through the recent era of exurban land development. Issues covered include urbanization, the rise of regional planning, consumerism, conservation and preservation movements, federal land policies, and the causes of exurbanization.

Introduction

Recent decades have witnessed the growing popularity of residential development beyond the suburban fringe in what is called the exurban sphere. Unlike sprawl, which is the uncoordinated outward extension of suburbs (Savage and Lapping 2003), exurbia is only loosely connected to cities and, instead, embodies the predilection for rural living. Such is the case with low-density (1–40 acre parcels) hobby farms and horse properties that grew tenfold from 1950 through 2000 (Brown et al. 2005; Theobald 2001, 2005). In other cases, exurbanites seek exposure to wildlife, open space, and direct access to outdoor recreation. Higher density retirement and resort communities accommodate these wants, as well as second/seasonal homes nestled in near-pristine wildlands, much of which abuts officially designated forests and preserves (Glennon and Kretser 2005). In contrast to these higher-end residents, exurbia is also home to a growing number of the nation's poor (Housing Assistance Council 2008). For them, rural living is a necessity rather than a choice. A manufactured home placed often on an ill-suited plot of land (e.g., in flood-prone

A.X. Esparza (✉)
School of Natural Resources, University of Arizona, Tucson, AZ 85721, USA
e-mail: axe@email.arizona.edu

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areas) provides the only shelter that low-income families can afford. Combined, these modes of residential development claim five to ten times more land than their urban and suburban counterparts and house about 37% of the country's population (Merenlender et al. 2005).

Development beyond the fringe comes at great cost as croplands and wildlands yield to residential land uses. The Natural Resources Conservation Service (2003) reports the loss of 52 million acres of cropland from 1982 through 2003 due to "urban development," an area roughly equal to the state of Kansas. According to the American Farmland Trust (2007), 2 acres of farmland is lost to development per minute. Natural lands also bear the brunt of exurbanization as encroachment fuels the loss of biodiversity, land fragmentation, and ecological damage. The environmental consequences of exurbanization are detailed in the chapters to come.

At a deeper level, exurbanization brings forward the fate of the nation's remaining privately owned lands. Knight (2002) refers to these lands as the "middle ground" that extends from cities to federal and state forests, parks, and preserves held in the public trust. At issue is the treatment of land as an economic commodity that finds value through its "highest and best use." This applies equally to agricultural lands and wildlands that are converted to residential uses because they offer higher returns to private property owners (Daniels 1999). For much of his career, Aldo Leopold struggled with how best to conserve privately owned lands and in the end, presented his "land ethic" as a guide (Leopold 1949; Newton 2006). Leopold's land ethic is grounded in ecological principles that position humans as equal (not dominant) participants in the human–land community. Such a vision is all encompassing in that humans are viewed as part of a broader ecological system. While Leopold's human–land community is compelling, it has scarcely been used to interpret land development in the United States historically. Such an approach is warranted because urban and environmental histories are treated as separate themes and seldom reveal the synergy that informed Leopold's thinking.

Taking Leopold's lead, this chapter presents a land history that synthesizes both the urban (human) and the environmental dimensions of land development in the United States. Given the scope of this undertaking, my efforts are modest and only sketch out principal themes and historic interdependencies that shaped the nation's land history from European settlement through recent times. Nevertheless, the narrative provides a fundamental understanding of how, and why, privately owned land falls victim to exurban development with such ease. The discussion emphasizes the connections between urbanization, land and natural resource exploitation, and the response by conservationists and regional planners who wrestled with how best to use land. The chapter concludes by placing exurbanization within the broader land history.

Colonization and the Human–Land Community

Much has been written about colonization of the New World from both urban and environmental perspectives. Here, I focus on how and why Leopold's vision of a human–land community failed to materialize and the land development path set in motion by this failure.

Prior to colonization in the early 17th century, the communal life that characterized European agrarian society was already in decline. Instead of "organic" self-sufficiency, agrarian communities began to import raw materials and manufactured goods from afar (Curry and McGuire 2002; Merchant 2002). The Puritans and Pilgrims who settled in coastal Massachusetts resisted the loss of community (and religious freedom), which prompted their journey to the New World. Thus, New England was founded on the principle of "township" where communities, not individuals, settled the land. In describing New England settlement, Curry and McGuire (2002, p. 45) indicate that "[w]hen more land was needed, a six-square-mile township was laid out and settled as a whole with the granting of land left to the corporate body of the town itself." They continue by noting that "[o]wnership of land in the town was tied to membership in the community." Life in these settlements revolved around the "common good," which led to restrictions on the harvesting of natural resources, especially timber, to secure the community's longer term welfare. Restrictions responded to the "tragedy of the commons" as depicted by Hardin (1968) and others and hinted at the conservation embodied in Leopold's (1949) human–land community. Even so, land outside the township was abundant and open to exploitation.

Other factors worked against the human–land community. First, colonists were armed with God's blessing, which bestowed authority over Earth's bounty (McPherson 2005; Black 2006). This engendered the perception of land and natural resources as God's gifts that should be mined for man's benefit. Thus even though the Puritans pursued conservation on behalf of the common good, their world view was decidedly anthropocentric. Second, despite the intentions of religious groups, the "individual spirit" soon surfaced in response to the promise of wealth. This held especially for the Pilgrims who, from the outset, had cast their eye on wealth accumulation (Kunstler 1993; Curry and McGuire 2002). Finally, the British Crown and the corporations that financed colonization sought to exploit North America's vast natural resources (Nace 2005). Exploitation was central to European mercantile ideology and sent ships across the globe in search of nature's riches.

These forces led to many forms of ecological damage. Colonists introduced nonnative vegetation (mainly grains) and imported livestock (pigs and oxen) that roamed freely through the countryside compacting soils, trampling native vegetation, and devouring natural grasses, all of which caused severe soil erosion and altered microclimates (Merchant 2002). Beaver and fox populations were depleted to meet Europe's demand for highly prized furs. But the clear-cutting of forests for timber products (resins, turpentine, and lumber) was the most profitable enterprise of all (Curry and McGuire 2002). New England was rich in coniferous and hardwood forests that were harvested both for local use and for international trade. The pace of forest cutting was so aggressive that in 1690 the British Crown imposed the first forest policy in the New World that limited the harvesting of timber for private enterprise. The Broad Arrow Policy prohibited the cutting of trees suitable for masts (trees with a 24 inch diameter, measured 12 inches above grade) that sped the royal navy's sizable fleet across the world's oceans (Merchant 2002).

By the close of the 17th century, the New World was mired in the search for wealth. Although New England's fledgling religious settlements tried to build community by nurturing the common good, individualism, religious ideology, and the corporate mandate laid their efforts to rest. Down the coast, the mid-Atlantic colonies made no pretense of piety. Rather, they launched fully into the harvesting of foodstuffs and tobacco that fed European appetites (Nace 2005). Port cities such as Charles Town (present-day Charleston), founded in 1670, flourished as trade filled merchants' pockets and eased the replication of European opulence (Rosen 1992).

The 18th century brought dramatic change as the colonial population grew and discontent with the British Crown festered. Port cities were the principal urban centers, with New York, Boston, and Philadelphia taking the lead. By 1790, the populations of New York and Philadelphia exceeded 25,000, and about 95% of the country's 4 million persons lived on the land (Frey, Abresch and Yeasting 2001). Suburbs appeared in these cities early in the century, although they scarcely resembled their contemporary version (Jackson 1985). Colonial cities were compact, built at the pedestrian scale, and rigid boundaries separated rural land from urban uses.

The country's formal founding institutionalized America's relationship with land and quelled any prospect of a viable human–land community. The Declaration of Independence, signed in 1776, set in stone the privileges granted to man through "natural law" (God's law) and also imprinted the rights of individuals over the common good. Much of this rationale was informed by John Locke, the British political philosopher who swayed Jefferson's thinking when crafting the Declaration. In the *Second Treatise on Government*, published in 1690, Locke wrote: "[g]od gave the world to men in common; but since he gave it them (sic) for their benefit and the greatest conveniences of life they were capable to draw from it, it cannot be supposed he meant it should always remain common and uncultivated. He gave it to the use of the industrious and rational—and labor was to be his title to it. . . ." (Peardon 1952, p. 20). This thinking reduced land to a commodity that yields value to private owners through their hard work. The principle of highest and best use is implicit in this doctrine because rational men seek to maximize returns to labor. In a nutshell, a level-headed farmer will use land to produce or harvest commodities that yield the highest benefit: only irrational men will do otherwise. This reasoning, coupled with the European-based social contract (which Locke also favored), championed individual rights and called for limited government infringement because it diminished returns from land and labor. The social contract argued that individuals voluntarily surrender some freedom (minimal regulation) and in exchange, government negotiates conflict between individual property owners, repels external threats, and promotes the economic betterment of all (Peardon 1952; Waldron 1989). The Constitution (signed in 1787) embodies aspects of this political philosophy. But others argue that political ideology had little to do with framing the Constitution. They see it as a practical device, a manual if you will, that defined procedures and rules of government and nothing more (Bradford 1993).

By design or not, individualism, private property rights, and the limited role of government were spelled out with the country's inauguration. The individual's rights to land and resources were valued above all, and the "common good" centered on economic betterment—wealth accumulation. Government was expected to uphold the common good by minimizing regulation and protecting the homeland from external threats. This ideology placed stewardship in the hands of private property owners with the understanding that rational men will nurture landrather than deplete it so that "returns" are produced over time. But the nation was rich in land and resources and any notion of depletion was unheard of. Thus there was no reason to entertain a human–land community. The discussion below examines how this ideology played out over time.

Land, Cities, and Conservation in the 19th Century

The commodification of land and resources during the 19th century was reinforced at the highest levels of government. Alexander Hamilton, Secretary of State under George Washington, believed that economic growth was vital to the country's success, especially basic industry and manufacturing, which were often controlled by large business enterprises. The exploitation of land and natural resources, therefore, was crucial to the nation's longer term prosperity (Black 2006). Thomas Jefferson felt otherwise: he saw land as the greatest resource and envisioned a nation of autonomous country farmers. To some extent, his thinking was influenced by the exploitive behavior of corporations, which had wielded enormous power since the country's founding (Nace 2005). Thus Jefferson resisted placing the nation's future in corporate hands. Ultimately, the country pursued the policies of both Hamilton and Jefferson (Gates 1971; Merchant 2002).

After ascending to the presidency in 1801, Jefferson fulfilled his vision of land ownership by establishing the rectangular survey system. The survey divided land into precise townships of 640 acres, nearly the same system used today. Jefferson reasoned that standardized measurement would promote efficient land sales west of the Appalachians. He was proven correct: federal land sales began in 1829 and by 1900, over 220,000 farms had been settled on 6 million acres in present-day Ohio and Indiana alone (Black 2006).

Farmers readied the land by clear-cutting hardwood forests without regard for environmental damage. But this was expected because deriving benefit from the land meant it must be cleared and then cultivated, and nearby forests were ripe with timber when needed (Merchant 2002). In effect, the abundance of land, combined with the doctrine of highest and best use, negated responsibility to others (then, and in the future) and set aside any sense of land stewardship. Farmsteads also established a new pattern of rural living. In contrast to Europe, where farmers lived in rural villages and walked to fields each day, the federal Pre-Emption Act of 1841 required that farmers live on their land (Curry and McGuire 2002). This led to the dispersion of farm houses across the agricultural landscape and set the pattern of rural settlement that many exurbanites mimic today.

The distribution of land across middle America led to widespread speculation. Families and speculators subdivided and sold smaller parcels of land even though the government tried to thwart these efforts. Similarly, soldiers saw land as a way to quick riches (Gates 1971). Since the American Revolution, soldiers were rewarded with land allocations, the parcel size determined by military standing. The rank-and file received a maximum of 160 acres, while generals in the revolutionary army received up to 15,000 acres. In subsequent years (wars) both enlisted men and officers were allotted 160 acres. Veterans subdivided or sold entire tracts of land (often to speculators), which further fragmented the rural landscape. The pace of speculation set to rest any doubt that land was first and foremost a commodity.

The federal government implemented conflicting and contradictory land policies as it responded to the problems of private land ownership. On the one hand, it brought vast territories into the public domain and dispensed them willingly. The government acquired over 1.6 billion acres, beginning with the Louisiana Purchase in 1803 and concluding with the Alaska Purchase in 1867 (Sayer 1965). Millions of acres were sold at rock-bottom prices (often at $2.50 per acre) or given freely to promote settlement and urban and economic growth. On the other hand, the government was aware that private ownership often led to the depletion of land and resources and pursued conservation accordingly. As early as 1817, Congress ratified legislation that protected forested lands. But timber companies opposed the legislation and invoked the doctrine of highest and best use in their defense. Despite efforts to transfer federal lands into private ownership, in 1831 the Supreme Court upheld the government's right to set aside millions of acres of forested land (Curry and McGuire 2002).

In the decades that followed, the federal government ratified a host of legislation that embodied the tension between private ownership versus public control. Legislation at times released millions of acres into private hands, yet at other times brought privately owned lands into the public domain (Curry-Roper 1989). Tracing this legislative history is an onerous task: by the 1960s over 5,000 pieces of forest legislation had been ratified (Sayer 1965). Even though the government succeeded in preserving millions of woodland acres, by the 1990s, about one-third of the nation's forests had been harvested or cleared for settlement (MacCleery 1994). Much of the remaining forested land is located in Alaska and a handful of western states.

Even though the country was overwhelmingly agrarian, population growth and urbanization were on the rise. From 1810 through 1890 the total population grew from 7.2 million to 63 million persons. Growth was caused by high rates of natural increase and immigration, which channeled millions into cities. During the same years, the urban population rose from 7 to 35%, an increase of more than 21.5 million urban dwellers (Martin 1965; U.S. Census Bureau 2008).

Urban planning was virtually unheard of and cities grew haphazardly, often with disastrous results. Waves of immigrants crowded high-rise tenements and working-class neighborhoods, smoke spewed from inner-city factories, centralized sewage disposal was yet to come, and drinking water was often contaminated. This led to widespread epidemics as cholera, small pox, typhoid fever, and other infectious diseases spread easily among urban populations (Laurian 2006). Fires were common because houses, built hurriedly to accommodate population growth, were virtual tinderboxes. Fire departments were in their infancy and did little to combat fires. The Chicago fire of 1871, which left 300 dead and displaced about 100,000 persons (one-third of the city's population), captured the nation's attention but fires were frequent in many cities (Pauly 1984).

Urban planning owes much to the "sanitary reform movement" that brought centralized sewage disposal to cities (Schultz 1989; Harris and Mercier 2005; Laurian 2006). Near the time of the Civil War, the "water carriage" system was introduced to the country (from England) and by the 1870s, systems had been installed in many cities. Sanitary reform encouraged planning because it required the careful inventory of land uses, as well as coordinated urban development. While planning in these years was mechanistic, sanitary reform opened the door to the planning profession (Peterson 1983a).

During these years, Frederick Law Olmstead, designer of New York's Central Park and arguably the most celebrated landscape architect of his time, instilled the suburban ideal that American's grew to cherish (Keating 1988). A firm believer in nature's restorative powers, Olmstead responded to the gloom of urban life by turning to the countryside. Through their sizable lots, manicured lawns, and curvilinear streets, Olmstead's communities offered a reprieve from urban living. Instead, his suburban communities were places where families flourished in nature's serenity. Olmstead designed over a dozen suburban communities across the country, but Riverside, Illinois (platted in 1869), located 8 miles west of Chicago, was his crowning achievement (Jackson 1985).

The nation's burgeoning cities and expanding economy ignited a frenzy of resource exploitation. Forests provided the lumber to build cities, oil was pumped from Pennsylvania's virgin landscape, mainly for kerosene, and by the 1850s, over 4 million troy ounces of gold had been removed from California's rustic mountains, much of it extracted through hydraulic mining methods that caused enormous environmental damage. Coal, the principal source of energy, was chiseled from the hills of western Pennsylvania along with iron ore and limestone that were used to produce iron and, later, steel (Black 2006; Boone and Modarres 2006).

Railroads played a critical role in fostering economic growth and supplying urban populations with sorely needed commodities. The Illinois Central, the world's longest railroad by the time of the Civil War, epitomized the economic promise of rail transportation. Stover (1954, p. 499) notes that the Illinois Central sought to "...connect the Great Lakes with the Mississippi, and the St. Lawrence with the Gulf of Mexico." In subsequent years, the Illinois Central became a principal pipeline for the Great Migration that brought African Americans from the South to northern industrial cities. The railroads were also one of the largest users of timber. According to Olson (1966, p. 3):

> [t]he use of wood per mile of railroad probably reached a peak about 1880 when the railroads of the United States were consuming 60 million crossties (over 2 billion board feet of timber), two-thirds for replacements and one-third for new construction. They were probably using another 500 to 700 million board feet for bridge and building construction, with more modest rates of replacement.

Given the pace of harvesting, it is not surprising that forests were often depleted.

Although the government attempted to preserve forested land, the public at large revealed little interest in conservation. But there were notable exceptions. The naturalist Thomas Say (1787–1834) established The Academy of Natural Sciences of Philadelphia in 1812 (with John Spearman) and is credited with establishing the science of entomology in the United States. He was the first scientist to journey inland to the Rocky Mountains and documented the rich variety of wildlife along the way. He spent his later years in New Harmony, Indiana, Robert Owen's utopian community, where he taught natural science and led field excursions (Stroud 1995). John James Audubon released *The Birds of North America* in 1824, inspiring many to embrace the aesthetics of nature. But a group of writers, artists, and intellectuals known as the "transcendentalists" were most successful in nurturing environmental awareness. Ralph Waldo Emerson, unspoken leader of the transcendentalists, published *Nature* in 1836, Henry David Thoreau's *Walden* was released in 1854, and John Burroughs' *Wake-robin* appeared in 1871. They were joined by Amos Bronson Allcott, Margaret Fuller, the feminist activist, and others who voiced deep concern for the loss of wildlands and spoke loudly of nature's spiritual invigoration. Artists rallied around the Hudson River School of art, which featured landscape painting (Merchant 2002; Black 2006). A few wealthy urban dwellers also carried the banner of conservation. Men feared the loss of fishing and hunting grounds, and women refrained from buying hats adorned with feathers retrieved from exotic bird species. John Muir, born in far away Scotland in 1838, immigrated to Wisconsin with his family in 1849. Muir, together with Gifford Pinchot, born in Connecticut in 1865, would set the stage for the checkered legacy of conservation and preservation in the years to come.

The Industrial City, Conservation, and Regional Planning

At the dawn of the 20th century, the country was ablaze with urbanization as the industrial city came of age. In 1910, the population topped 92 million and grew to nearly 123 million by 1930. In the same year, over 55 million persons (45%) lived in cities and many moved outward to suburbs. From 1910 to 1930, the suburban population grew twofold, from 7 to 14% of the urban population (Hobbs and Stoops 2002). As in the past, natural increase and immigration accounted for the rise in population.

Armed with new technologies and civic pride, progressive reformers sought to remedy the abysmal conditions of urban America. Many of these efforts began in the late 1800s and continued through the 1920s when the progressive era slowed. Progressives pressed for nationwide sanitary reform and championed the "city beautiful movement," which called for beautification through civic design that featured parks and promenades, statues, and grand public buildings. Many of these monuments of urban reform remain today (Peterson 1983b; Schultz 1989). These efforts were complemented by technologies that made cities more livable. In the 1880s, Thomas Edison and George Westinghouse brought electricity to cities (Usselman 1992). This supplied industry and homes with a seemingly endless supply of energy, illuminated previously dark streets, and powered mass transit.

The industrial city also brought mass consumerism to urban America. The days of deriving livelihood directly from the land were gone. Instead, urban dwellers spent their days in factories working long hours (often in deplorable conditions) earning wages. Businesses encouraged the spending of wages by implanting consumerism in the public's consciousness. Leach (1993, p. 9) notes that "[f]rom the 1880s onward, a commercial aesthetic of desire and longing took shape to meet the needs of business. And since that need was constantly growing and seeking expression in wider and wider markets, the aesthetic of longing and desire was everywhere and took many forms." Department stores were one way that consumerism found expression. Stores such as Wanamaker's in Philadelphia, Macy's in New York City, and Marshall Fields in Chicago all opened business near the turn of the century (Leach 1993). Wares were displayed in massive store-front windows that attracted huge crowds, especially during holiday seasons. The public also embraced the automobile, which began rumbling off assembly lines in the early 1900s. From 1900 to 1910, annual auto registration rose from 8,000 to 469,000 vehicles (Kay 1997). With the release of Henry Ford's Model T in 1908, Detroit became the world's center of the automobile industry (Foster 2003). Cars eased suburbanization and also carried families into the countryside as day trips and summer vacations near lakes and forests became a popular way of reconnecting with nature.

Urbanization and consumerism were fed by natural resources, which were mined like never before. John D. Rockefeller, founder of the Standard Oil Company, developed new oil extraction techniques, positioning petroleum as the country's new energy source. Oil was tapped in Texas in 1901 and in nearby Oklahoma at nearly the same time. Vast oil reserves were also found farther west, in California. Foster (2003, p. 7) notes that "[b]etween 1893 and 1903, oil production in the Sunshine State leaped from 470,000 barrels to 24 million barrels; it tripled again by 1910 to 73 million barrels." At the dawn of World War I, California was producing about 25% of the world's oil supply. Iron and steel were needed for countless commodities ranging from cars and trains to consumer products and military hardware. Pittsburgh became the center of global production, and by 1925 was producing one-quarter of the country's iron and steel. In that same year, over 13.6 million gross tons of iron ore were shipped from the Lake Superior region (especially Minnesota) to Pittsburgh via the Great Lakes. Early on, coal was the single energy source but by the 1890s, the steel industry had shifted to natural gas (White 1928). Companies such as the Bethlehem Steel Corporation (renamed the Bethlehem Steel Company in 1901) led the charge as they adopted new technologies to meet consumer demand (Hessen 1972). Copper was another natural resource vital to economic growth. In the late 1800s, the majority of copper was mined from the Great Lakes (especially Michigan) but Arizona soon became the nation's leader, producing 361,327 tons of copper in 1925, over 43% of the country's supply (Richter 1927). By 1936, there were over 500 underground mines extracting high-grade copper ore from Arizona's rugged hills (O'hUallachain and Matthews 1996). There were few environmental regulations to slow industry, and economic growth forged ahead with little constraint.

Birth of the Conservation and Preservation Movements

The conservation and preservation movements arose from this backdrop. Theodore (Teddy) Roosevelt and Gifford Pinchot are credited with founding the country's conservation movement, while John Muir led the charge for preservation (Devall 1982; Sessions 1987). The conservation movement responded to the rampant and reckless depletion of natural resources as corporations rushed to amass huge profits. Like others, Pinchot feared that profiteering was destroying the nation's lands. When describing natural resource exploitation near the turn of the 20th century, he commented that "[a] tremendous urge to get rich possessed our people. Those were the days when to be rich was proof of virtue...[t]here was a fury of development abroad in the land. The American Colossus was fiercely at work turning natural resources into money" (Pinchot 1937, p. 259). Conservation sought to stop unbridled exploitation by fostering the efficient use of land and natural resources. Even so, Pinchot saw resources as commodities, especially the nation's forests. Pinchot remarked that "[w]e must remember also that the forest is a crop.... Forestry then is a way of producing crops of wood from the soil, and therefore is tied up with the production of all other crops" (Pinchot 1937, p. 255). These sentiments meant that land and natural resources must be managed wisely—conserved—but used for human betterment nonetheless.

Teddy Roosevelt was an avid outdoorsman and archetypical progressive who pursued reform on many fronts. After becoming president in 1901, he pushed for woodlands conservation by establishing the US Forest Service in 1905 and appointing Pinchot Chief Forester (Black 2006). Roosevelt and Pinchot advocated the efficient use of forest lands and encouraged the adoption of forest science methods. Roosevelt also set aside millions of acres of forested land by dedicating numerous national parks.

John Muir arose from obscurity to become the nation's leading advocate for environmental preservation. While conservationists urged the cautious use of land and resources, Muir believed that nature was God's crowning achievement and should be left untouched altogether. Even though ecology was not widely recognized at the time, Muir understood nature's fragile balance and feared that human encroachment brought irreparable harm (Devall 1982; Hays 1982; Sessions 1987). Among other things, Muir is credited with founding the Sierra Club and was instrumental in the designation of several national parks, including the Petrified Forest, the Grand Canyon, Yosemite (previously a state park), and Mount Rainier, to name a few (Reed 1992). Muir is often cast as a mystical figure who held sentiments akin to the transcendentalists (Worster 2005). Regardless of his leanings, he was befriended by prominent politicians and intellectuals who sought his counsel. Ralph Waldo Emerson, John Burroughs, Theodore Roosevelt, and Gifford Pinchot were among Muir's friends.

Muir and Pinchot parted company over the dam built in the Hetch Hetchy Valley, located in Yosemite National Park (Nash 1967; Reed 1992; Black 2006). Events surrounding Hetch Hetchy led to Muir's preservation movement and also demonstrated the interplay between urbanization, natural resources, and conservation.

By 1900, San Francisco's population neared 342,000 and the scarcity of potable water threatened the city's growth (Maher 2008). City leaders sought to bring water from Yosemite's Hetch Hetchy Valley and competed with Pacific Gas and Electric, which wanted to dam the valley for its hydroelectric power (Nash 1967). But Yosemite's status as a national park prevented development and congressional action was needed to approve the dam's construction. Muir was incensed by overtures to build the dam and in 1901 began organizing opposition. Through the Sierra Club, Muir built a nationwide coalition of preservationists who spoke on behalf of Yosemite. In contrast, Pinchot and other conservationists believed the dam would provide valuable water and electric resources: in their view, human needs outweighed the mandates of preservation. This ideological divide led Muir and Pinchot to different camps and ended the friendship. Years before, William Kent, a devout conservationist and Muir enthusiast, purchased and dedicated land for the present-day Muir Woods National Monument. By the time of Hetch Hetchy, Kent had become a California congressman and was forced to weigh in on the conservation versus preservation debate. Kent, like Pinchot and other conservationists, was aware of the environmental destruction left in the path of corporate money making: in this case, Pacific Gas and Electric. Fearing corporate power, he sided with the city of San Francisco and pushed for approval of the dam on the city's behalf (Nash 1967). Congressional approval came in 1913. Kent's decision ended his friendship with Muir, who died the following year. Today, the Hetch Hetchy system provides about two-thirds of San Francisco's water (Bay Area Water Supply and Conservation District 2007).

Regional Planning, Conservation, and the New Deal

The progressive movement was in full gear as the Great Depression approached. Government officials pushed for improvements in watershed management, hydropower generation, and efficient use of the nation's land and resources (Hays 1982). Progressives also noted the growing divide between urban and rural dwellers and pinned the chasm to rural underdevelopment. They pressed for rural electrification and better care of farmlands, which were often overworked and mismanaged (Phillips 2007). It was widely understood that underdevelopment fueled rural–urban migration and therefore led to overcrowding in cities, rural population loss, and economic instability.

These inequities brought regional planning forward as planners sought to bring equality to rural and urban areas. The Regional Planning Association of America (RPAA), founded in 1923, brought together prominent conservationists and planners who embraced the region as the appropriate scale for land and resource management (Maher 2008). They included the human dimension (the rural population) in conservation and looked to government for support (Phillips 2007). Benton MacKaye, a schooled forester who in 1921 proposed development of the Appalachian Trail, and Lewis Mumford, the noted urban scholar, were the most visible members of the RPAA. They both were well acquainted with Patrick Geddes, the so-called father of regional planning in the United States (Anderson 2002). The RPAA conducted research on regional inequities and promoted MacKaye's plan for the Appalachian Trail.

The years that followed challenged the very core of America as the Great Depression and the Dust Bowl imposed enormous hardship on urban and rural dwellers alike. Much has been made of these historic events, but for present purposes, Franklin Delano Roosevelt's (FDR) New Deal programs are noteworthy because they launched the country's second conservation "wave" (Devall 1982; Sessions 1987). Prior to his presidency in 1933, FDR served as governor of New York, where he pursued rural development and embraced regional planning. He took these sentiments to the White House and assembled an impressive cadre of conservationists and regional planners, including Benton MacKaye (Anderson 2002; Phillips 2007). They designed programs and policies aimed at regional development: the Tennessee Valley Authority (TVA) the most visible of their many initiatives. The TVA, passed by Congress in 1933, accomplished multiple objectives including rural electrification, flood control, mitigating farmland soil erosion, promotion of outdoor recreation, and putting the country's unemployed to work (Maher 2008). The Civilian Conservation Corps (CCC) brought these objectives together by employing over one-half million Americans who worked on dozens of conservation projects across the country, including the TVA.

At first, the nation rallied behind FDR's bold initiatives. But his programs were positioned on the "old conservation" that saw nature as an economic commodity (Phillips 2007). All his programs, from the TVA to the CCC, sought to "improve nature" through efficiency mandates and sound resource management. Rural programs showcased the superiority of technology over nature and often ignored ecological integrity. The CCC carved recreation areas out of environmentally sensitive lands, reforestation programs introduced nonnative species, estuaries were drained without regard for ecological damage, and farmland protection featured engineering solutions. In the early 1930s, Aldo Leopold supported the CCC but his enthusiasm soon waned (Maher 2008). Reflecting on the government's treatment of Wisconsin's marshlands, Leopold noted that "[d]istant politicians bugled about marginal land, over-production, unemployment relief, conservation. Economists and planners came to look at the marsh. Surveyors, technicians, and CCC's buzzed about" (Leopold 1949, p. 100). His comments on their solutions are telling: "[t]o build a road is so much simpler than to think of what the country really needs. A roadless marsh is seemingly as worthless to the alphabetical conservationist as an undrained one was to the empire-builders" (Leopold 1949, p. 101). In contrast to the old school of conservation that guided FDR, Leopold and others embraced the principles of ecology, called for a deeper understanding of human-induced impacts, and urged a balanced approach to land management (Phillips 2007; Maher 2008). These new ideas of conservation swept the country as a growing number of environmental scientists and government officials acknowledged the pitfalls of New Deal programs. Their opposition eventually led Congress to step back from FDR's vision. Even though FDR's programs embraced traditional conservation, they instilled the need to reposition conservation on a new ecologically based foundation (Devall 1982; Phillips

2007). Aldo Leopold played a critical role in forging conservation's new direction (Jahn 1998).

Suburbs, Planning, and Environmentalism in the Post War Years

The country weathered the Great Depression, World War II, then the Korean War and was poised for growth as the 1950s drew to a close. The total population reached 179 million in 1960, and over 112 million persons (63%) lived in cities. Suburbanization swept the country and by 1970 suburbs housed more people than did central cities for the first time in the country's history (Hobbs and Stoops 2002). Consumerism was in full bloom, and autos were the most treasured commodity. In 1950, Americans owned over 40.3 million autos, about 76% of the world's inventory. By 1960, an additional 21.3 million cars had been added to the nation's fleet: a 53% increase during the decade. Petroleum consumption grew with auto dependence. By 1960, the nation was consuming 9.8 million barrels of oil per day, 46% of global production (U.S. Bureau of the Census 1971).

Volumes have been written about suburbanization during the 1950s and 1960s, but three interdependent themes warrant discussion. First, suburbanization required vast tracts of land to accommodate the flurry of housing construction. During the 1950s, federal subsidies and programs enabled construction of over 15 million homes, mainly at the urban fringe (Rome 2001). This led to the conversion of agricultural lands and natural open space at an unprecedented pace, especially in the west where cities were booming. Fishman (1987, p. 178) indicates that suburban growth in Los Angeles after the 1940s required "...the transformation of over 900 square miles of agricultural land into suburban tract developments, and the construction of almost 500 miles of freeways to forestall the congestion created by new homes." Much of this land was acquired through annexation. Findlay (1992, p. 31) notes that "[i]n Phoenix, where annexation was seen by some as the central goal of postwar urban planning, 75 percent of the population in 1960 lived in neighborhoods that had been added to the central city since 1950. Between 1941 and 1954, towns in Los Angeles County annexed 458 separate parcels, and those in Orange County annexed 235 parcels."

Second, suburbanization was largely facilitated by the interstate highway system. By design, highways uprooted low-income inner-city neighborhoods, encircled metropolitan areas, and crisscrossed the countryside in pursuit of a national highway network. While highway construction was underway decades before, the Federal-Aid Highway Act of 1956 launched the era of unbridled construction. Daniels (1999, p. 23) indicates that "[b]etween 1956 and the early 1970's, 42,500 miles of high-speed, interstate highways were paved."

Third, suburbanization during the 1950s and 1960s fostered environmental awareness and reshaped the public's engagement with government agencies. The pace of suburban development raised public concern as near-pristine lands and open space fell to the bulldozer (Rome 2001; Siskind 2006). Developers displayed little concern for environmental integrity: natural drainage was filled, all vegetation removed, and hills were flattened in preparation for streets and houses. Few (if any) regulations were in place to prevent such careless land modification. Suburbanites also lamented the loss of open space when tract housing appeared on adjacent land (the “nimby” syndrome: not in my backyard). This led to a national outcry for open space set asides and greater involvement in local politics. Fearing property devaluation because natural amenities disappeared, home owners lobbied local governments for open space preservation (Fischel 2001; Rome 2001). Construction of the interstate highway system was also met by stern opposition. These “highway revolts” began in the late 1950s and gained momentum in subsequent years. Grassroots organizations opposed the conversion of valuable agricultural land and wildlands at the city’s periphery and beyond (Mohl 2004; Dyble 2007). Highway construction fueled a public backlash that forced greater public involvement in federal-level decision making. The government resisted public scrutiny at first, but over time yielded to criticism and opened the door (somewhat) to public engagement. Today, many federal agencies require public input as part of the planning process.

Urban planning during the 1950s and 1960s responded fully to the consequences of suburbanization (Levy 2000). Armed with traditional tools of zoning and land-use regulation, planners struggled to keep pace with suburban housing construction. Their efforts were compromised by the ethos of money making that gave developers the upper hand. Cities were reluctant to rein in development because of the perceived benefits—jobs and property taxes (Fischel 2001; Beauregard 2006). Highway construction led to numerous problems that drew the attention of planners. Inner-city minority neighborhoods were often razed to make room for highways, thus causing dislocation and social inequity. At the city’s periphery, highway and road construction led to the relocation of jobs and commercial and retail outlets that sought access to suburban populations. This carved the pattern of strip commercial development, peripheral high-rise office buildings, and far-flung shopping malls that typify the contemporary city. Planners did their best to accommodate growth but faced an uphill battle. Suburbanization and highway construction led to central city decline as “parasitic” growth funneled people and financial resources to the fringe (Beauregard 2006). Planners responded by launching inner-city revitalization programs that tried to keep businesses in place and bring residents back to core neighborhoods.

These forces led to new developments in the planning profession. First, the loss of open space led to the emergence of environmental planning as a specialized field within the discipline. Planners pushed for regulations that required open space dedications, as well as environmentally sensitive development. In the years that followed, environmental planning gained popularity in response to the public’s growing environmental awareness (Levy 2000). Second, state and local governments turned to growth controls to manage suburbanization and preserve land beyond the metropolitan fringe (Rome 2001; Siskind 2006). Hawaii adopted the first statewide program in 1961 (Nelson and Dawkins 2004).

Wilderness preservationists gained ground even though suburbanization moved ahead. These efforts crystallized in the 1950s when preservationists sought blockage of the Echo Dam in Colorado’s Dinosaur National Monument (Devall 1982; Smith 1995; Maher 2008). Like the Hetch Hetchy Valley nearly 50 years before, the federal government proposed construction of a series of dams to harness the

Colorado River's hydroelectric power. Preservationists organized opposition (led by the Sierra Club) and succeeded in lobbying for the proposal's denial in 1956. Preservationists rallied around the Echo Dam defeat and moved forward with an aggressive agenda.

The efforts of urbanites on the one hand, and wilderness preservationists on the other, coalesced to build an environmental movement. "Environmentalism" was rarely (if ever) mentioned in the pre-World War II years, but by the late 1960s, it was firmly entrenched in the American psyche. This new brand of environmentalism brought together the concerns of urban dwellers and wilderness preservationists who recognized population growth, consumerism, and suburbanization as principal causes of environmental degradation. Their vision was informed by path-breaking research and social change afoot in the country. In 1962, Rachel Carson's *Silent Spring* drew attention to the harms of pesticides, and Stewart Udall's *The Quiet Crisis*, published in 1963, dramatized the need to preserve the nation's wilderness. Ian McHarg, the noted landscape architect/urban planner, released *Design with Nature* in 1969, which presented techniques on environmentally sensitive urban design. Others drew attention to the human–land interface by focusing on the environmental consequences of population growth. Paul Ehrlich's *The Population Bomb*, which appeared in 1968, revisited Malthusian themes by tying population growth to resource depletion. In 1969, Jay Forrester published *Urban Dynamics,* which used computer-based simulations to link urban growth with social problems and environmental decline. His efforts led Donella Meadows and her colleagues to publish *The Limits to Growth* in 1972, which was the most widely read environmental book of its time. Meadows et al. looked broadly at the longer term consequences of population growth, environmental degradation, and natural resource depletion.

Societal sentiments also contributed to the environmental movement. The Cold War was in full swing and the prospects of global annihilation fostered introspection, and many turned to nature for solace (Smith 1995). The civil rights movement, antiwar protests, and the feminist movement stirred the cauldron of discontent and gave environmentalism a stronger foothold. Despite the popularity of suburban living, critics were already pointing to the homogeneity and sterility of suburban life (Beauregard 2006). Richard Yates, the noted novelist, published *Revolutionary Road* in 1961: a haunting tale of a family's struggle to find meaning and purpose in a Connecticut suburb.

Events at the highest levels of government supported the country's move toward environmentalism and spirited the potential of Leoplod's human-land community. John Fitzgerald Kennedy and Stewart Udall, his Secretary of the Interior, are credited with initiating the country's third wave of environmentalism (Devall 1982; Sessions 1987). In the 1950s, JFK was a newly elected senator from Massachusetts. Unlike Teddy Roosevelt, who embraced nature fully, Kennedy expressed no interest in the outdoors whatsoever. Thus, during the 1950s he favored the conventional model of conservation that characterized his predecessors (Smith 1995). Even so, as a liberal democrat he supported legislation that set aside millions of acres of forests and he championed coastal preservation. After becoming president in 1961, Kennedy and Udall embarked on an ambitious conservation program that responded to the public's growing environmental consciousness.

Although Udall also held conventional notions of conservation, he was inspired by naturalists such as Henry David Thoreau and John Muir and recognized the aesthetic value of nature (Udall 1963; Devall 1982). Through the Wilderness Bill and other legislations, Kennedy and Udall pressed for sweeping programs that are summarized by Smith (1995, p. 360): "[t]he year after JFK's death, the 88th Congress, sometimes called the "Conservation Congress," enacted the Wilderness and Conservation fund bills, created Canyonlands National Park, Fire Island National Seashore, and the Ozark National Scenic River ways." The Kennedy/Udall initiatives surpassed efforts by Truman and Eisenhower (Kennedy's predecessors), who did little to advance conservation or preservation, but fell short of FDR and Teddy Roosevelt's programs. Nevertheless, Kennedy and Udall forged a new direction in federal environmental legislation.

Environmentalism and Conservation Since the 1970s

The 1970s brought an even deeper commitment to environmentalism. Guided by Washington State senator Henry Jackson, Congress approved dozens of bills in the late 1960s that targeted air, ground, and water pollution, offshore oil drilling, endangered species, watershed management, scenic land set asides, and wilderness preservation (Jackson 1970; Nolon 1996). The Endangered Species Act (ratified in 1973) arose from the hotbed of environmentalism to become one of the country's strongest pieces of environmental legislation (Bryner 1998). While working through this impressive stack of legislation, Jackson found that environmental regulation and monitoring were spread across numerous federal agencies with little cooperation. He therefore proposed the National Environmental Policy Act (NEPA), which came into effect on January 1, 1970. The NEPA was administered through the Environmental Protection Agency (EPA), which centralized oversight. Among other things, the NEPA required environmental impact statements that detailed the likely outcomes of development projects. This opened the door to public scrutiny and mandated greater government accountability (MacCleery 1994). The NEPA also promoted the field of environmental planning because planners were needed to assess local impacts and weigh in on proposed developments (Levy 2000).

Jackson buttressed the NEPA with legislation that called for a National Land Policy Act, the most sweeping conservation and land-management scheme ever proposed in the United States (Nolon 1996; Rome 2001). Responding to the country's fragmented approach to conservation and land management, Jackson noted:

> the history of conservation and environmental concern in this country has been a history of specific, isolated confrontations—a history of focusing on the issue or the crisis of the moment, be it forest management, wilderness preservation, an oil spill, or air pollution. A comprehensive management approach to environmental administration has not been achieved. Our institutions and procedures still condition us to fight brush fires (Jackson 1970, p. 1079).

Jackson's bill called for coordinated land-use planning at federal, state, and local levels of government and required the designation of urban, agricultural, environmental, and industrial land uses (Jackson 1970). Paul McCloskey, a Congressional Representative from California, pushed Jackson's legislation even further by proposing a National Land-Use Commission that controlled all land development in the country (McCloskey 1970). The commission was guided by five objectives that aimed to preserve the nation's wilderness. The commission would determine urban and agricultural land uses and identify lands for preservation and outdoor recreation. The commission's approval was needed to develop all lands, public or private. Despite strenuous efforts to pass Jackson's bill, it was defeated in 1970 and 1971 and the bill died in 1974 (Nolon 1996; Rome 2001). Needless to say, McCloskey's bill failed as well.

The National Land Policy Act is the closest the nation has come to embracing Leopold's vision of the human–land community (Jahn 1998). Even though the Act never received full Congressional approval, it signaled a decisive shift in the country's treatment of land and demonstrated the evolution of environmental consciousness. It also shaped other federal land legislation. The Federal Land Management Act of 1976, for example, called for increased cooperation between federal agencies, coordination with state and local governments, and broader public participation in land-management decisions (U.S. Bureau of Land Management 2001).

But Ronald Reagan's ascent to the presidency in 1981 quieted any hope of a viable human–land community. The "Reagan Revolution" returned the country to its founding principles of private property rights, minimal government intervention, and wealth accumulation. This led to an assault on environmental regulation and a shift toward privatization in federal land policies (Runge 1984; Durant 1987). The oil crisis of the 1970s prompted overtures to open wilderness areas to oil and shale extraction. James Watt, Reagan's first Secretary of the Interior, vowed to achieve energy independence by granting oil companies access to the nation's pristine lands. But his attempts were largely repelled by Congress, due mainly to public opposition, and Watt resigned in 1983. Even so, his successors pushed for privatization, state control of land use and conservation, and the opening of public lands to resource extraction.

The Clinton administration (1993–2001) managed a few key pieces of environmental legislation and preservation, but the Republican-led Congress, which came to office in 1995, challenged many initiatives (Fisher 1995). It also continued the Reagan legacy of promoting private property rights and pressed the issue of uncompensated "takings:" the loss of land value resulting from regulations that limit (or prohibit) development. The Endangered Species Act was among federal legislation that came under scrutiny (Thompson 1997).

The Bush administration (2001–2008) continued to roll back environmental regulations that interfered with corporate profit making (e.g., air pollution standards), and favored market-based incentives, rather than regulation, to encourage conservation. Bush's refusal to endorse the Kyoto Protocol in 2001 sent a clear message that economic interests come first, and the administration's own version of the protocol (prepared in 2002) was built on voluntary participation and incentives (Vespa 2002). Bush's "legacy of cooperative conservation" employed the same strategies of volunteerism and market-driven incentives. They were pivotal to Bush's Landowner

Incentive Program, which urged ecological restoration, and the Private Stewardship Grants initiative, which encouraged protection of endangered species. Both programs apply to privately owned lands and are voluntary (Thompson 2005). The Bush administration has also opened public lands to resource extraction, especially for petroleum.

Despite the government's retreat, environmentalism continued to evolve. The deep ecology movement, proclaimed by some as the country's fourth and most recent wave of environmentalism, advocates a biocentric perspective that opposes the country's ideological foundations (Devall 1982; Sessions 1987; Worster 2005; Diehm 2007). Drawing on Muir, Leopold, and others, deep ecologists argue that the commodification of land and resources undermines the premise of a human–land community and necessitates a "deeper" shift in environmental thought so that all biota are valued equally.

Policy makers and planners gained some ground in advancing environmentalism at the local level. First, the environmental justice movement grew as grassroots organizations pointed to inequities in quality of life and environmental health. Environmental justice looks to the relationship between class, race, and exposure to degraded environments such as brownfields and superfund sites (Higgins 1993; Brulle and Pellow 2006; Resnik and Roman 2007). Second, "smart growth" legislation acquired a stronger foothold as states, multicounty jurisdictions, and cities adopted policies and devices to contain sprawl. The cost of providing public facilities and the loss of open space and agricultural lands motivated these efforts (American Planning Association 2002).

Exurban Growth and Housing Markets

The volumes of environmental legislation passed over the years did little to stop the sales of privately owned lands (agricultural and wildlands), the lifeblood of exurbanization. This allowed exurbanization to transform the rural landscape as the population moved to the countryside. In the 1970s, the nation's rural population grew faster than the metropolitan population for the first time in well over a century, leading many observers to proclaim a "rural renaissance" (Fuguitt and Beale 1996). But rural population growth slowed in the 1980s, raising doubts about a sustained rural turnaround. In the 1990s, rural population growth accelerated once again, a trend that continues today. Currently, about 37% of the country's population live in exurban areas (Merenlender et al. 2005; Domina 2006). Population growth led to the conversion of millions of privately owned acres. Theobald (2001) finds that from 1960 through 1990, the quantity of exurban land more than doubled, from 156 million to 333 million acres. Similarly, Brown et al. (2005) find that from 1950 through 2000, the country's exurban land inventory increased four to five times in size. Exurban land conversion outpaces population growth because of comparatively low residential densities.

There are many explanations for exurban growth. First, the retirement-age population has long sought wide-open spaces. The elderly have moved consistently to rural areas for several decades, and the trend is expected to continue as "baby boomers" reach retirement age. Second, highway and road improvements encouraged the move to exurbia because they eased rural travel and opened previously remote lands. Finally, the movement of jobs and commercial and retail outlets to the suburban fringe enabled exurbanites to move further from built-up areas. Prior to suburbanization, people shopped and worked in central cities, but employment, services, and shopping moved to the periphery along with suburbanites. This shortened travel distances for exurbanites and allowed them to move even further into rural areas (Johnson, Nucci, and Long 2005; Johnson 2006).

Exurban housing markets are far more complex than their urban and suburban counterparts. First, the rural poor account for a growing share of the exurban housing market. As of 2003, more than 14% of the rural population (7.5 million persons) lived below the poverty line, with minorities comprising the fastest growing segment. Poverty leads many rural dwellers to manufactured housing because it is affordable. Although rural poverty is widely dispersed, pockets are found in Appalachia, the Mississippi Delta, and the US–Mexico border region (Housing Assistance Council 2008). Second, transitional housing is gaining popularity. This segment consists of recreational vehicles (RV) and "fifth wheels" that carry seasonal visitors across the countryside (Dallen 2004). Mobility is the principal advantage of transitional housing, especially among retirees who seek out remote wilderness preserves and coastal areas. Third, corporate builders (also called "public builders") have moved affordable "starter-home" subdivisions well beyond the suburban fringe. Unlike suburbia, these exurban subdivisions commodify nature by locating close to near-pristine lands that offer spectacular view sheds, open space, and access to wildlife. The cost and the availability of land are pivotal to this exurban housing segment (Frey 2003; Harvard Joint Center for Housing Studies 2006). For this reason, corporate builders often purchase former ranches because they provide thousands of acres of developable land and simplify land acquisition (Natural Resource Conservation Service 2006). Fourth, low-density hobby farms and horse properties are the largest users of exurban land and are the most visible signs of exurban development (Glennon and Kretser 2005). Parcels typically range from 1 to 40 acres in size and are often located on or near pristine lands. Finally, second and seasonal homes comprise a growing share of the exurban housing market. This housing segment is driven by the retirement-age population (but not exclusively) that for decades sought rural landscapes for temporary or seasonal housing. They often locate in, or near, small rural communities that offer direct access to wildlands. These communities previously specialized in resource extraction (timber and mining) but shifted to ecotourism because their near-pristine environments attract growing numbers of tourists and seasonal visitors (Reeder and Brown 2005; Winkler et al. 2007; Matarrita-Cascante and Luloff 2008). Resort communities located in rustic settings are also part of the seasonal housing market. Condominiums and "time shares" are popular because they provide access to outdoor recreation such as skiing, kayaking, and mountain biking.

In sum, the exurban housing market spans the full breath of American society but is particularly appealing to those who value the outdoors. For a variety of reasons, a growing number of Americans wish to reconnect with nature and rekindle their agrarian roots. Privately owned land makes these exurban lifestyles possible.

Conclusion

All life is ultimately tied to the land. Aldo Leopold (1949) understood this and offered his land ethic as a guide to preserving nature's balance. His human–land community is central to the land ethic because it points to our relationship with land: how we use, conserve, and preserve it. The chapter summarized the country's land history with the aim of understanding why a viable human–land community never materialized. This required the merging of urban (human) and land histories in order to trace the nation's treatment of land. From the outset, the use of land was forged by the principles of individualism, private property rights, and wealth accumulation, which collectively reduced land and resources to commodities. The story evolved with the ebbs and tides of urbanization, conservation, regional planning, and environmentalism. There is little doubt that America's relationship with land has changed as evidenced by the reams of environmental legislation ratified over the years. Either by necessity or an evolved consciousness, the public is far more willing to pursue preservation.

But how does exurbanization fit within the country's land history? On the one hand, it demonstrates that land remains a commodity that yields profit to private land owners. Exurban land conversion would not be possible otherwise. On the other hand, exurbanites appear to hold different attitudes than their predecessors. In many cases, they do not seek profit from the land but, instead, pursue a wilderness experience that offers connection with nature. As the following chapters demonstrate, this exposure brings ecological damage even though it is often unintended. Nevertheless, exurbanization poses the most direct threat to agricultural and wildlands and raises concerns about the future.

Most scholars expect that the popularity of exurbanization will grow in the years ahead. But changes are afoot that may well alter the pattern of exurban living. The "peak oil" crisis is perhaps the most critical issue because it will likely change the way all Americans live. Exurbanization may well dwindle as the cost of transportation continues to rise. But the energy crisis may spark even more rural living as the population increasingly seeks independent lifestyles "off the grid." Such efforts are double edged: on the one hand, reconnecting people with nature, but on the other, raising the potential for ecological degradation. The chapters to come respond to exurbanization by promoting Leopold's human–land community.

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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

G. McPherson (✉)
School of Natural Resources, University of Arizona, Tucson, AZ 85721, USA
e-mail: grm@ag.arizona.edu

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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

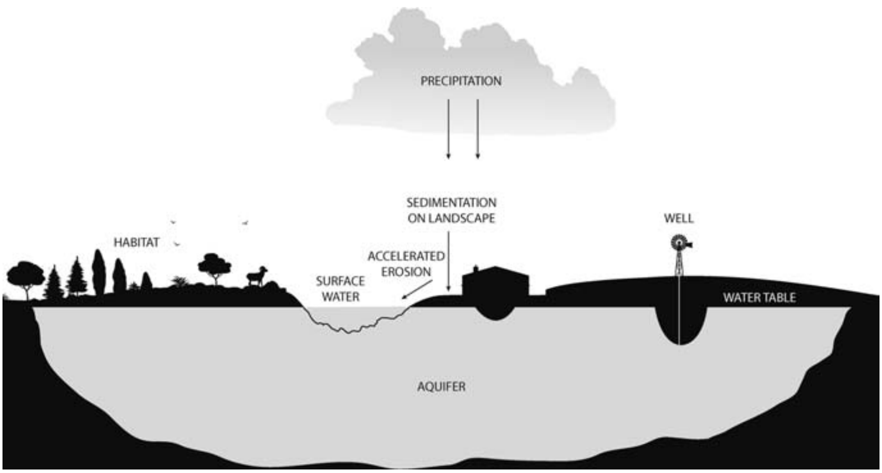

Fig. 2.1 Ecological systems in exurbia. Source: Guy McPherson

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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Chapter 3
Climate Change and Ecology in Rural Lands

Joel R. Brown

Abstract Climate change has gained wider attention in recent years as issues of longer term environmental sustainability are debated in research circles and among the public at large. For this reason, considering how climate change will affect ecology and management of rural lands should be one of the pillars of knowledge supporting land-use planning and management. This chapter reviews three important aspects of climate change and ecology of rural lands: the fundamentals of climate change, how climate change is likely to affect critical ecological processes on rural lands, and, finally, some practical, accessible tools that can be used to integrate the knowledge and experience of land managers into models to improve the quality of decision making.

Introduction

Climate change is well established as a fact of life for land managers and resource conservation professionals. The contentious debate of the last decade over the role of human activities as the primary driver of climate change, while important in developing long-term responses, has been somewhat irrelevant to farmers, ranchers, other land managers, and resource conservation professionals whose livelihoods depend on understanding the effects of climate and responding effectively. The ability to cope with a highly variable climate, in addition to unpredictable economic conditions, has always defined success or failure for managers of land-based enterprises.

But even with the experience gained over decades of dealing with climate variability as a basis for improved decision making, natural resource managers are challenged by the accelerating pace of change in local climates. Application of

J.R. Brown (✉)
USDA Natural Resources Conservation Service, National Soil Survey Center,
Jornada Experimental Range, New Mexico State University, Las Cruces, NM 88003, USA
e-mail: joelbrow@nmsu.edu

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knowledge is difficult for managers confronted with highly complex environments where climatic anomalies, regardless of whether they are directional or short term, are difficult to discern and may only happen once or twice in a lifetime. In addition, institutional assistance and support tools have typically lacked the necessary spatial and temporal precision to elevate decision making from art form to science.

General information about climate trends or ecological rules, however accurate, is virtually useless when it comes to managing a particular piece of land (Bestelmeyer et al. 2009). Incorporating explicit information about specific soil/vegetation/disturbance relationships that are peculiar to a given piece of land is essential to successful land management, especially when one of the primary drivers, climate, is expected to change.

Given our existing understanding of the drivers of climate change as well as our best predictions of the direction and pace of that change, considering how climate change will affect ecology and management of rural lands should be one of the pillars of knowledge supporting land-use planning and management. This chapter reviews three important aspects of climate change and ecology of rural lands: the fundamentals of climate change, how climate change is likely to affect critical ecological processes on rural lands, and, finally, some practical, accessible tools that can be used to integrate the knowledge and experience of land managers into models to improve the quality of decision making.

Some Climate Change Basics

The climate is the long-term average (>30 years) of the weather (temperature, rainfall, and wind) for a particular region. Thus, 'climate change' can be defined as a long-term change in the average weather (Le Treut et al. 2007). Although public attention has only recently focused on the science of climate change, the current, and ongoing, explanation of how and why Earth's climate changes has developed over many years and through the efforts of a wide range of scientific disciplines (see Weart 2003 for a history of climate change science). The short version is that Earth's climate is the result of a complex interaction of a number of controlling processes, called 'forcings' that affect the amount of energy incident upon the planet. These forcings can be divided into three general groups: (1) factors that affect the amount of energy reaching Earth's surface; (2) factors that affect the amount of incoming solar radiation that is reflected; and (3) factors that affect the amount of reradiation (energy absorbed by Earth and radiated back into space). These factors interact to affect the amount of Sun's energy retained by Earth, the primary controller of the climate system.

Early in the 20th century, Milutan Milankovitch, a Serbian engineer, developed a theory to explain the recurring advance and retreat of glaciers during ice ages. Milankovitch's research was based on the work of James Croll, a Scottish scientist, who described the effects of gravitational pull on Earth by other solar bodies and how the resulting changes in the orbital pathway influenced the amount of radiation reaching the planet. Popularly known as Milankovitch cycles, these variations in Earth's orbit fall into three categories: eccentricity (orbital shape) with a 100,000-year cycle; obliquity (axial tilt) with an approximately 40,000-year cycle; and precession (wobble) with an approximate cycle of 25,000 years (Milankovitch 1998). The 11-year cycle of sunspot activity might also influence the amount of energy incident upon Earth.

What happens on Earth might also have an influence on radiation capture and, ultimately, on the climate system. As the continents shift (plate tectonics), changes in land mass positioning, relative to the oceans, can affect the amount of radiation captured as well as greatly alter ocean circulation patterns (Le Treut et al. 2007). In addition, the release of sulfur aerosols from volcanic eruptions can result in cooling at the global level. For example, the eruption of Mount Pinatubo in the Philippines in 1991 caused a cooling of Earth's atmosphere on the order of 0.5°C (Self et al. 1996).

The 'greenhouse effect' refers to the process by which radiation is emitted by Earth's surface and is absorbed by the atmosphere (Schroeder 1999). Although the analogy of a greenhouse is somewhat incorrect (because the atmosphere reduces radiation losses from Earth to space, while a real greenhouse reduces losses by limiting convection), it does provide an understandable example of how increases in some gases (notably, CO_2, CH_4, and N_2O) in the atmosphere lead to increased energy capture and global warming. In general, energy emitted from the Sun as high-energy, short-wave radiation passes through the atmosphere and is absorbed by Earth's surface. In turn, radiation emitted from Earth toward space travels in a longer wave, lower energy form. The molecules of the so-called 'greenhouse gases' allow the short-wave radiation to pass through, but the longer wave radiation is absorbed. The net effect is a higher energy (warmer) atmosphere and that energy has an important forcing effect on the global climate (see http://science.nationalgeographic.com/science/environment/global-warming/gw-overview-interactive.html for an interactive demonstration).

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (Forster et al. 2007) examined evidence from a wide variety of sources and concluded human activities, such as burning fossil fuels, livestock management, and fertilizing crops, have led to increases in greenhouse gas levels and are extremely likely (>95% confidence) to have exerted a warming influence on the global climate since 1750. Although there has been a substantial amount of discussion and effort in designing policies and programs to reduce the human influence on the climate, the outcome is still clearly in doubt. Even if greenhouse gas emissions are reduced and the reductions have the desired effect, it is still likely that a human influence on the climate will extend well into the future. Even in the complete absence of a human influence on the climate, investigations of the historical climate record via a variety of techniques have clearly shown that the climate, at the temporal scale of humans, is not stable in its influence as an important ecosystem component. Thus, accounting for the effects of, and responding to, climate change and variability must be a central focus of land management.

How Land Use and Management Interact with Climate Change

The way humans manage land influences, and is influenced by, the climate system (Pielke 2008). Soils and vegetation exchange matter and energy (flux) with the atmosphere, including greenhouse gases such as CO_2, N_2O, and CH_4. Globally, the pool of carbon in the soil (>1500 Pg [Petagram, 10^{15}g] in the upper 1 m) and vegetation (>650 Pg) is substantially greater than the amount stored in the atmosphere (˜750 Pg; Food and Agriculture Organization 2001). How land is used can have a large influence on the direction of these fluxes. In general, disturbance (burning, tillage) and degradation (loss of vegetation cover, loss of soil organic matter) tend to increase the flux toward the atmosphere. Conversely, soils and vegetation can be managed to remove and store carbon from the atmosphere. In 1750, 6–7% (7.9–9.2 million km^2) of the globe's land surface was cultivated land, while in 1990 cultivation expanded to 45.7–51.3 million km^{2}or 35–39%, a five- to sixfold increase. Changes in land use are estimated to have contributed approximately 120 Pg of carbon to the atmosphere from 1850 to 1990 (Houghton 2003). Over the same period, fossil fuel burning was estimated to have released 212 Pg of carbon to the atmosphere (Marland, Boden and Andres 2006). However, while the flux of fossil fuel emissions was entirely toward the atmosphere (increasing greenhouse gas levels), Forster et al. (2007) estimated there was a net flux *toward* the terrestrial pool because of changes in land use and management. This 'terrestrial carbon sink' and the calculation behind it illustrate the potential of land use and management change to influence greenhouse gas levels in the atmosphere as well as the importance of terrestrial ecosystem management in addressing the problem of global climate change (Intergovernmental Panel on Climate Change 2007).

The purposeful management of terrestrial ecosystems to increase their carbon storage is referred to as 'carbon sequestration' and has been identified as a viable and important component of a greenhouse gas management and climate change mitigation strategy. Pacala and Socolow (2004) identified seven 'wedges' that, taken together, would meet the goal of stabilizing greenhouse gas levels at 500 parts per million (ppm) by 2054. Each wedge represents 1 Gigaton (1000 metric tons, or 1,000 kg) carbon per year (Gt C/year). Analyses of forestland, cropland, and grazing land (Thomson et al. 2007; Brown and Sampson 2009) estimated approximately 0.8 Gt C/year could be sequestered by land management globally (0.5 Gt for forests, 0.2 Gt for cropland, and 0.1 Gt for grazing lands), approaching one wedge.

Franzluebbers and Follett (2005) estimated the potential for increased carbon sequestration on a wide variety of land uses in North America. On croplands, the focus of management activities in the analysis was the implementation of reduced tillage technologies (0.27–0.48 Mg [Megagram, 10^6g] C/ha/year), conversion of marginal cropland to perennial cover (0.32–1.03 Mg C/ha/year), and improved crop rotations (0.12–0.29 Mg C/ha/year). The range in values is defined primarily by precipitation and soil fertility. All of the practices are well researched and have relatively widespread adoption currently, but require increased emphasis and incentives to spur further adoption. Range and pasture lands can also sequester significant amounts of carbon, but are more highly variable because of erratic precipitation and soils with lower fertility (Follett et al. 2001; Brown et al. 2009). The contribution of improved grazing land management to increased carbon sequestration ranges between 0.10 and 1.0 T C/ha/year (T = metric ton = 1,000 kg), again depending on precipitation and inherent soil fertility. Changes in forestland management, reforestation, afforestation, and avoided deforestation have potential to dramatically increase ecosystem carbon because of year-to-year carryover of wood biomass (Thomson et al. 2007). Many forests can sequester in excess of 2.0 T C/ha/year. For all these land uses and management practices, relatively simple tools are available to estimate carbon sequestration potential (see Brown and Sampson 2009). In addition, governments and the private sector are devising new incentives to enhance the adoption of carbon sequestration technologies (Intergovernmental Panel on Climate Change 2007).

Removal of vegetation or disturbance of soils can also affect the reflectance (albedo) of Earth's surface and influence the local and global temperature. While there is a great amount of variability in how natural vegetation, cultivation, and structures affect albedo, typically, vegetation removal or soil disturbance darkens the surface and increases the absorption of energy (Budikova, Hall-Beyer and Hassan 2008). Pielke et al. (2002) review the range of changes that may occur in local and global climate as a result of changes in land use and cite several examples of the complex interactions between management for greenhouse gas reduction via carbon sequestration in terrestrial ecosystems and the radiative forcing that occurs as a result of changes in surface albedo. They suggest that changes in surface albedo may rival or exceed those of greenhouse gases in regions where human-caused land-use change is intensive. For instance, in regions where snow cover is extensive, afforestation (to increase carbon sequestration) could have the unintended effect of decreasing surface albedo and increasing surface temperatures (Betts 2000).

The complexity inherent in the interactions of local- and regional-scale effects (changes in surface albedo) and global effects (changes in greenhouse gas levels) as a result of the same action requires a thoughtful and precise analysis to most cost effectively meet objectives and avoid unintended consequences. Although the contribution of actions taken by an individual on a particular piece of land may be relatively small, the cumulative effects and their interactions can result in unintended consequences at larger scales (Peters et al. 2008). This combination of complexity and connectivity demands that planners at all scales be knowledgeable of climate change processes and drivers and integrate them into the decision-making process governing how land is used and managed.

How Climate Change Affects Land Management

People use land in a variety of ways to achieve their desires. Achieving sustainability, an indicator of which is the ability to pursue new goals, requires not only knowledge of ecological processes, but also the factors affecting those processes and how human activities interact to influence those processes. While it is tempting to continually increase inputs in an attempt to control and shortcut ecological processes as land use intensifies, eventually economic and/or ecological reality sets in. The best example of this misdirected approach is the suppression of forest fires in the American West over the past century. Great amounts of resources were expended by the private and public sectors to control naturally occurring forest fires. As fuels accumulated to dangerous levels, the resulting fires, whether natural or human-caused, generated great damage both to ecosystems and to human systems (Stephens and Ruth 2005; Jensen and McPherson 2008). Although realizing that making ecological processes the basis for land use and management decisions is a sound approach and is widely acknowledged (at least in principle), the frequency with which it is ignored in practice necessitates more attention to the integration into the planning process.

Developing a land use and management plan that integrates climate change requires both an acknowledgement of how important the information is and a realization of its lack of precision at the scale of most planning. An important first step in devising a climate change response strategy is a hypothesized model of what the changes in weather patterns are likely to be. Although it is unlikely that models will be available to precisely predict local climate at a spatial or temporal scale to alleviate all risk, there are very good estimates of likely change at the regional level (see Climate Change Science Program 2008). As different as current local climates within any given region are, future spatial variability in climates will be just as complex. However, there are several aspects of climate that can be assessed, evaluated, and responses developed.

Most of the attention in the climate change discussion to date has focused on temperature. Analyses of temperature trends over the past 100 years clearly show an increasing trend in global average temperatures as greenhouse gas levels increase (Intergovernmental Panel on Climate Change 2007) and there is confidence that continued increases in greenhouse gas levels will result in an increasing global temperature, although predictions will never carry the same level of reliability as post hoc analyses (Forster et al. 2007). Although there is confidence in the predictions of higher global average temperature over the next century, the temporal and spatial distribution of those temperature changes around the planet is of vital importance to planners. In addition to changes in the average temperature for a given location, which can be misleading, the variability at daily, weekly, monthly, yearly, and decadal timescales can dramatically affect ecosystem functions. In addition to changes in average temperatures, planners should integrate changes in measures of variability into decision making and implementation guidance. Important indicators of change in increased climate variability are observations of daytime maxima and minima, consecutive days of high or low temperatures, and expressions of evaporative demand (humidity, evaporation, and wind).

Similarly, precipitation changes tend to be viewed in terms of year-to-year average (Hatfield et al. 2008). However, the true impacts of change in rainfall or snowfall are more likely to be felt in the changes in extreme events (Ryan et al. 2008). The same amount of annual rainfall may be distributed within that year in a variety of ways. Form of precipitation (snow vs rain) can affect water availability within the growing season (soil moisture), storage (snowpack vs reservoir), and, ultimately, irrigation water availability for development and agriculture. Seasonality of precipitation can dramatically affect the relationship among native vegetation types (cool season vs warm season, shrub vs grass) as well as planning for vegetation to be planted and maintained as part of a land use or management change (Archer and Predick 2008).

It would be difficult to the point of ridiculousness to try to cover the range of possibilities for the local effects of global climate change in this chapter. However, there has been a significant amount of effort within the scientific community to develop accessible and understandable assessments of potential climate change directions and the effect on ecosystems at scales relevant to land use and management planning. Recent reports have thoroughly discussed climate change effects on US land and water resources (Climate Change Science Program 2008), human systems (National Science and Technology Council 2008), and global rangeland management (Society for Range Management 2008) and include extensive reviews of impacts on a variety of sectors (Intergovernmental Panel on Climate Change 2007). Many of these products are produced by multiagency working groups and represent the current state of the science. They are updated on a regular schedule and are generally available free of cost. In short, a lack of information on climate change at the regional and local scale should never constrain the integration of this important aspect of human ecology into land use and management planning and decision making.

The second important step in integrating climate change into land-use planning and management decisions is the selection of an appropriate model to describe ecosystem behavior. The conceptual model chosen to underlie decision making is important both in the construction of alternatives and in how those alternatives are presented to the people who make the decisions and the people whose lives are affected by those decisions. An inappropriate model leads to both poor decisions and poor explanations.

A conceptual model should include the current state of the science as well as the opportunities for updating as new information becomes available. A model with utility for integrating the effects of climate change should be driven by the influence of climate on the behavior of ecosystems and their components, such as plant and animal communities, on ecosystem services (Fig. 3.1). Ecosystem services are those goods and services extracted from an ecosystem that benefit human well-being (Millennium Ecosystem Assessment 2005) and cover the range of uses and products that are derived from ecosystems, including many that are difficult to value objectively. While humans have devised highly functional means of valuing many of the goods from ecosystems, such as provisioning services (food, fiber), the management of ecosystems for many services suffers because of a lack of well-developed marketing systems (Havstad et al. 2007). The relationship between land management and the output of ecosystem services, however complex and tortuous, is the basis for making realistic land-use decisions and implementing appropriate management regimes.

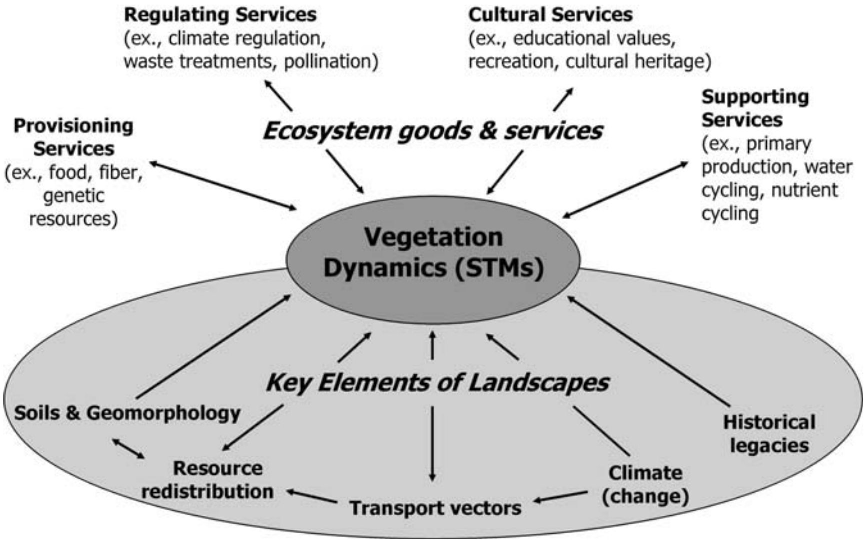


Fig. 3.1 Five key elements of landscapes interact to determine vegetation structure and dynamics with resulting effects on ecosystem goods and services. (1) Historical legacies of past climate, disturbances, and human activities, including land use, can leave long-lasting signatures on landscapes that influence current vegetation patterns and dynamics. (2) Climate and climate change determines local weather and can have important direct and indirect effects on ecosystem dynamics through influences on (3) transport vectors, such as the run-on and run-off of water during extreme rain events. Other transport vectors include human activities, wind, and animals that (4) redistribute resources, such as soil, nutrients, and seeds, within and among spatial units of the vegetation. (5) Soils and geomorphology refer to spatial variability in parent material, topography, plant production, soil nutrient status). A key characteristic of this template is the arrangement or distribution of spatial units that influences their connectivity via transport vectors. The harvest of goods and services can certainly have reciprocal effects on the structure and dynamics of these landscapes (redrawn from Peters et al. 2006; Havstad et al. 2007)

Just as local climates and the effects of climate change are highly variable, ecosystem behavior is similarly peculiar. If ‘all politics is local,’ then surely land management is the ecological version of politics. In both politics and land management, change is inevitable. Understanding the nature of that change is critical to framing decisions and communicating outcomes. For much of the time that ecosystem behavior has been studied as an organized endeavor, it was viewed as a linear, deterministic process (Brown and MacLeod 1996). In essence, ecosystems, and the landscapes, communities, populations, and individuals that compose them, proceeded through an orderly progression (the process of succession) until they reached a stable climax. In the event of a disturbance (a single event or series of events that disrupts ecosystem processes and cause degradation), time was the necessary ingredient to achieve recovery. In some cases, the addition of missing species might be necessary, but in general, full recovery was a matter of alleviating the disturbance event (fire, soil disturbance, logging, grazing) and allowing the process of succession to play out.

Long-term observations have led to the emergence of a new view of ecosystem behavior, one of nonequilibrium dynamics (Holling 1978; Kay 1991; Bestelmeyer et al. 2009). Even in a stable environment, events can initiate change within an ecosystem and lead to irreversible changes. The soil properties (organic matter, nutrient levels) or vegetation processes (loss of seed sources, invasion by exotic species) are irreversibly changed and are unable to recover without significant intervention. When the impacts of climate change are added to the mix of factors that affect plant communities and ecosystem services (Fig. 3.1), predicting how ecosystems will respond takes on a new level of difficulty. While nonequilibrium dynamics have been quantified quite elegantly post hoc in a variety of ecosystems (e.g., Archer and Smeins 1991; Gunderson and Holling 2002), the lack of precision in the ability to predict both climate change and nonequilibrium ecosystem dynamics will likely limit the utility of predictive models for nonprofessionals. However, in the hands of professional planners, a lack of precision (and an emphasis on accuracy) does not negate the value of predictive models as tools to aid in planning and implementation. But using those models requires knowledge of their utility, in terms of precision, accuracy, and reliability, in order to interpret and communicate potential pitfalls and opportunities. Spatial and temporal variability and ecosystem resistance and resilience are two critical concepts that must be employed to interpret information about ecological processes if management is to be successful. A working knowledge of these concepts and the ability to apply them to site-specific local situations are essential to effective and successful land management.

This discussion of climate change so far has focused primarily on temporal variability and the range of responses ecosystems are likely to exhibit. The practical application of land management science in responding to climate change also requires an understanding and accommodation of spatial variability. Regardless of the spatial scale of interest to planners (lot, development, community, county, state), an assumption of homogeneity is a poor basis for building and implementing a realistic plan. The study of spatial variability and enhanced understanding of its importance in determining how land systems respond to disturbances, such as climate change, has emerged as an important field of ecology (Turner, Lambin and Reenberg 2007). Acknowledging this important aspect of land-based ecology requires planners to integrate not only estimates of average behavior, but also of the range of behaviors likely to be observed for any property of interest.

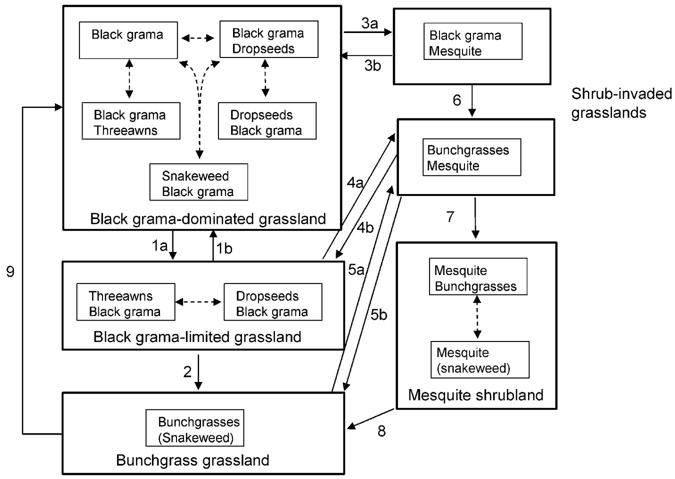
Regardless of the scale at which planners work, it is impossible to isolate that particular scale from its context. Land systems are hierarchical in their organization and their behavior (Allen and Starr 1982). Any level within the hierarchy is influenced by the other levels and, in turn, influences behavior of other levels. The value of an attribute at any particular scale is the sum of the values of the individual units at the next finer scale of resolution *plus* interactions. If sites did not interact via ecological processes, such as cycling of nutrients or water, it would be relatively easy to calculate the landscape value of an attribute by combining site scale information. However, the interaction(s) among sites imparts unique character to landscape and also has a substantial impact on the success or failure of management.

This connectivity requires an acknowledgment and integration of the context within which a particular piece of land (and its planned use and management) exists. Even though portions of a particular landscape may be well managed, degrading processes on surrounding areas can overwhelm smaller units (Peters et al. 2006). Climate change can trigger undesirable changes on susceptible sites, and the processes driving these undesirable changes can spread to surrounding land units, even though they are managed to resist the change. A good example can be observed in the behavior of many invasive species. Some landowners make special effort to manage land to resist exotic species invasion, yet other landowners (with more susceptible land or management practices) fail to exclude the invasive species. From these 'pioneer' sites, invasion proceeds to less susceptible sites and eventually overwhelms even the best management (Christen and Matlack 2006). When these types of dynamics are at play, landscape management to resist degradation requires multiple landowners to act in concert and may require different responses in different parts of the landscape.

A site description is an invaluable tool to aid planners in identifying and making important management decisions. It should be relevant to the spatial scale at which decisions are made and implemented, but it should also provide reliable information at coarser (larger) and finer (smaller) scales. The utility of a site description also depends on whether it offers a realistic representation of the dynamics of the site and the factors that drive change. Finally, a useful site description should be flexible and readily adaptable to new uses and to new information (i.e., climate change). The professions of forestry and rangeland management have a relatively long history of developing, using, and supporting site descriptions (Shiflet 1975). A systematic approach to identifying land units with similar soils, climate, and vegetation dynamics first emerged in the early 20th century (Korstian 1919). Although the initial emphasis was on forest yield, the focus ultimately shifted to soil/vegetation dynamics applicable to both rangeland and forestland. The National Cooperative Soil Survey and the principles developed for mapping and describing soils have been the basis for classification, interpretation, and communication of soil information, including site descriptions (Helms, Effland and Durana 2002). Like any science-based activity, site descriptions have changed and will continue to be refined as new information emerges.

Ecological Site Descriptions (ESDs) are the current version of site descriptions most widely used by resource professionals. Ecological Site Descriptions and their key component, state and transition models (STMs), are relatively new technologies for land management decision making (USDA, NRCS 2003). As a land classification system and a planning and management tool, ESDs differ from most descriptions in one important aspect. Ecological Site Descriptions are based on potential, not existing, vegetation associated with a unique soil. Because any particular soil (however narrowly defined) includes an assumed distribution of properties that have important effects on vegetation behavior, a soil may be associated with a similar range of vegetation attributes. Regardless of the scale of mapping, soil map units generally comprise associations of distinct soils. Typically several soil mapping units are combined into a site, assuming the climatic and soil properties and the vegetation behavior and animal impacts are similar. Vegetation assemblages on any particular soil also reflect disturbance and short-term climatic fluctuations. Thus, a soil may be occupied by a relatively wide variety of plant communities, which presents planners and managers with a confusing array of choices. Ecological Site Descriptions can be used to display and explain those dynamics within the context of management decisions. Due to the nature of rangeland ecosystems, ESDs must include a relatively wide range of variability in any given soil or vegetation property. While they lack the illusion of precision of narrowly defined mathematical models, they have the flexibility necessary to accommodate uncertainty associated with complex ecosystems and multiple land management objectives. Constructing STMs is an iterative process. By far the most important input is expertise, whether it is experimental or management based.

Figure 3.2 illustrates the STM portion of an ESD. States are relatively broad groupings of plant communities possessing similar ecological function and structure. Transitions are the trajectories between states that contain a threshold. Generally, moving between states, whether by design or unintended consequence, requires



1a. Grazing in drought periods, moderate soil degradation. **1b.** Restoration of soil fertility (if climate not involved)
2. Black grama extinction due to heavy grazing in drought, severe soil degradation.
3a. Introduction of mesquite seeds, reduced grass competition, lack of fire. **3b**.Shrub removal, restoration of fuel loads and fire.
4a, **5a**. Mesquite invasion. **4b**, **5b**. Shrub removal, restoration of fuel loads and fire.
6. Black grama extinction due to mesquite competition and grazing.
7. Heavy grazing and grass loss, inter-shrub erosion, soil fertility loss, high soil temperatures, small mammal herbivory.
8. Dune destruction, mesquite removal, soil stabilization, nutrient addition, seeding during wet periods.
9. Reseeding, replanting with restoration of soil fertility.

Fig. 3.2 A state and transition model for the sandy ecological site in the southcentral/southwestern Chihuahuan Desert of New Mexico, USA. *Smaller boxes* are plant communities identified by dominant perennial species and the large boxes are states defined by differences in ecological function. *Dashed arrows* between communities represent known pathways of change caused by variation in disturbance intensity and frequency or variation in the timing and amount of precipitation. *Solid arrows* are transitions that are described in the text below the model. See the text for further description of components (Redrawn from Bestelmeyer et al. 2004) a substantial event (drought, fire) that alters ecological processes and cannot be reversed by managerial responses once it is breached. Plant communities and pathways occur within any individual state and are generally regarded as being amenable to relatively common management actions or climatic fluctuations. While they can accommodate information derived from virtually any theoretical or empirical interpretation of community scale change in rangeland ecosystems, they are most identified as a way to capture dynamics associated with rangelands not at equilibrium. State and transitional models were first proposed in the late 1980s and have been extensively applied to rangeland situations throughout the world (Westoby et al. 1989). Key elements in this approach are the concepts of resistance and resilience. In many arid land systems, STMs have been expanded to include soil/plant interactions that are central to the resistance and resilience characteristics of any ecological site.

The concepts of resistance and resilience are fundamental to interpreting and predicting ecosystem behavior, setting realistic goals and objectives, and making management decisions. Resistance is the amount of disturbance (for instance, fire, drought, or soil disturbance) a plant community or soil can tolerate before it changes to another functional state. Resilience is the probability that a plant community or soil will return to its original state when the disturbance is suspended. A qualitative understanding of resistance and resilience for specific sites is fundamental for making effective planning, implementation, and monitoring decisions (see Pickett and White 1986).

Understanding the level of disturbance that a given plant community or landscape can tolerate requires both an understanding of the attributes of the land itself and the nature of the disturbance (Briske et al. 2006). A substantial amount of effort has been devoted to defining and quantifying these concepts by the scientific community, particularly in rangeland and forestland management, where disturbances are often distributed heterogeneously across extensively managed landscapes and ecological complexity precludes the use of energy-intensive technologies (Bestelmeyer et al. 2009). Although few experiments have been conducted within the context of climate change, interpretations often address the effects of historical climatic shifts. While the effects of climate change on intensive land management activities such as crop production are complex, they are usually expressed in terms of the effects on yield, at a variety of scales (Hatfield et al. 2008). The effects on less intensively managed lands are more difficult to predict and to quantify. Because extensively managed land is more susceptible to the effects of the interactions of disturbance and climate change on dominant ecological processes and the array of ecosystem services is broader and more diverse, the link between climate change and ecosystem services of interest is less clear and more difficult to predict (Ryan et al. 2008). The role of disturbance and the inherent resistance and resilience of a particular piece of land is critical to developing land use and management plans and response strategies.

Essentially, STMs regard anthropogenic disturbance and management responses as part of the system rather than as external to the system. States are used to describe the general configurations that a particular plant community may assume (i.e., short grass vs shrub dominated) and the associated soil and vegetation attributes. Transitions describe the trajectories of change between states. These descriptions include climatic, natural disturbances, and management associated with the change and the probabilities that each of these combinations may occur. Particularly useful is the identification of climatic events that may facilitate the successful application of a management response. Land management using STMs is a fairly logical process of inventory (What is the current state?), planning (What is the desired state?), implementation (applying management under appropriate circumstances) to achieve (or avoid) the change, and monitoring (Are the actions having the desired consequence?).

In early applications, STMs have greatly improved communications among land managers, scientists, and the interested public. Scientists have used STMs to illustrate to land managers where research fits in the context of land management and the importance of understanding ecological processes. Land managers have used STMs to frame their problems for scientists and to better explain decisions to the interested public and funding bodies. Many ecosystems have been the subject of extensive and exhaustive investigation, but on-the-ground experience is critical for interpreting the information in management terms. There is no single mathematical model underlying STMs, but many STMs have been constructed based on model outputs, experimental results, and observations. The definition of the poorly known is as important as the elucidation of the well known (Bestelmeyer et al. 2004). Seldom are planners confronted with well-defined inputs, quantifiable processes, and clear objectives for outcomes. Quantification (or at least, qualification) of uncertainties can determine critical points for future decision-makers and aid in designing monitoring schemes with strong feedbacks to improve effectiveness of land management.

Finally, and perhaps most important, successful land-use planning, implementation, and management require an appropriate management model. Any management textbook, regardless of the disciplinary focus, emphasizes the need for selecting an appropriate management model, including a mechanism for measuring progress toward objectives and making adjustments in the event of a change in the environment or a change in goals (Daft 2008).

As the idea of managing a resource, land, that

- behaves in a nonequilibrium fashion;
- exists in a changing environment (climate change);
- is expected to deliver a constantly shifting set of products and services.

has started to emerge as a way of doing business for scientists, planners, and managers, the adoption of a more appropriate management model is a necessity (Gunderson and Holling 2002). As the practical, applied nature of managing resources under these assumptions has become a part of managers' operating plans, more have adopted an 'adaptive management' approach (Holling 1978).

Adaptive management is an approach to management that recognizes uncertainty and attempts to deal with it by emphasizing the need to constantly update models with the best available information and also focuses on monitoring as a basis for adjusting management. Passive adaptive management places a greater emphasis on adjusting models used as the basis for decision making, while active adaptive management emphasizes monitoring in an experimental context, extending all the way to a 'management by hypothesis' approach (Bowman 1995). Both approaches share an emphasis on iterative learning through constant monitoring and adjustment. Another important part of the adaptive management approach is the acknowledgment and integration of risk and uncertainty (Walters 1986). While there is a substantial literature on the employment and evaluation of adaptive management in making natural resource decisions, its application is inconsistent.

Conclusion

Well-developed tools for land-use planning such as Ecological Site Descriptions (ESDs) and state and transition models (STMs) provide planners with not only explanations of processes, but sources of uncertainty and probabilities of occurrence. Those process/probability pathways can be used to identify threats and opportunities for implementation of a plan. For instance, if an event, say, weed invasion, is a moderate threat to land management objectives, but only has a small probability of occurrence, that risk can be mitigated by implementing a low-cost monitoring system to detect invasion in the early stages and initiate a rapid response. On the other hand, an event, such as wildfire, that is a major threat to defined objectives can be mitigated by monitoring more intensively for fine fuel accumulation patterns and implementing regularly scheduled fuel-reduction operations targeted at critical locations and times. Ecological Site Descriptions and state and transition models are very effective tools for organizing this type of information. In much the same way, climate change is a known threat to most land management objectives, but the exact time and location and effect are exceedingly difficult to predict. An accurate ESD can array the probabilities and aid planners in defining risks, monitoring threats, and implementing responses to climate change, whether expressed as chronic long-term change or as abrupt short-term events.

Given the current understanding of ecosystem behavior, ecosystem service expectations and climate change, deploying these tools would appear to be a basic requirement for planners and managers. The challenge, as with most tools, is in knowing the right combination and timing. Most of the information presented in this chapter has been generated in the last decade, the majority in the past 5 years. The fundamental and unchanging principles of ecosystem behavior and climate change include

- nonequilibrium dynamics;
- complexity and importance of spatial interactions;
- resistance and resilience;
- predictions that lack precision.

each of which requires planning tools that can be, first and foremost, flexible in incorporating new information and new desires and, second, accommodate and encourage participation of a broad array of users and stakeholders. The tools and approaches presented in this chapter meet those criteria. The combination of Ecological Site Descriptions/state and transition models and adaptive management offers planners an ability to both integrate new knowledge and communicate it to end-users and improve decisions.

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Part II
Exurban Land Development, Habitat, and Wildlife

Chapter 4
Biodiversity and Residential Development Beyond the Urban Fringe

Carl E. Bock and Jane H. Bock

Abstract This chapter describes the impacts of rural exurban development on the abundance and variety of plants and animals in North American ecosystems. The principles of landscape ecology provide a framework for considering the ways that exurban development can impact biodiversity. We survey the literature and describe the responses of varying components of biodiversity to rural exurban development in North America. Results suggest that habitat loss and landscape fragmentation have relatively minor impacts on exurban biodiversity, except at the highest housing densities. In contrast, perforation edge effects and land-use changes are highly important in most cases. Positive perforation effects include the provision of resources such as water and shade that otherwise can be scarce in natural habitats. Negative perforation effects include competition, predation, and nest parasitism from household pets and other human commensal species and escapes of exotic vegetation from landscaped areas into adjacent natural ecosystems. The chapter concludes by suggesting ways in which planners and property owners can mitigate or avoid impacts on habitat and wildlife.

Introduction

Low-density exurban housing developments are replacing natural and agricultural landscapes in the United States at a high rate, with significant but understudied impacts on biological diversity (Theobald 2001; Brown et al. 2005; Hansen et al. 2005). Exurban development occurs at the edges of urban centers and in rural areas distant from cities. While the boundaries between these two types of exurban land conversion are not absolute, the purpose of this chapter is to consider the responses of biological diversity to rural residential development beyond the urban fringe. This emphasis addresses a subject much less thoroughly studied than the environmental

C.E. Bock (✉)
Department of Ecology and Evolutionary Biology, University of Colorado at Boulder, Boulder, CO 80309, USA
e-mail: Carl.bock@colorado.edu

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consequences of development at the boundaries of large metropolitan areas (Marzluff 2005; Pickett and Cadenasso 2006; Chace and Walsh 2006; Keys et al. 2007).

We begin this chapter by categorizing the ways that exurban land conversion might impact biodiversity, based on the principles of landscape ecology. Next, we present and describe the results of a survey of the primary scientific literature on this subject. This is followed by a synthesis of those results through which we have attempted to learn which sorts of organisms are most affected by which particular aspects of exurban development. This in turn leads us to a series of recommendations about continuing research needs and another set of recommendations directed to planners and developers about ways to minimize the impacts of rural exurbanization on biodiversity.

Conceptual Framework

Biodiversity is defined as "the sum total of all biotic variation from the level of genes to ecosystems," while *species richness* is the number of different species living together in an area (Purvis and Hector 2000, p. 212). Conservation biologists frequently study biodiversity at the level of species or groups of similar species in particular places and then ask how human activities affect their reproduction, survival, and resulting persistence or decline. That is the approach we have taken in this chapter.

The principles of landscape ecology provide a framework for considering the ways that rural exurban development can impact biodiversity (Wiens and Moss 2005; Lindenmayer et al. 2008). The most obvious of these is *direct habitat loss* through conversion of agricultural and natural ecosystems into buildings, gardens, and roads. This results in the replacement of species indigenous to native and agricultural habitats by those adapted to built landscapes. Habitat loss is arguably the greatest threat to biodiversity worldwide (Wilcove et al. 1998; Foley et al. 2005). However, the amount of habitat lost in most exurban developments is limited because of low housing densities. Therefore, various indirect effects of development that impact habitat quality are likely to be more important to biological diversity than is absolute habitat loss.

Indirect effects of rural residential development fall into three categories. First, buildings and landscaping can *fragment* remaining undeveloped lands into isolated patches that may be too small and too isolated to sustain viable populations (Fahrig 2003). Fragmentation could be significant even in low-density developments for species unwilling to live near houses or to cross roads. Second, human habitation creates landscape *edges* (Ries et al. 2004), not only in those largely suburban places where high-density housing developments contact adjacent ecosystems but also in exurbia, where scattered home sites "perforate" undeveloped areas (Collinge and Forman 1998). See Chapter 5 for a detailed discussion of land fragmentation.

Exurban *landscape perforations*, represented by buildings and associated landscaping, can have both positive and negative impacts on regional biodiversity. Those species with a particular affinity for built landscapes are called human *commensals* or *synanthropic* species (Marzluff 2005), and they usually respond very differently to development than do other groups of species. Positive perforation effects include the provision of resources such as water, nectar, seeds, and shade that may be scarce in natural habitats. Wide-ranging animals may visit such exurban "oases" (Bock et al. 2008) to obtain food or water, even when they live primarily in adjacent natural areas. Other species with relatively small home ranges, such as insects and certain small mammals, may live entirely within the exurban perforations, thereby increasing overall biodiversity compared to undeveloped areas. However, exurban perforations can also negatively impact native biodiversity when they provide living places for predators, both wild and domestic, that forage out into adjacent natural areas. Landscaped areas around houses also function as sources of exotic vegetation that can escape into nearby undeveloped lands, frequently at the expense of native species.

The third way that exurban development can impact regional biodiversity is by changing the ways that landowners use and manage the land adjacent to their homes, thereby altering ecological pattern and process (Hansen et al. 2005). Examples of *land-use change* include both the introduction and the elimination of domestic grazing animals, changes in tilled agriculture, planting of exotics, thinning of trees and understory vegetation, removal of deadfall, and modification of natural fire regimes (Hansen et al. 2005; Theobald and Romme 2007).

Whatever be the impacts of exurban development on biodiversity, it is likely that responses by native plants and animals will be correlated with the density and distribution of the houses. First, clustered houses may have different impacts than houses spread evenly across the land, independent of overall housing density (Theobald et al. 1997; Lenth et al. 2006). Second, correlations between housing density and biodiversity may be nonlinear. If so, there can be *thresholds* of development (McDonnell and Pickett 1990; Groffman et al. 2006), above which abrupt losses of biodiversity will occur and below which it will be possible to conserve and perhaps even enhance much of the original flora and fauna.

The Literature Survey

We obtained abstracts of articles in the primary scientific literature using the Web of Science database (www.isiwebofknowledge.com), searching on key words such as exurban, development, rural, and biodiversity. We then obtained copies of the full articles that were available to us electronically or in paper form in the library of the University of Colorado. We used the references cited in these articles, as well as citations of these articles as reported in the Web of Science database, as additional sources of information. In general, the most useful studies were those that compared one or more components of biodiversity between undeveloped and exurbanized areas beyond the urban fringe or those that compared rural areas with different amounts of exurban development. Undeveloped areas could be relatively natural areas, such as preserves or wilderness areas, or agricultural areas with very low housing densities that were being replaced by exurban development.

We found numerous publications comparing various aspects of biodiversity across an urban-to-rural gradient, but most of these were not appropriate for our database for one of three reasons. We excluded these studies from our analysis (1) if the exurban areas were adjacent to urban centers (e.g., Gehrt and Chelsvig 2004; Marzluff 2005), (2) if the studies compared exurban with more developed instead of with undeveloped areas (e.g., Miller et al. 2003), and/or (3) if the data were presented as correlations between various measures of biodiversity and the percentages of the landscape that were developed across an entire rural–urban gradient (e.g., Pidgeon et al. 2007). We did include results from studies of urban-to-rural gradients when it seemed clear that the exurban areas were beyond the urban fringe and when the data were presented in such a way that we could distinguish the findings in exurban areas from those in more urbanized landscapes. We used the generally accepted definition of an exurban landscape as one with a development density of 2.5 homes/ha or less (Brown et al. 2005), and we excluded some studies that were self-identified as exurban when average housing densities were above this limit (e.g., Haskell et al. 2006).

We found 39 cases, from 23 different study areas, describing the responses of varying components of biodiversity to exurban development in North America (Table 4.1). Several publications reported on the response of two or more taxonomic groups of species, and we list these as separate cases in the table. There were 12 studies of birds, 12 involving various sorts of mammals, 8 related to vegetation, 2 on reptiles, 2 on fishes, and 3 on insects. Seven of the 23 study areas were in the Rocky Mountain region, 4 from the Northeast, 3 each from the Midwest and Southwest, 2 each from the Pacific Coast and Great Lakes regions, 1 from the Southeast, and 1 from the western edge of the Central Plains. In the analyses that follow, numbers in parentheses indicate the particular cases described in Table 4.1.

The Different Effects of Exurban Development on Biodiversity

It is much easier to document negative or positive impacts of exurban development on biodiversity than it is to determine which particular aspects of development have been responsible. In many of the cases we reviewed, the patterns were clear but the cause-and-effect pathways were a matter of speculation. Nevertheless, it is important to summarize the evidence for these various causal relationships, as an aid to planners and developers hoping to minimize the ecological consequences of exurban growth.

Habitat Loss

The average housing density for exurban neighborhoods in the studies we reviewed was about one home per 4 ha (about 10 acres). Estimating a generous 2,500 m^2 converted to buildings and formal landscaping leaves an average 94% of each parcel in

Table 4.1 Studies describing effects of rural exurban development on biodiversity in the United States and Canada

Case	and Group	Reference	Region	Habitat	Housing density – Exurban area
1	Birds	Bock et al. 2008	Southwest	Grassland/savanna	0.2 homes/ha
	Results	Species richness: Positive exurb effects due to increased water and other resources; negative threshold effect at higher housing densities Abundance: Positive exurb effects on abundance related to increased water and other resources; negative threshold effect at higher housing densities for many species			
2	Birds	Craig 1997	Rocky Mountains	Coniferous forest	0.02 homes/ha
	Results	Abundance: 29 species unaffected; 17 species more common in exurb, especially Steller's jay (*Cyanocitta stelleri*), common raven (*Corvus corax*), hummingbirds, and other human commensals; attributed to bird feeders; 6 species more common in undeveloped area, including a variety of forest insectivores Nest predation: Double in exurbs, due largely to jays – an exurban edge effect			
3	Birds	Fraterrigo and Wiens 2005	Rocky Mountains	Pine forest	0.24 buildings/ha
	Results	Species richness and housing density uncorrelated Abundance positively correlated with housing density, due to increased numbers of generalists, seed eaters, ground feeders, and aerial foragers using home site resources; numbers of insectivores and snag nesters negatively correlated with numbers of homes			
4	Birds	Friesen et al. 1995	Great Lakes	Deciduous forest	1–3 homes within 100 m
	Results	Species richness and abundance of Neotropical migrants higher in woodlots without adjacent homes; no differences for birds as a whole, suggesting some compensation among other species			
5	Birds	Glennon and Porter 2005	Northeast	Mixed forest	Rural = 0.29 homes/ha
	Results	Species richness: Specialists higher in undeveloped areas; generalists higher in rural areas Conclusion: Development more harmful than land uses such as timber harvest and recreation, even when housing densities are low			

Table 4.1 (continued)

Case and	Group	Reference	Region	Habitat	Housing density – Exurban area
6	Birds	Kluza et al. 2000	Northeast	Mixed forest	0.60–6.70 homes/ha
	Results	Abundance of Neotropical migrants, forest interior, and ground-shrub nesters lower in more highly developed sites; attributed to increased nest predation edge effects (jays, commensal mammals, etc.)			
7	Birds	Lenth et al. 2006	Central Plains	Grassland	0.1 homes/ha
	Results	Species richness higher in undeveloped than in either clustered or dispersed exurbs; no benefit of clusters Abundance of grassland birds higher in undeveloped areas; abundances of human commensal birds higher in developed areas; no differences between clustered vs. dispersed housing Nesting success: No difference between undeveloped vs. clustered vs. dispersed exurbs			
8	Birds	Maestas et al. 2003	Rocky Mountains	Grass/shrubland	0.06 homes/ha
	Results	Species richness: Exurban > ranches = ungrazed reserves Abundance: 7 species of tree nesting and commensals higher in exurbs attributed to feeders, trees, nest boxes, etc.; 6 species of ground or shrub nesters more common on ranches and/or reserves, including grassland sparrows			
9	Birds	Nilon et al. 1995	Midwest	Hardwood forest	<1/ha dispersed; >1/ha clustered
	Results	Species richness: No difference between undeveloped, low-density dispersed, and clustered housing Abundance: Forest interior birds: wildlands > dispersed > clustered; opposite for nest predators (jays)			
10	Birds	Odell and Knight 2001	Rocky Mountains	Shrubland	0.1–1.0 homes/ha
	Results	Abundance: Of 23 species, 6 more common exurbs, 8 more common undeveloped, 9 unaffected; exurban species included common "backyard" birds; no striking differences between high- and low-density developments; some species were distance sensitive and avoided exurban edges			

Table 4.1 (continued)

Case	Group	Reference	Region	Habitat	Housing density – Exurban area
11	Birds	Phillips et al. 2005	Great Lakes	Deciduous forest	No housing data
	Results	Cowbird (*Molothrus ater*) parasitism: Higher among wood thrush (*Hylocichla mustelina*) nests in woodlots with exurban homes, at two sites Nest predation: Higher among wood thrush nests in exurban woodlots, only at one of two sites Nestling production: Higher among wood thrush nests in undeveloped areas, at one of two sites			
12	Birds	Tewksbury et al. 2006	Rocky Mountain	Riparian woodland	0–12% landscape home sites
	Results	Nest predation: Predation rates linked to percentage of area in agriculture and/or woodland, but apparently not related to housing Nest parasitism by cowbirds: Strongly positively correlated with percentage of area in home sites, with a threshold at about 2%			
13	Rodents	Bock et al. 2006a	Southwest	Grassland/savanna	0.2 homes/ha
	Results	Species richness and abundance: Numbers higher in ungrazed areas, independent of development; weakly negative correlation between rodent abundance and housing density within developed areas			
14	Rodents	Glennon and Porter 2007	Northeast	Mixed forest	0.29 homes/ha
	Results	Species richness not different between old growth, managed forest, and exurban development Abundance: Old growth > managed forest > exurban development; developments had more generalists and squirrels (oaks, feeders) but fewer specialists dependent on debris and understory			
15	Rodents	Lenth et al. 2005	Central Plains	Grassland	0.1 homes/ha
	Results	"Field mice" more abundant in undeveloped than in dispersed or clustered exurbs; no cluster benefit			

Table 4.1 (continued)

Case	and Group	Reference	Region	Habitat	Housing density – Exurban area
16	Rabbits	Bock et al. 2006b	Southwest	Grassland/savanna	0.2 homes/ha
	Results	Abundance of cottontails (*Sylvilagus*) higher in developed areas, probably due to water and cover; positive correlation with housing density; negative correlation with livestock only in undeveloped areas			
17	Carnivores	Harrison 1997	Southwest	Pinyon–juniper woodland	0.26 homes/ha
	Results	Abundance: Gray foxes (*Urocyon cinereoargenteus*) at least as abundant in rural residential areas as undeveloped area, but with a threshold at 0.5–1.25 homes/ha; water in exurbs a benefit			
18	Carnivores	Mace and Waller 1998	Rocky Mountains	Coniferous forest	No housing data
	Results	Grizzly bear (*Ursus arctos*) abundance: National Forest > wilderness > rural; mortality: rural > wilderness > National Forest; key factor was human-caused mortality or removal in rural area; wilderness also high due to shooting during black bear hunts and human defense against attack			
19	Carnivores	Maestas et al. 2003	Rocky Mountains	Grass/shrubland	0.06 homes/ha
	Results	Abundance: Coyote (*Canis latrans*): ranch > reserve > exurb; bobcat (*Lynx rufus*): reserve > ranch > exurb; avoidance of exurbs perhaps due to increased numbers of dogs and cats			
20	Carnivores	Odell and Knight 2001	Rocky Mountains	Shrubland	0.1–1.0 homes/ha
	Results	Red fox (*Vulpes vulpes*) and coyote less common in exurban areas, perhaps due to dogs and cats; no differences between high- and low-density housing areas			
21	Carnivores	Riley 2006	Pacific Coast	Oak–shrub–grassland	No housing data
	Results	Bobcats never used developed areas within a National Park, whereas gray foxes used developments			

Table 4.1 (continued)

Case and Group		Reference	Region	Habitat	Housing density – Exurban area
22	Deer	Storm et al. 2007	Midwest	Hardwood forest	0.2 homes/ha
	Results	White-tailed deer (*Odocoileus virginianus*) home ranges smaller and survival higher in an exurban area compared to published results from rural areas; higher survival attributed to lower hunting pressure. However, deer avoided the immediate vicinity of homes			
23	Deer	Tull and Krausman 2007	Southwest	Sonoran Desert	No housing data
	Results:	Mule deer (*Odocoileus hemionus*) home ranges smaller than elsewhere; locations closer to houses and to water than random; a key factor may be water availability in desert mule deer			
24	Deer	Vogel 1989	Rocky Mountains	Agricultural valley	Variable but exurban
	Results	Abundance threshold effect: Very few deer in areas where housing densities >0.05 homes/ha; mule deer avoided developed areas more than white-tailed deer			
25	Lizards	Audsley et al. 2006	Southwest	Grassland/savanna	0.2 homes/ha
	Results	Abundance: Arboreal species unaffected; terrestrial species less abundant in developed areas, especially in the presence of livestock; likely cause increased predation, especially by roadrunners (*Geococcyx californianus*) and perhaps also by household pets			
26	Snakes	Enge and Wood 2002	Southeast	Pine–oak sandhills	No housing data
	Results	Abundance on roads: Fewer than expected when road bordered by lawn (=housing) than by natural or agricultural habitats; attributed to loss of natural habitats, including elimination of fire			
27	Fishes	Carpenter et al. 2007	Upper Midwest	Lakes	0.04–0.17 homes/ha
	Results	Abundance: Native fish decline with increased amounts of rural housing that results in removal of near-shore woody debris, more fishing pressure, and introductions of exotic baits			

Table 4.1 (continued)

Case	and Group	Reference	Region	Habitat	Housing density – Exurban area
28	Fishes	Scott 2006	Southeast	Streams	No housing data
	Results	Abundance: Proportion of endemics vs. cosmopolitan species negatively correlated with the amount of development in the landscape			
29	Grasshoppers	Bock et al. 2006c	Southwest	Grassland/savanna	0.2 homes/ha
	Results	Species richness: No effects of housing development or livestock grazing Abundance: Higher in exurban areas where landowners kept livestock than in cattle ranches or ungrazed areas, likely due to bare ground and weedy forbs on horse pastures; no housing density effects			
30	Butterflies	Bock et al. 2007a	Southwest	Grassland/savanna	0.2 homes/ha
	Results	Species richness: Interaction between housing development and habitat; housing effects positive in grasslands probably due to increased water, shade, nectar; weakly negative in oak savannas, perhaps due to increased predation; no effects of livestock grazing; no housing density effects Abundance: Patterns similar to those of species richness, with positive effects of housing in grasslands, most evident among relatively immobile, multivoltine, dietary generalists			
31	Butterflies	Niell et al. 2007	Pacific Coast	Oak woodland	0.4–81 ha parcels
	Results	Species richness: Highest in areas with intermediate amounts of remaining oak woodland, but richness of univoltine dietary specialists higher in less developed areas with most oak woodland; possible threshold effect at about 10 ha parcel size, below which oak cover and specialists decline but land use important, because small parcels with intact oak woodland still good for specialists			
32	Plants	Barton et al. 2004	Northeast	Hardwood forest	No housing data
	Results	Abundance of exotic invasives: Number of patches of invasives along roads positively correlated with the amount of cultivated lawns along road (indicator of housing density and landscaping)			

Table 4.1 (continued)

Case and Group		Reference	Region	Habitat	Housing density – Exurban area
33	Plants	Bock et al. 2006c	Southwest	Grassland/savanna	0.2 homes/ha
	Results	Ground cover: Forb canopy higher on exurban horse pastures than on cattle ranches or ungrazed areas			
34	Plants	Bock et al. 2007a	Southwest	Grassland/savanna	0.2 homes/ha
	Results	Ground cover: Exotic grass canopy <5%, not different between exurban and undeveloped areas			
35	Plants	Bock et al. 2006a	Southwest	Grassland/savanna	0.2 homes/ha
	Results	Ground cover: Height and canopy cover of grasses greater on ungrazed areas, independent of presence versus absence of exurban development; no housing density effects			
36	Plants	Fraterrigo and Wiens 2005	Rocky Mountains	Pine forests	0.24 buildings/ha
	Results	Vegetation canopy: Unrelated to housing density, except a negative correlation between housing density and abundance of snags, stumps, and downed wood. (Perhaps due to homeowner activity?)			

Table 4.1 (continued)

Case	Group	Reference	Region	Habitat	Housing density – Exurban area
37	Plants	Lenth et al. 2005	Central Plains	Grassland	0.1 homes/ha
	Results	Species richness: Native species richness higher in undeveloped areas; exotic species higher in developed areas, with no differences between dispersed and clustered housing developments Ground cover: Same pattern as species richness; higher cover of exotics in developed areas attributed to disturbances related to development and possible planting of exotic grasses by homeowners			
38	Plants	Maestas et al. 2003	Rocky Mountains	Grass/shrubland	0.06 homes/ha
	Results	Species richness: Native plants: ranch > reserve = exurb; exotics: ranch < reserve = exurb Ground cover: Ranches had lower forb cover, highest native grass cover, and lowest exotic grass cover; exurbs had highest exotic forb cover; exotic cover in reserves attributed to trail disturbance; exotic cover on exurban properties attributed to horses			
39	Plants	Odell and Knight 2001	Rocky Mountains	Shrubland	0.1–1.0 homes/ha
	Results	Vegetation canopy: Shrub cover similar between undeveloped, low-density, and high-density exurbs			

some sort of natural vegetation. Therefore, it is not surprising that we found only one study attributing loss of biodiversity to loss of habitat – a survey of snakes in Florida where numbers were lower on roadsides bordered by lawns than elsewhere (Table 4.1, case 26). There may have been additional cases, however, where loss of plant cover was a factor at the highest housing densities in the study area. A possible example is our own work on birds in southeastern Arizona (case 1), where bird species richness and abundance were higher in exurban than in undeveloped landscapes, but where bird abundance and housing densities were negatively correlated within the exurban areas. These results led us to conclude that the benefits of exurbanization, including provision of otherwise scarce resources such as water and nest sites, were highest at the lowest housing densities and that habitat loss may have neutralized or negated these benefits at higher housing densities. Another similar example is that gray foxes apparently were attracted to low-density exurban developments in New Mexico because of water availability, while they avoided higher density developments, perhaps because habitat lost to roads and yards would have resulted in unacceptably large home ranges (case 17).

Landscape Fragmentation

Formal landscape fragmentation produces discreet habitat patches that are spatially isolated from one another as a result of being embedded in a matrix of other land-use types (Collinge and Forman 1998). Populations in the patches are at risk of extinction because of their small sizes and because new individuals may not be able to cross the intervening matrix (Fahrig 2003). Small habitat fragments have large edge-to-area ratios, so it is very difficult to attribute their frequently lower biodiversity to fragmentation versus edge effects such as the intrusion of predators living in the matrix (Fletcher et al. 2007). Indeed, we found no studies that unambiguously attributed biodiversity loss in exurban landscapes to fragmentation as opposed to negative edge or land-use effects (Table 4.1).

There were three studies of birds in woodlot fragments isolated by agricultural fields, where nearby houses created negative edge effects but were not a cause of the fragmentation (cases 4, 11, and 12). Some authors described their study areas as being fragmented, but it was evident that the word was being used not to describe isolated habitat patches but as a more encompassing term for all sorts of landscape changes caused by development, including edge and perforation effects (e.g., cases 6, 23, and 26).

Networks of roads, unlike houses and landscaping, can truly fragment even the lowest density exurban developments, but only for those organisms unable or unwilling to cross them. There is a rich literature on the ecological effects of roads (Forman and Alexander 1998; Trombulak and Frissell 2000). Because roads in exurban neighborhoods usually are narrow and lightly traveled, they are less likely to serve as barriers to animal movement than are major highways. In two cases (17 and 21) the home ranges of mammalian predators were bounded by major roads, but it is not clear that this limited their abundance in sparsely developed exurban areas.

Roads can affect landscape biodiversity not only through fragmentation but also by causing direct mortality through vehicle collisions, by changing patterns of runoff and sedimentation, and by serving as corridors for dispersal of exotic species (Trombulak and Frissell 2000; Eigenbrod et al. 2008). Roads doubtless impact the flora and fauna of exurban developments, and higher density developments almost certainly will have more of them except in those cases where home sites are well clustered (Odell et al. 2003). It seems likely that roads impact exurban biodiversity more through edge, perforation, and land-use changes than by true landscape fragmentation, but this is a subject in need of further research.

Perforation Effects

The studies we reviewed attributed changes in animal biodiversity at least partially to perforation effects in 26 of 31 cases, suggesting that landscape perforation probably is the most important way that exurban development affects animal populations. Among these 31 cases, 6 were entirely positive (1, 3, 14, 16, 23, and 31), 10 were negative (6, 11, 12, 15, 19, 20, 22, 24, 25, and 28), while 10 revealed both positive and negative effects (2, 4, 5, 7, 8, 9, 10, 17, 21, and 30). Positive perforation effects usually were attributed to the provision of resources around home sites, including water, cover, shade, nectar, nest sites, and seeds (Fig. 4.1). Negative perforation effects mostly involved increased predation, competition, and nest parasitism by pets and other species living in association with home sites (Fig. 4.2).

In most of the cases involving both positive and negative perforation effects, species that were relatively generalized and/or adapted to built environments benefited from exurban development, while another group of habitat specialists dependent on such things as mature woodlands or heavy ground cover declined. This pattern has been documented most often for birds (2, 4, 5, 7, 8, 9, and 10), but also for butterflies (30). Species richness frequently was higher in exurban than in undeveloped areas because low-density housing developments provided opportunities for both groups.

Fig. 4.1 A mourning dove and grassland sparrows visiting an exurban water source. Water is one of the resources associated with exurban home sites that may benefit biodiversity, especially in arid landscapes. Photograph by Carl and Jane Bock

Fig. 4.2 A lesser earless lizard (*Holbrookia maculata*), one of several lizard species that were less abundant in exurban than in undeveloped landscapes in southeastern Arizona, probably due to increased predation around home sites (Audsley et al. 2006). Photograph by Carl and Jane Bock

In contrast to animal studies, only one of nine studies involving plants attributed a change in biodiversity to a perforation effect – a case (32) where exotic vegetation spreading into native ecosystems apparently originated in landscaped yards. Declines in plant biodiversity usually resulted from changes in land use and management.

Land-Use Effects

Unlike landscape perforation, changes in the use and management of lands between home sites rarely had positive impacts on exurban biodiversity (Table 4.1). Declines in birds (3 and 5), rodents (14), fishes (27), and butterflies (31) have been attributed to removal of trees, ground cover, and woody debris. Introduction and spread of exotic vegetation has negatively impacted birds (7 and 8), rodents (15), and native plants (37). Overgrazing by horses in small pastures on exurban properties reduced native plant cover, increased bare ground, and encouraged the spread of exotics (33 and 38; Fig. 4.3). Fire suppression caused plant-cover changes that impacted snakes (26), while grizzly bears' numbers were lower in exurban neighborhoods than in undeveloped areas because many were shot or trapped and relocated (18). The only cases where exurban development resulted in a positive change in biodiversity were one where reduced hunting pressure increased deer numbers (22) and another where heavy grazing by horses created vegetation mosaics favored by grasshoppers (29). In our own work in Arizona, rodents (13) and native grass cover (35) benefited from exurban development, but only when landowners did not keep livestock on their properties.

Fig. 4.3 An exurban "ranchette" in northeastern Colorado. Note bare ground and degradation of the streambed resulting from heavy grazing by horses. Inset: a grasshopper, one of the few sorts of animals that can reach high densities in such disturbed areas (Bock et al. 2006c). Photograph by Carl and Jane Bock

Clustered Housing

Grouping houses together in exurban neighborhoods could benefit biodiversity by reducing road density and edge effects and by increasing the sizes of open space areas (Odell et al. 2003; Hansen et al. 2005). However, we found only two studies that have actually evaluated this possibility in the field – one of birds (case 9) and one of birds, rodents, and vegetation (cases 7, 15, and 37). In neither study did clustered development result in any significant benefit. The problem may be one of the scale at which clustering occurs. The sizes of open space areas gained by grouping together small numbers of homes may be insufficient to overcome the perforation and land-use effects characteristic of most exurban developments. At some larger scale these benefits almost certainly would accrue (Odell et al. 2003; see cases 10 and 20).

There may be circumstances when dispersed rather than clustered housing provides a greater benefit to regional biodiversity, as long as housing densities are low (Bock et al. 2008). This could be the case when exurban home sites function as scattered ecological oases, especially as point sources of water and shade in otherwise arid and open environments. Under these circumstances, the benefits of scattered home site perforations may outweigh their ecological costs, at least for some species of birds (case 1), rabbits (16), foxes (17), deer (23), and butterflies (30).

Threshold Effects and Housing Densities

The majority of studies we reviewed showed that higher housing densities had more strongly negative impacts. Despite the potential ecological significance of nonlinear correlations between biodiversity and development (McDonnell and Pickett 1990), we could find only six cases where development threshold effects were described or were evident from the data – two for birds (1 and 12), one for rodents (13), one for foxes (17), one for deer (24), and one for butterflies (31). In two of these cases the relationship between exurban development and biodiversity was positive at low housing densities but negative to neutral at higher densities (1 and 17). In these cases the threshold points where housing effects turned negative were relatively high – about 0.5–1.25 homes/ha. In the remaining four cases, where there was little or no evidence of any positive effects of development, negative threshold points occurred at lower housing densities – about 0.05–0.15 homes/ha (Fig. 4.4). This translates to threshold values of 17–50 acres per home site, compared to an average 10-acre parcel size for all the studies we reviewed. Therefore, these limited results suggest that housing densities in most exurban areas are above the level of tolerance for the most sensitive species or groups.

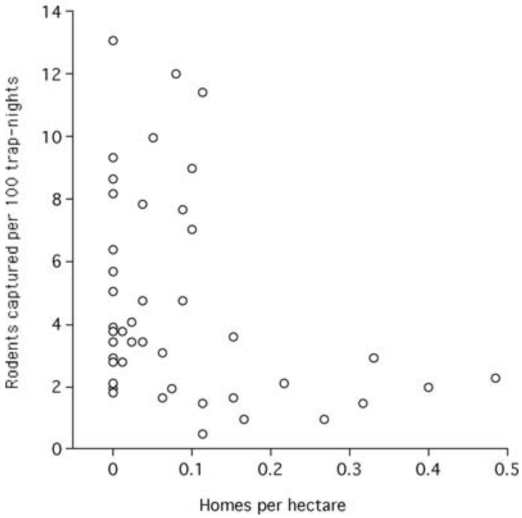

Fig. 4.4 Rodent abundance vs. housing density across 48 study plots in southeastern Arizona; note the threshold at about 0.15 homes per hectare, above which rodents did not achieve high densities on any of the plots (unpublished data collected by the authors; see also Bock et al. 2006a)

Changes in Fire Regimes

Fires threaten homes in ecosystems where wildfire is a natural and regular occurrence, at the same time that fire suppression threatens much of the biological diversity of those same places (Platt 2006; Theobald and Romme 2007). Ecosystems where fire plays a critical role in sustaining biodiversity include pine forests of the Southeast, shrublands along the Pacific Coast, most coniferous forests of the Rocky

Mountain and Sierra Nevada cordilleras, boreal forests of Canada, and nearly every sort of grassland (Pyne et al. 1996; Saab and Powell 2005). Attempts to suppress fire in these ecosystems often result in unnaturally heavy accumulations of fuel so that historically frequent, low-intensity burns are replaced by infrequent, much hotter burns that not only destroy property but often exceed the limits of tolerance of much of the native flora and fauna (Spyratos et al. 2007; Theobald and Romme 2007). Exurban development in fire-prone landscapes is a foolish idea.

We found only one study that attributed a loss of biodiversity to fire suppression in an exurban landscape: a study of snakes in the sandhills region of Florida (26). Another clear example is the encroachment of juniper (*Juniperus* spp.) into grasslands of Oklahoma resulting from changes in historic fire frequencies (Coppedge et al. 2001), but the design of this study was such that we could not distinguish suburban from exurban patterns. We attribute the scarcity of studies about fire in exurban landscapes to two factors. First, most work on this subject understandably has centered on more heavily urbanized regions, such as much of California, where the magnitude of threats to human property is higher (Keeley 2002; Syphard et al. 2007). Second, the science of fire ecology is sufficiently mature that the consequences of changing fire regimes in exurban landscapes are easier to predict than other sorts of land-use and perforation effects.

Exurban Development of Cattle Ranches

A particularly rapid form of exurban growth in the American West involves the conversion of private ranchlands into low-density housing developments (Hansen and Brown 2005). Prevailing opinion is that development of western ranches will negatively impact biodiversity (Brussard et al. 1994; Knight et al. 1995; Maestas et al. 2002). However, an alternate possibility is that development could benefit some species by liberating landscapes from the controlling and sometimes negative effects of livestock grazing (Fleishner 1994; Wuerthner 1994).

This "cows versus condos" debate continues unresolved, for at least two reasons. First, in certain ways it is a false dichotomy and a set of nonexistent choices (Siegel 1996). Some level of western development is inevitable, and in many cases, exurban landowners choose to keep livestock (especially horses) on their newly acquired "ranchettes" (Sengupta and Osgood 2003). Second, the debate continues to boil because it has been well fueled by opinion but surprisingly uninformed by data.

We are aware of only two field studies that have compared the biodiversity of western cattle ranches with exurban developments – our own work in southeastern Arizona (1, 13, 16, 25, 29, 30, 33, 34, and 35) and studies by Richard Knight and his colleagues in northeastern Colorado (8, 19, and 38). Both studies revealed that some components of biodiversity have benefited from development, while others have not. However, there were more negative effects in Colorado than in Arizona.

Grazing by bison (*Bison bison*) was a major ecological and evolutionary force in grasslands of northeastern Colorado long before the introduction of domestic grazers, whereas bison have been scarce or at least ephemeral in southeastern Arizona since the end of the Pleistocene (Truett 1996). Although grazing by bison is fundamentally different from grazing by cattle in many ways, grazing by large ungulates represents an exogenous disturbance in much of the Southwest, but a comparatively natural force in the grasslands of northeastern Colorado, and one that native biodiversity might be expected to tolerate or perhaps even require (Milchunas 2006). This likely explains why ranches in Colorado supported a higher proportion of native plant species richness and ground cover than either nature reserves or exurban developments (case 38). In contrast, ground cover of exotic plant species did not differ between ranches and developed areas in Arizona (case 34), and another study suggests that livestock grazing encourages the spread of nonnative grasses in the Southwest (Bock et al. 2007b).

It is premature to attempt full resolution of the cows versus condos debate on the basis of only two field studies. However, we are prepared to offer two general conclusions. First, the impacts of converting cattle ranches to exurban developments will depend on the historical importance of grazing animals such as bison in shaping the evolution and function of the ecosystems at stake. Grasslands of the Southwest and Intermountain West supported relatively few bison compared to grasslands of the Central Plains (Mack and Thompson 1982; Milchunas 2006), so it is in these places that release from livestock grazing might benefit native biodiversity. Second, regardless of region, exurban livestock (usually horses) almost always graze at much higher stocking densities than livestock on cattle ranches. As a result, exurban horse pastures often are barren, invaded by weedy exotics, and devoid of native biodiversity compared to ranchlands, ungrazed exurban properties, or nature reserves (cases 29, 33, and 38; Fig. 4.3).

Research Needs

Based on the preceding analysis, we recommend the following directions for future research on the impacts of rural exurban development on biodiversity.

Gather More Data

There is a rich body of opinion and prediction about the likely consequences of converting natural or agricultural landscapes into exurban housing developments (e.g., Knight et al. 1995; Theobald et al. 1997). Most of these predictions are likely to be accurate, given the experience of most individuals making them. However, there is no substitute for actual data on the subject, and at this point we do not have anything approaching an adequate quantity. Studies of any sort will be helpful, as long as the results are presented in such a way that we can distinguish effects of development in exurban areas from those in more heavily urbanized landscapes. However, the following aspects are particularly in need of further investigation.

Determine Cause and Effect

There have been many more studies describing patterns of biodiversity in exurban landscapes than there have been attempts to determine the causes of those patterns. This leaves planners and decision makers with limited information about ways to mitigate the impacts of exurban development, other than not to do it in the first place. We have attached causes to the patterns whenever possible (Table 4.1), but this usually was based on the reasoned (and usually reasonable) conjecture of the researchers, rather than data. Both carefully designed field experiments and investigations of population demographics beyond simple numbers would help alleviate this problem. As an example, point sources of water could be added to undeveloped landscapes to test the hypothesis that water around home sites is the reason various animal species are attracted to exurban neighborhoods. As another example, several studies have attributed declines in native wildlife to predation by pets or human commensals, but there have been very few studies actually quantifying those predatory impacts. Studies of reproductive success and survival will help determine whether exurban landscapes function as population sinks or sources (Pulliam 1988) and whether exurban populations might be dependent on nearby undeveloped areas for recruitment.

Broaden Taxonomic and Ecosystem Coverage

Birds and some larger mammals have been reasonably well studied in connection with exurban development, but we know relatively little about most other kinds of animals. Bats, amphibians, and insects are of general conservation concern in urban environments, but they have been studied little or not at all in strictly exurban landscapes (Gehrt and Chelsvig 2004; Rubbo and Kiesecker 2005; Smith and Lamp 2008). There is scant information about the impacts of exurban development on any components of soils and aquatic ecosystems (but see Carpenter et al. 2007). Ecologists have examined the ways that exurban development can affect animals by changing vegetation structure (e.g., Maestas et al. 2003; Niell et al. 2007), but there have been very few studies of the plants themselves beyond simple measures of ground cover. Plant population biology has a rich tradition in ecology and evolution (White 1985), but we are aware of no comparisons of key factors such as plant phenology, reproductive success, survivorship, or plant–pollinator interactions between undeveloped and rural exurban landscapes.

Conduct More Work on Thresholds and Clustered Developments

Conventional wisdom holds that there are thresholds of housing density beyond which biodiversity will be negatively impacted and that these negative effects will be reduced in clustered as opposed to dispersed housing arrangements (Odell et al. 2003). In fact, there is scant information to support (or refute) either assertion.

Conduct More Studies on Effects of Subdividing Western Ranches

Ranchettes are replacing ranches across much of the American West. Beyond conservation, there are deep cultural, historical, and emotional reasons for sustaining ranching as a way of life in the West (Knight et al. 2002; Sayre 2002). Therefore, it is important to understand its actual ecological consequences compared to various sorts and degrees of exurban development. Studies comparing ranches to ranchettes should have three components. First, they should include large ungrazed and undeveloped areas to serve as true control landscapes. Second, they must consider ranching and exurban development as continuous rather than categorical variables, with attention given to housing and livestock densities. Third, the mix of exurban developments should include some where homeowners keep livestock and others where they do not, since parcels of land that are both grazed and subdivided are being subjected to the worst (or the best) of both land uses.

Conclusion: Tentative Guidelines for Planners and Developers

Although much good fieldwork remains to be done, the evidence to date leads us to the following general guidelines about ways to reduce the impacts of exurban development on biodiversity.

Keep Housing Densities Low

Probably our least surprising discovery is that negative environmental effects of exurban development usually are correlated with housing densities. Critical limits to housing density will vary depending on the ecosystem and the species involved, so it is difficult to make general recommendations. Based on those few studies reviewed above, an upper limit of one home per 10 ha (25 acres) probably would buffer all but the most sensitive species against the negative effects of development. It seems likely that many of these effects will also be ameliorated by clustered as opposed to dispersed housing arrangements. However, exurban home sites may have value as scattered ecological oases in arid and relatively open landscapes, especially as point sources of water. Dispersed rather than clustered housing might have greater conservation value in such environments, as long as housing densities are low. The comparative value and impacts of clustered versus dispersed housing require much further study.

Plan for Large-Scale Mixed-Use Landscapes

For every species dependent on uninterrupted open spaces, there is another that requires the environmental heterogeneity produced by exurban development. For every species that takes advantage of resources such as water and shade provided by scattered home sites, there is another whose reproductive success is diminished by household pets and synanthropic predators. For every species dependent upon low-stature ground vegetation created by grazing livestock, there is another equally dependent on taller ground cover that can grow only in the absence of livestock. Our findings therefore support the conclusions and recommendations offered by Marzluff (2005) that planning for a regional mix of land uses, rather than the spatial dominance of any one, is likely to result in greater conservation of biodiversity. Exurban development can be an ecologically valuable part of this mix as long as housing densities remain low and landowners leave most of their properties in a relatively undisturbed and natural condition.

Reward Minimal Land Management and Land Use

The literature indicates that many of the negative impacts of exurban development are caused not by the presence of homes and landscaping but by the ways that property owners use and manage the undeveloped parts of their land. Thinning trees and shrubs, mowing grass, overgrazing by livestock (especially horses), planting exotic vegetation, and removing woody debris from a lakeshore or a forest understory are all examples of ways that landowners can negatively impact biodiversity on their properties. The good news is that all of these are voluntary activities. We strongly encourage planners and developers to create incentives for exurbanites to minimize the ways that they impact the lands they own, through covenants, zoning, and property tax adjustments.

Advocate for an Exurban Land Ethic

We have been studying the grasslands and savannas of southeastern Arizona for more than 35 years in a valley where some but not all cattle ranches have been converted to low-density exurban housing developments (Bock and Bock 2000, 2005; Bock et al. 2008). Large exurban properties that are left undisturbed support a rich assemblage of native plants and animals. However, exurban lands that are overgrazed, mowed, cleared, weedy, and cluttered with corrals and outbuildings are absolutely the worst places in the valley for biological diversity. There are difficult issues at stake here, mostly about property rights, but it seems reasonable to reward landowners who help to sustain the beauty and diversity of the land that drew them out there in the first place. We urge landowners to adopt an exurban land ethic (Leopold 1949) by which they recognize and work to protect the ecological value of their own backyards. We urge county commissioners, planners, and developers to help by providing information, education, and financial incentives.

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Chapter 5
Wildlife Corridors and Developed Landscapes

Stephen DeStefano

Abstract An obvious consequence of exurban land development is fragmentation of natural areas. Fragmentation leaves patches of habitat of various sizes, which can become increasingly isolated as development continues. A compelling approach to mitigation is the creation of corridors. Corridors in their simplest form are strips of habitat that connect patches and allow for wildlife movements. Intuitively, corridors make sense and land planners and managers often find them useful in land conservation. However, do wildlife corridors perform as expected? Do they work for all species? And how should they be configured (e.g., width, length, placement)? This chapter addresses these and other questions related to wildlife corridors and exurban land development.

Introduction

By this point in the book you have probably internalized the message that of all the activities or processes that threaten the integrity and continued existence of wild animal and plant communities, habitat loss is among the leading causes (Wilcove et al. 1998; Hilty et al. 2006). There are certainly many factors that contribute to habitat loss, but land fragmentation ranks high on the list. This chapter investigates the causes and consequences of land fragmentation and the use of wildlife corridors as a way of circumventing fragmentation. The chapter begins by describing habitat loss and the composition of fragmented lands including patches, edges, and their distribution and configuration. The nuances of connectivity and corridors are then discussed, especially their role in the movement of wildlife between urban centers and outlying exurban lands. These wildlife corridors are vital to sustaining wildlife populations and species diversity in and near urbanized areas. The chapter concludes

S. DeStefano (✉)
USGS Massachusetts Cooperative Fish and Wildlife Research Unit, University of Massachusetts, Amherst MA 01003, USA
e-mail: sdestef@nrc.umass.edu

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by describing well-known corridor projects and suggesting ways in which planners can use corridors to enhance the well-being of wildlife and their habitat.

Background

Habitat loss can result in the reduction of biological diversity – what we think of as biodiversity impoverishment – on local and regional scales (Wilson and Peter 1988; Meffe and Carroll 1997). If habitat loss is extensive enough, local populations of certain species of plants or animals can be lost or extirpated from a large portion of their range, and if the problem is pervasive enough, an entire species can be threatened with extinction.

As the diversity of habitats themselves is reduced and the land is developed by humans (e.g., fewer wetlands because of filling for development), species richness declines and homogenization of species assemblages can occur. Homogenization occurs when relatively few species in a given area are present in large and dominating numbers. A good example is avian communities in North American cities: there are fewer species of birds in cities than in exurban areas and those species that do exist, such as American robins (*Turdus migratorius*), rock doves (domestic pigeons; *Columbia livia*), European starlings (*Sturnus vulgaris*), and house sparrows (*Passer domesticus*), are often present in large numbers (Marzluff et al. 2001). Often these "overabundant" species are exotic or nonnative (as are the latter three), introduced either intentionally or unintentionally by people, and they can outcompete the native fauna and disrupt local flora and natural processes because of their particular adaptations for life in human-altered environments. Because adequate habitat is key to the survival of wild animals and plants, habitat loss is certainly one of the biggest concerns of conservation biologists.

Habitat loss can occur in numerous ways. Outright loss of habitat occurs when the landscape is changed dramatically, such as when a forest is cleared, a wetland filled, or a meadow paved over. These are of course human activities, but natural catastrophic events can cause habitat loss, although these are relatively rare, such as volcanic activity, earthquakes, or tsunamis (Reice 2005). For the past two centuries, however, human development of the landscape has been and continues to be the major cause of habitat loss, degradation, and alteration around the globe. Many of these losses result from how people develop the land for urban, suburban, industrial, agricultural, and recreational purposes. Today, conservationists are particularly alarmed about urban and suburban development, and in fact one leading landscape ecologist, Richard T. T. Forman of Harvard University, has referred to such activity as the "development tsunami." Human development, including the outright loss of habitat through urban or industrial development (DeStefano and DeGraaf 2003), partial loss of habitat through exurban development of some of the landscape (Heimlich and Anderson 2001), or degradation of habitat by decreasing habitat quality through pollution, soil compaction or erosion, disruption of natural cycles of fire or flooding, and other processes, occurs throughout the world and is fueled by both our burgeoning human population and our demand for resources (Johnson and Klemens 2005).

Fragmentation: Causes and Consequences Revisited

Of the many ways that habitat can be lost or degraded, fragmentation is perhaps the most widespread and among the most troublesome. Fragmentation takes place when otherwise large intact and contiguous tracts of habitat are broken up into smaller patches (Lindenmayer and Fischer 2006). Habitat fragmentation has been defined as "an event that creates a greater number of habitat patches that are smaller in size than the original contiguous tract(s) of habitat" (Bender et al. 1998, p. 517). As more fragmentation occurs, the remaining habitat patches become smaller and more isolated from one another. Depending on the size and mobility of extant organisms and the scale at which habitat fragmentation occurs (i.e., area of coverage), individuals of a species can become stranded on their patch of habitat, surrounded by inhospitable land. As time goes on these isolated individuals interbreed and genetic diversity (i.e., diversity within a species) declines (Myers 1997). In effect the surviving organisms are restricted to an island of sorts and if they cannot get off or if other individuals cannot get to them, their numbers dwindle and eventually their "island" population disappears. These ideas have been articulated in a well-known set of constructs known as the theory of island biogeography (MacArthur and Wilson 1967), and many of the principles that have been used to describe the ecology of real islands (i.e., islands surrounded by water) have been applied to habitat islands (i.e., remnant patches of habitat that remain amid the surrounding, altered landscape).

The interactions of humans with their natural environment and the causes of habitat loss, biodiversity impoverishment, and species extinction are complex, to be sure. But to simplify and summarize the troubling scenario of loss of biodiversity and extinction of species, the process often follows this sequence: the pressures from an overabundant human population with its demands for many resources cause habitat loss. Among the chief causes of habitat loss is human development of the landscape. And of the many ways that habitat can be affected, fragmentation is a major concern.

Thus habitat loss often starts as fragmentation and it is usually the activities of humans that fragment the landscape. One of the reasons why fragmentation is so common is because of the way we tend to develop the land, especially outside of our large metropolitan areas. Big cities are actually a very efficient way to store large numbers of the carbon entities we call people. People in large cities tend to take up less space, commute shorter distances and drive less overall, use more mass transit, and otherwise consume fewer resources than people living in rural areas. However, as we move away from cities and get into the fringe areas just beyond the reach of the most immediate suburbs, we see farmlands, open range, prairies, forests, and deserts broken up into parcels that are widely scattered across the land. These parcels, often a few to several acres in size, usually have single, stand-alone, large houses on them (what have been called "trophy houses"), and as such relatively few people are dispersed across enormous areas. These large-lot homes are usually surrounded by some remnants of the previous natural environment. What are left are patches of woods or fields or desert with houses intermixed. Soon other development follows, such as gas stations and strip malls, as needed services and economic opportunities follow the building of houses.

Construction of houses is not the only kind of development that causes fragmentation. Agricultural, industrial, and recreational development also fragments habitats, as does mining, energy exploration and development, and logging (Hilty et al. 2006). But exurban development and our desire for trophy houses set on large lots outside the city limits is a very common source of fuel that feeds the fires of habitat fragmentation.

Of course, the precursor to any kind of development is the construction of roads. Roads are a very common cause – perhaps *the* most common cause – of habitat fragmentation. Our roadway system has been called the largest human artifact on the planet (Forman et al. 2003). Roads not only physically break up the landscape, but also form a tremendous hazard for wildlife living in the adjacent remnant patches of habitat. When these species try to move among habitat patches or islands, many are killed by cars, and for some species, such as amphibians (salamanders, frogs, and toads) and reptiles (turtles and snakes), the death of breeding adults as they try to make their way to breeding sites can devastate the population.

You can view any of this as a landscape of island patches of habitat in a matrix of inhospitable terrain. Again, all is relative and the degree of inhospitableness depends on the species and the type of development. For example, the brushy borders of farmland can form wonderful habitat for quail and rabbits but not for songbirds that nest in the interior of contiguous forest. The so-called "sky island" mountain ranges in the southwestern United States provide habitat for many interesting species. Desert bighorn sheep were once found on the rocky ledges of these mountains around Tucson, Arizona, but as development filled the Tucson basin, the sheep, apparently unwilling to travel through the Tucson metropolitan area to other mountain ranges, were cut off from one another and some of these isolated populations have "winked out," while others are in the process of disappearing from their former high-elevation haunts throughout the "sky islands." The consequences of fragmented habitats for species conservation are well documented (Crooks and Sanjayan 2006; Hilty et al. 2006), including chapters in this book (see Chapters 4 and 6). The challenge before us now is to understand why habitat connectivity is so important to animal and plant communities, think of creative ways that we can use to stop, slow, or mitigate habitat fragmentation, and incorporate these ideas and concepts into the community planning process.

Connectivity and Metapopulation Dynamics: Separate but Linked

You may have heard the saying that a butterfly that flaps its wings in North America can cause an earthquake in China. Well, maybe. The connectivity of all of nature is an interesting philosophical and ecological topic. But on the landscapes throughout the world where wild populations of plants and animals struggle for survival, connectivity has a more mundane and immediate importance. When populations are small and isolated, they are vulnerable to extinction through a combination of demographic, environmental, and genetic factors (Gilpin and Soulé 1986; Sanjayan and Crooks 2005).

However, when small populations are connected in some way, interchange of individuals can occur. It is this connectivity among patches of habitat and interchange of breeding individuals among smaller groups of animals and plants that allow for the continued viability of species. In a world that is now so heavily fragmented, a key goal in conservation is to reduce the fragmentation of habitat and the isolation of small populations of fauna and flora by protecting or restoring connectivity. This goal has become so important in conservation biology that it is now being called "connectivity conservation," and it includes not only enhancing the movements of wild populations across the landscape but also protecting or restoring "spatially sensitive ecological processes," such as hydrology and the movement of water, energy flow, and nutrient recycling (Crooks and Sanjayan 2006).

Traditionally, ecologists often thought of populations as "panmictic," meaning that all individuals are equally likely to mix and interact with all other individuals in the entire population. That is, all individuals have an equal opportunity to meet, breed, or otherwise interact with every other individual of the same species. Population ecologists now largely see that view as unrealistic, and the idea of "metapopulations" rose to prominence in the 1980s and 1990s (Hanski and Gilpin 1997). The metapopulation concept introduces the idea of space and spatial relationships into our understanding of how populations work. In most cases, individuals of a species are not distributed at random or evenly across the landscape. Rather, groups or clusters of individuals are distributed among areas of suitable habitat. Suitable habitat is usually patchy in its distribution naturally, but habitat has of course become increasingly patchy because of human development and activities. Thus clusters of individuals within a suitable patch of habitat have a greater probability of interacting among themselves than they do with individuals in other patches. The further away the adjacent patches and the more inhospitable the surrounding matrix of land in between, the less likely the interactions among individuals residing in different patches. It is clear that if patches become too small and isolated, the chance of them harboring viable groups of individuals and the chance of the members of one patch interacting with individuals from other patches are low, and eventually the probability of such interactions could become zero or close to zero. As we go to the extreme – i.e., smaller and smaller patches, further and further apart, with fewer and fewer individuals – clusters of individuals "wink out" and local extirpation or extinction follows.

Metapopulation biology deals with all these aspects of populations and their spatial relationships to one another and to the land. Hanski and Simberloff (1997, p. 6) describe the metapopulation approach as having two key premises: "that populations are spatially structured into assemblages of local breeding populations and that migration among the local populations has some effect on local dynamics, including the possibility of population reestablishment." The idea of migration among these local populations and the importance of movement in keeping populations viable and extinction at bay gave rise to the idea of wildlife corridors.

Patches and Corridors: Definitions and Concepts

When habitat is fragmented, patches are left. So a patch can be defined as a remnant area of natural habitat that is surrounded by different kinds of land cover. For species that use a variety of vegetation types, this patchiness might be exactly what they need. For example, white-tailed deer (*Odocoileus virginianus*) thrive in patchy environments, where there is some mature or well-developed forest for cover, young forest for browse, and fields or agricultural land for forage. However, when a patch of suitable habitat for a species is surrounded by an unsuitable habitat, that species has a difficult time surviving, especially as the patches of suitable habitat become smaller, further from like patches, and less abundant on the landscape. In the same patchy environment that is a good overall habitat for deer, pine martens (*Martes americana*) or several species of wood warblers typically decline. In these cases, the patches of suitable habitat (mature forest) are surrounded by unsuitable habitat (cleared forest and fields).

Patches of habitat become even more obvious when they are surrounded by development. Although there are some species that thrive in urban and suburban environments, especially if it is intermixed with some remnant patches of natural habitat, or even areas such as parks, golf courses, and vacant lots (DeStefano and Johnson 2005), many other species have difficulty (DeStefano and DeGraaf 2003). Development, especially exurban development, not only divides the landscape into patches but also creates other challenges for native species. Introduced exotic plants and animals, including and especially domestic cats and dogs, compete with or prey on native fauna. In fact, the spread of nonnative species follows the path of human development across North America (Whithers et al. 1998). Roads and traffic, chemicals and fertilizers applied to lawns, artificial lights, activities such as mowing and brush clearing, and even just the normal presence and daily activities of people affect wildlife and their ability to survive in the land surrounding their remaining patches of habitat.

The characteristics of the remaining habitat patches have everything to do with the amount and type of fragmentation that has occurred and, subsequently, how well the patches can provide for the viability of populations. In the case of exurban development, the way we develop the landscape dictates the number and type of patches that are left. Several variables or patch characteristics are important, and these include size, distance, distribution, makeup, and configuration. The following paragraphs provide more detail about these important patch characteristics.

One of the first issues related to patches is size (MacArthur and Wilson 1967; Bender et al. 1998). In general, bigger patches are better because larger patches potentially contain more habitat, which translates to more species and greater number of individual members of any given species. Very large patches likely contain a diversity of habitat types within them, providing for a host of different species.

With real islands, the size of the island is directly related to the number of different species that occupy that island (MacArthur and Wilson 1967). The process is perhaps a bit more complex when we talk about habitat "islands" surrounded by land rather than water, but the basic precept is the same: big islands have more species and a greater likelihood that those species will continue to exist.

A second important consideration when discussing patches and islands is distance. In general, closer islands allow exchange of genetic material because individuals on different islands can move to other islands. When distances among islands are small, there is less inhospitable or dangerous area to traverse and individuals can travel shorter distances to get to needed food, water, and cover. Odds for surviving as an individual animal moves from patch to patch increase as the distance between patches decreases. However, when the distances among patches are large and the surrounding land is unsuitable or inhospitable, there is a much greater likelihood that individuals will not be able to physically make the trip, may not even attempt it, or will perish if they try.

Distribution of patches on the landscape is a third consideration. How patches are distributed over the land is important, and when planning for conservation developments, it is critical to take a broad-scale view of the landscape. Ideally there will be patches of habitats throughout the area, with no large "holes" or areas where there are no habitat patches. A patch that becomes too isolated, i.e., left on its own at too great a distance from any similar patch, is not likely to be used on a continuous basis by certain species. In addition, when patches are too isolated or there is too much distance between them, the consequences of loss of these remnant habitat patches because of environmental catastrophes increase (e.g., fire, windstorm, and insect infestation). A windstorm might move through an area and take down a few woodland habitat patches, but if there are several of these well-distributed patches in the area, the loss of a few is not imperative. On the other hand, if patches are not distributed well, the loss of even a few of the remaining rare patches might spell the loss of that type of habitat over a much greater area.

The composition of patches is critical. Sometimes the assumption is made that remaining habitat patches are "pristine." The question that must be asked of any remaining patches is: has that patch of woods or desert or prairie been altered or degraded to the point that, even though it is a patch of what we might call woods or desert or prairie, it no longer has the components or features that are necessary for the wildlife populations that we wish to support? Knowledge of life history and habitat requirements is a critical background information for making such determinations.

Finally, patch configuration or shape plays a role in patch dynamics. A circular patch will have the least amount of edge and the most interior habitat (e.g., in the case of mature woods). Long, linear-shaped patches will have the most edge per area. In many instances, long, linear patches are very important, for example, when protected habitat follows a stream or a river. There is another instance when long, linear patches play a key role in conservation: when they act as corridors.

Corridors connect patches. Conservation corridors have been defined as simply as "any space, usually linear in shape, that improves the ability of organisms to move among patches of their habitat" (Hilty et al. 2006, p. 50). Corridors have similarly been defined as "areas of more or less stable habitat serving to link population centers [and that] can facilitate actual movement of organisms between centers or provide for reproductive individuals so that centers are linked by transmission of genes" (Morrison et al. 1998, p. 105). The latter part of this definition points out that corridors, if large enough, can serve as habitats for resident individuals as well as travel corridors for individuals that live in the connected patches. Of course, just as not all patches are the same for all species, not all corridors are alike for all species. When planning for the establishment of patches and corridors, it is important to consider the species or suites of species that one hopes to help. Also, corridors can be either natural, such as vegetation running along a stream, or man-made, such as dense hedgerows.

We tend to think of corridors as long, relatively narrow, continuous strips of habitat that connect one patch to another. And often this is exactly the form they take. So, for example, two patches of mature hardwood forest could be connected by a stream that runs between the two patches with a continuous but narrow strip of deciduous forest canopy. Likewise, the grassy–brushy vegetation that runs under power transmission lines can connect blocks of fields, meadows, or shrub cover for species that use these types of habitats. Even stream culverts, if properly designed, can form narrow liner corridors that allow free and safe passage of animals below roads.

Corridors can be continuous, as described above, or can serve as "stepping stones" of suitable habitat that allow species to rest and feed during movements such as dispersal or migration (Sanjayan and Crooks 2005). Migratory birds make use of these kinds of corridors as they seek out patches of suitable habitat on their migration flights during spring and fall. A corridor of sorts can also be formed when certain specific habitat components are provided in a linear fashion, such as power poles used for perching and nesting by species such as ravens (*Corvus corax*) and hawks (Knight and Cosimo 1993).

Related Issues

SLOSS: The "Single Large or Several Small" Debate

During the 1970s, when concern for habitat fragmentation was becoming an important topic in conservation biology, a well-known ecologist named Jarred Diamond published a paper on reserve design that suggested a single large reserve was better than several smaller reserves (Diamond 1975). This suggestion seemed to make sense from a number of standpoints. Larger islands or patches can support more species, more individuals of a given species, and more viable populations. However, another well-known ecologist, Daniel Simberloff, challenged Diamond's idea and suggested that several smaller reserves might actually have more species than one large reserve (Simberloff and Abele 1976, 1982). What followed was an argument that raged in the scientific conservation literature over the question of whether a “single large or several small” reserves were a better design for conservation. This debate was abbreviated as SLOSS.

Proponents of a single large reserve argued that a large reserve is better for species that require large areas, such as many carnivores, raptors, and large ungulates, and that survival of species might be greater following a catastrophic event, such as a wild fire or hurricane, because large preserves would be less vulnerable. Proponents of the several-small-reserves idea argued that different reserves would likely have a larger variety of species spread among them and that the risk of extinction of any one species, due to disease, for example, would be reduced because not all individuals would be restricted to one patch.

The debate has died down in recent years but has never been fully resolved (Hilty et al. 2006). There has been a general consensus that the best solution is several large reserves! This undoubtedly makes sense. The second part of some rather obvious advice for land planners is to work together with scientists and managers and do the best you can (McPherson and DeStefano 2003). Setting aside any patches of natural, native habitat will be beneficial, especially if those patches can conform to the recommended suggestions described above: larger, well-connected preserves are the ultimate goal.

The Matrix: What Lies Between

The area between habitat patches is often referred to as the matrix. The matrix is, by definition, different from the patches. So if the patches consist of mature woods, the matrix is something else: open fields or cut forest, for example. The matrix can also be development: asphalt, housing subdivisions, malls, and parking lots. Depending on the type of matrix, the ability of animals to move through the matrix varies. For many forest wildlife species, moving from a patch of mature forest through younger forest to another patch of mature forest is not difficult. The probability of surviving that move and making it to another patch is high. However, if the matrix is dominated by human development, an animal could be crushed by a vehicle, killed by a domestic cat, become vulnerable to predation by other predators, or (for amphibians) become desiccated on dry pavement. Thus, the matrix may be more or less permeable, that is, easier or more difficult for a given species to travel through, depending on the characteristics of the matrix.

Indeed, the matrix surrounding habitat patches can be composed of or contain a variety of barriers to the movements of some animals. Roads, fences, ditches, and canals can be human-made barriers to movement, whereas streams, rivers, valleys, and ridges can form natural barriers. Plant cover in the matrix that is very different from the habitat patches can also form a relatively impermeable barrier, especially in areas that are drier, hotter, or more exposed to predation and other hazards than the habitat in which the species normally lives. Various components of the built environment can form impermeable areas to the passage of wildlife. It is when the matrix is particularly impermeable that corridors are especially useful. This is especially evident in very developed areas, where strips of vegetation, reclaimed railway beds, and other greenways connect remnant patches of habitat. The general rule is that the more inhospitable the matrix around the habitat patches, the more desirable it is to have well-placed and properly designed corridors to connect those patches.

A Word About Edges: Not All Bad, Not All Good

During the middle of the 20th century, when wildlife management was in its early stages, biologists and managers strived for a mix of cover types on the landscape (Leopold 1933; Yoakum and Dasmann 1971). Game species such as deer, grouse, and rabbits thrived in these areas of mixed vegetation types, and where these different types met, there was edge. So-called edge habitat is productive and large numbers of species of both plants and animals can be found in areas with a high degree of edge. In woodlands, openings in the forest canopy allow sunlight to reach the ground, which stimulates the growth of woody and herbaceous plants, berry-bearing bushes, and other sources of food as well as cover for many species of wildlife. Thus, management to produce edge was encouraged.

Over time, however, biologists recognized that many other species were associated with large patches of mature forest and that proximity to edge could actually be detrimental to these populations (Morrison et al. 1998). Intensive timber harvest leads to increased edge and a decrease in the size and distribution of large, contiguous tracts of mature forest. Clear-cutting of enormous areas of forest has taken place throughout the North American continent, beginning with colonial times in New England and the east and extending to the Pacific Northwest in more recent decades. With the recognition of the effects of these kinds of practices on some species, such as spotted owls (*Strix occidentalis*) and marbled murrelets (*Brachyramphus marmoratus*), issues related to forest management have become very controversial and political. Forests in the northeastern United States – the first forests to be clear-cut in North America – have since recovered from the large-scale clearing that occurred during the colonial period to the extent that much of this region is covered by relatively uniform second- or multiple-growth forest, much of it very similar in age and structure. Biologists are now concerned about too little variation in forested vegetation in New England and other regions of the country. The status of many of the species that thrive in young forest and shrublands, such as ruffed grouse (*Bonasa umbellus*), American woodcock (*Scolopax minor*), New England cottontails (*Sylvilagus transitionalis*), chestnut-sided warblers (*Dendroica pensylvanica*), field sparrows (*Spizella pusilla*), and indigo buntings (*Passerina cyanea*), has become an important conservation issue.

The message in all of this is one of balance and foresight. In fact, it could be considered a version of Aldo Leopold′s (1993, pp. 145–146) oft-quoted advice to “keep every cog and wheel [as] the first precaution of intelligent tinkering.” Biologists, managers, planners, politicians, and the public need to recognize the importance of a mix of habitats for a wide variety of wildlife. However, notwithstanding the issues of diversity and balance, the issue of fragmentation is still very much at the forefront of conservation concerns. Forestry practices obviously influence the composition of forests, but increases in the built environment span the gamut of virtually all ecosystems, not just forests. Development on the prairies, in deserts, canyon lands, in the foothills and on the sides of mountain ranges, in the vicinity of wetlands, and along stream corridors has led to fragmented landscapes, remnant patches of increasingly smaller and isolated patches of habitat, and a great need to address these concerns. Thus, the need for connectivity is universal among most types of landscapes.

Corridors and the Planning Process

Some Examples: Putting Corridors to Work on the Land

Many examples of conservation corridors in action are large, ambitious projects involving multiple organizations, agencies, states, provinces, and even countries. Below are a few examples from various parts of the world. These conservation initiatives are far-reaching in their goals and approaches and represent the kind of forward thinking that will be required to truly maintain animal and plant populations, ecological processes, and a higher quality of life for humans throughout most if not all of the globe. Small-scale local examples of conservation corridors, from say a single town or county, are much less known. Figure 5.1 shows their localized use; in this case, woodlands lining the waterway provide a corridor through an agricultural area. Figure 5.2 illustrates a local wildlife corridor that enables safe passage in more built-up areas, while Fig. 5.3 shows the monitoring devices used to track wildlife movements so that corridors can be planned.

It is important to remember, however, that large-scale projects are built on small-scale initiatives, and these very local, often very grassroots attempts to preserve habitat and restore connectivity are the building blocks of much larger programs. Hopefully learning about some of these larger conservation projects will be both

Fig. 5.1 A wooded riparian corridor connects other patches of woodlots in agriculture lands in the midwestern United States. Image courtesy of USDA-Natural Resources Conservation Service, Des Moines, Iowa

Fig. 5.2 Overpasses allow some animals to move freely between habitat patches and avoid the hazards of crossing busy highways. Photograph by Scott Jackson

Fig. 5.3 As moose expand their range southward in New England, biologists are monitoring their movements with GPS technology, in part to see if moose use corridors to assist in their dispersal south. Photograph by Stephen DeStefano

informative and inspirational for local communities, residents, and planners. It is a good idea to find out if your community is or could be part of a larger effort. Local residents, local politicians and policy makers, and members of town councils and planning boards make large, broad-scale projects a reality through their efforts to preserve habitat and maintain or create connectivity on a variety of scales.

Yellowstone to Yukon, Central United States and Canada

The Yellowstone to Yukon Conservation Initiative (Y2Y for short) is comprised of more than 800 organizations in the United States and Canada focused on maintaining and sustaining wilderness, wildlife, and the processes of nature from Yellowstone National Park north to the Yukon (www.y2y.net). A major goal for this effort is to provide habitat for what is described as the full historical suite of carnivores and ungulates in one of the last places in the lower 48 states where these species, such as grizzly bears (*Ursus horribilis*) and caribou (*Rangifer tarandus*), can be found by connecting the mosaic of ecosystems that exist in this vast region. Large areas like these are necessary to maintain large animals, and in doing so myriad other species will be protected. This is an excellent example of the idea of "umbrella species," i.e., by protecting a big enough region for a large species like the grizzly, many, many other species will benefit from that protection as well.

Quabbin to Cardigan, Central New England

The Quabbin to Cardigan Conservation Collaborative (Q2C) is an effort of both public agencies and private citizens to create a broad corridor of connected conservation land from the Quabbin Reservoir and Watershed in central Massachusetts to Mount Cardigan and points north in the White Mountains of New Hampshire (www.spnhf.org/landconservation/q2c.asp). This region has one of the largest remaining tracts of intact forest in central New England. Development pressure is great, however, and most if not all of the communities within the Q2C initiative are experiencing rapid growth. The overall goal is to protect a broad corridor in this two-state region by creating corridors and connectivity among the protected lands that do exist or that will be purchased. It is an ambitious, encouraging, and inspirational effort of local citizens working with state and federal agencies, private landowners, and communities to preserve a part of nature in a region that has some of the highest densities of people in the nation. Included in the organization's goals are to conserve up to 25% of open space in each community, protect forests while supporting a sustainable forest-based economy, preserve habitat and biodiversity, and protect working farms. This is not only a good example of sound and well-thought-out conservation but also an excellent example of the concept of working landscapes and nature preserves intermingled among local communities.

The Rewilding Institute

The Rewilding Institute views conservation in North America on a continental scale (www.rewilding.org). It has a focus on large carnivores and the vital role they play in maintaining fully functioning ecosystems. Strong emphasis is placed on protecting core areas (i.e., permanently protected habitat preserves) and promoting landscape permeability to facilitate connectivity for the movements of large carnivores and other wildlife. Four continental "megalinkages" have been identified as the foundation for restoring (or rewilding) North America: along the Pacific coast, along the Atlantic coast, along the Rocky Mountain range, and in the arctic–boreal region.

International Corridor Projects

There are many additional corridor projects throughout the world, including the Green Corridor project in Vietnam, the Friends of Oolong in New South Wales, Australia, who promote reforestation and the connection of forests on lands cleared for agriculture, a 37-mile-long corridor that connects important tiger (*Panthera tigris*) habitats in India, establishment of a network of corridors in Rheinland-Pfalz, Germany, for the endangered European wildcat (*Felis silvestris*), an effort to connect nature reserves with small private properties in the Bío Bío region of Chile, South America, and the Emerald network to conserve wild flora and fauna of Europe.

Some Advice for Planners: Incorporating Conservation into Planning

Perhaps the first important thing all planners and others interested in protecting habitat and maintaining biodiversity should realize is that publicly protected preserves, reserves, or refuges are not enough. Lands protected and maintained by federal agencies (e.g., U.S. Fish and Wildlife Service and U.S. Forest Service), state agencies (such as the state fish and wildlife or department of natural resources agencies), or nongovernmental organizations (NGOs) form the backbone of land preservation in many regions of the country, but they alone cannot do the job. Private lands make up such an enormous portion of land ownership in the United States, especially in the east, that the combined forces of public and private lands are needed to form effective networks of land conservation for nature. Ideally, these lands will be connected in some way by habitat corridors, and many of these corridors will need to cross private lands.

Promoting community participation is key to the success of any planning process, and getting private landowners to buy into conservation planning is essential. These people need to be a part of the planning and implementation process and truly be stakeholders. Conservation goals motivate the actions of many landowners, but economic incentives are what drive many more. Part of the success of such an approach will likely need to embrace the idea of working landscapes. Incorporating local forestry, farming, the harvest of natural crops (plant or animal), and other activities that can be done on a sustainable basis and that support local economies are part of the key to land conservation success. We should not underestimate the importance of the human factor in all its forms (social, political, economic, and philosophical) in efforts to preserve habitat and to provide connectivity through habitat corridors.

The actual planning and implementation of wildlife corridors into the landscape is somewhat complex, but there are many sources for advice and recommendations (e.g., Beier and Loe 1992; Fleury and Brown 1997; Hilty et al. 2006, as well as many sources available on the Internet). Beier and Loe (1992) recommended six steps for evaluating and planning wildlife corridors, including (1) identifying patches to connect, (2) selecting a species or several species of interest, (3) evaluating the needs of those species, (4) evaluating how each corridor will accommodate movement by each species of interest, (5) drawing the corridor(s) on a map, and (6) designing a monitoring program to determine if and how the corridor is being used by wildlife. Other issues include deciding how wide to make the corridor (generally the wider the better), whether and how land will need to be acquired, implementing ways to protect the corridor from encroachment or further development, and perhaps even considering issues like limiting the amount of artificial lighting close to the corridor.

There are also many suggestions for designing and maintaining culverts as wildlife passages or corridors (Clevenger et al. 2001; Aresco 2005).

Finally, in this age of specialization and seemingly endless volumes of information, there is a real need to involve professional biologists in the planning process. Conservation issues in general can be complex and the design, implementation, and maintenance of wildlife corridors are no exception. The scientific literature on the topic has grown tremendously and the amount of reliable information on wildlife corridors is nothing short of incredible. Professional biologists that have bachelor's and advanced degrees (master's, doctorate) in wildlife ecology, conservation biology, or a related field have the background, training, and experience required to sift through huge amounts of information and interpret scientific findings for people less familiar with the science of ecology. Professional organizations such as The Wildlife Society of North America and the Ecological Society of America have certification programs that identify individuals as having a specified amount of education, training, and background. These trained professionals will be very helpful in navigating the complexities of wildlife corridor design and other issues related to the conservation of biodiversity. A professional biologist working with someone with expertise in Geographic Information Systems (GIS), the town planning board, and local interested citizens would make an excellent team for planning, designing, and establishing wildlife corridors.

Conclusion

Habitat corridors are one of those things that just seem like a good idea. On the surface one might think, how could they not be? Intuitively the concept of corridors of native habitat connecting patches of native habitat amid a fragmented world seems to be nothing but a good idea. At the very least, corridors add acres of habitat to the landscape, and at the very best, they actually facilitate movement of species among patches. Nonetheless, there remains some controversy over the effectiveness of habitat corridors (e.g., see Simberloff et al. 1992, Rosenberg et al. 1997, Beier and Noss 1998 for earlier discussions on corridors; see Crooks and Sanjayan 2006 and Hilty et al. 2006 for more recent discussions). There have been some concerns raised about the use of corridors, such as their ability to spread nonnative species or attract animals to places where they are more vulnerable to predation (Hilty et al. 2006).

Perhaps the biggest criticism of habitat corridors, however, is that they might not be doing what we think they are doing; that is, they are not serving as movement corridors for wildlife. To date there is not a lot of reliable data to indicate that corridors aid in the maintenance of populations by promoting or facilitating movement among patches, as metapopulation models suggest. But that evidence may be accumulating. Based on genetic information, researchers have found that red-backed voles (*Clethrionomys gapperi*) use corridors to move between forest patches (Mech and Hallett 2001). Perhaps the first solid proof of the efficacy of corridors comes from a large-scale study of plant populations illustrating that habitat patches connected by corridors retain more plant species than do isolated patches (Damschen et al. 2006). This research found no evidence that corridors promote invasion by nonnative plant species. These findings are based on a large-scale replicated experiment, the "gold standard" for science that is rarely attained in studies of wildlife populations.

A little-discussed topic of the benefit of conservation corridors, at least in the ecological literature, is the potential positive effects on humans. Linear parks, walking paths, and bike corridors have long been recognized as desirable features for residents of cities and larger towns. In more exurban areas, conservation corridors can also have a positive effect on local residents. The addition of corridors to a community can mean increased opportunities for recreation, relaxation, privacy, exercise, nature observation, solitude, and other activities. Many of these values may seem intangible, but throughout much of North America, properties adjacent to habitat preserves and conservation corridors are more likely to have higher economic value. Property values are a direct measure of how society sees worth or value. While it is true that wildlife corridors can take on a number of different forms, the addition of linear strips of natural habitat connecting larger patches of preserves, conservation land, or otherwise protected habitat in a community is a worthwhile goal for planners to pursue and implement.

In the final analysis we may never be absolutely certain how well corridors perform for wildlife populations. At some point in the planning process, however, decisions have to be made and then plans followed through on the ground. Our intuitions about corridors may have to be enough for us to go on, but our best guesses about the benefits of corridors for both wildlife and people seem to far outweigh the possible negative effects. Community planning involves a good deal of intuition, creativity, and careful forethought, and it would appear that wildlife corridors fit that philosophy and that approach.

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Chapter 6
Exurban Land Development and Breeding Birds

R. William Mannan

Abstract This chapter reviews the influences of exurban development on breeding birds and identifies how positive influences may be enhanced and negative influences reduced. Exurban development affects breeding birds primarily by altering (reducing or increasing) structures required as nest sites, availability of food for adults or nestlings, and the number of predators and competitors. The presence of humans also potentially changes behavior of nesting birds. A given development scheme will likely favor some native species while harming others. Identifying the "best" development scheme will depend on the assemblage of species present and the conservation objectives.

Introduction

The number of people living in the United States continues to increase (US Census Bureau 2008), but there has been a substantial shift over the last 50 years in where they choose to live (Brown et al. 2005). More people currently are opting to live in small, rural subdivisions than in urban centers, and the conversion of relatively pristine land, and lands used for agriculture and forestry, to exurban development (i.e., low-density rural housing [6–25 homes/km^2], Hansen et al. 2005) is now the dominant form of land alteration in the United States. In 2000, exurban areas in the United States occupied 15 times the area occupied by high density, urbanized development (Brown et al. 2005).

The conversion from relatively undeveloped to developed lands significantly alters existing ecological systems, including the kinds and numbers of animals that can be supported on the land. In this chapter, I review the effects of exurban development on breeding birds. I begin with a brief review of the concept of habitat and

R.W. Mannan (✉)
School of Natural Resources, University of Arizona, Tucson, AZ 85721, USA
e-mail: mannan@ag.arizona.edu

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the role vegetation plays in providing habitat for birds. I then summarize what happens, in general, to bird communities after development and provide information about some urban-related problems from which birds suffer. I close with some suggestions for how to plan and manage exurban developments to reduce their impacts on native birds.

Concepts

Habitat

The concept of "habitat" is key to understanding how exurban land development affects populations of breeding birds. A bird's habitat is, in the most general sense, the place where it lives (Morrison et al. 2006). Every species of bird (or any animal) is morphologically and physiologically adapted to take advantage of a particular set of resources and environmental conditions, and individuals seek out places to live that match their adaptations. Thus, habitat is "an area with a combination of resources (like food, cover, water) and environmental conditions (temperature, precipitation, presence or absence of predators and competitors) that promotes occupancy by individuals of a given species (or population) and allows those individuals to survive and reproduce" (Morrison et al. 2006, p. 10). Understanding the important elements of habitat for a given species, therefore, is critical to developing management strategies for mitigating or ameliorating the negative effects of exurban land development or enhancing the positive effects.

Vegetation

For many species of birds, vegetation plays an important role in providing the resources that make up their habitat. For example, vegetation often provides support for nests, materials from which nests are constructed, direct sources of food (e.g., fruit or nectar), sources of food for insects and other animals upon which birds feed, cover from predators and inclement weather, and sites for perching and roosting. Thus, the plant species present in an area, and their abundance, largely determine the species of birds the area will support. For example, urban areas where native plant species have been maintained support more native bird species than areas where native plants have been replaced with non-native plants (Chace and Walsh 2006). The physical arrangement of plants in an area also influences the bird species that live there. Areas where different plant species are arranged (naturally or through planting) to maintain "structural complexity," (i.e., multiple layers and high volume of foliage) often support more bird species than areas where the arrangement of plants is structurally simple. The influence of vegetation on bird communities is illustrated in areas immediately adjacent to lakes, streams, and rivers. These areas, called riparian zones, usually support different and more diverse plant communities than nearby upland areas, especially in arid regions (Fleishman et al. 2003). Because of these traits, riparian zones often add substantially to the number of bird species an area can support (Lehmkuhl et al. 2007).

Another concept directly related to vegetation and indirectly related to habitat is the productivity of plants. Green plants convert the energy of light from the sun into chemical energy for their own use through photosynthesis. The rate of photosynthesis, called primary production (Ricklefs 2000), depends on a host of factors, including temperature, and availability of water and nutrients. Because plants form the foundation of biological communities (i.e., plants are eaten by herbivores that are in turn eaten by carnivores), high rates of primary production potentially lead to diverse animal communities.

General Effects of Exurban Development on Birds

Changes that take place in bird communities after exurban development depend, to some extent, on the condition of the land before development. The potential for dramatic changes is highest when the land being developed is in a relatively natural state (i.e., native plants dominate the area). Development in a natural area potentially changes the foundation of the existing biological community, including the species of plants present and primary productivity. Thus, all elements of habitat for birds, such as cover, the type and availability of food, and availability of water, also are likely to change. Because habitat requirements are species specific, the effects of exurban development on birds in a given environment can be complex and ideally should be assessed on a species by species basis. However, reviews of the impacts of development on birds have revealed some general patterns (Hansen et al. 2005; Chace and Walsh 2006). One well-documented effect of development on bird communities is that urban areas tend to support a higher biomass of birds, but fewer species, than more natural areas (Hansen et al. 2005; Chace and Walsh 2006). This trend is most apparent at the core of urban areas and diminishes as the urban landscape transitions into more natural environments (Blair 1996). The trend also appears to be non-linear, in that diversity of birds remains relatively stable (or even increases) compared to natural areas after some development, but decreases rapidly once a certain level of development is reached (Hansen et al. 2005). The most plausible explanation for these patterns involves a combination of two factors: (1) native plants at the core of urban areas usually have been replaced with exotic plants and (2) plants used for landscaping in residential areas, parks, golf courses, and businesses often are fertilized and watered and are very productive (i.e., primary production is high). These changes result in the loss of many native bird species and the dominance of a few non-native birds that can take advantage of the resources available in urban centers.

Species of birds that are closely associated with humans and become abundant in urban settings tend to be omnivorous or granivorous, and often nest in cavities

(Chace and Walsh 2006); examples include the house sparrow (*Passer domesticus*), European starling (*Sturnus vulgaris*), American crow (*Corvus brachyrhyncos*), and brown-headed cowbird (*Molothrus ater*) (Hansen et al. 2005). Also, some species of predatory birds (e.g., kites, hawks, falcons, owls, and eagles) occasionally reside in urban landscapes (Adams 1994; Gehlbach 1994; Smith et al. 1999; Anderson and Plumpton 2000), and a few species such as the Mississippi kite (*Ictinia mississippiensis*) (Parker 1996), merlin (*Falco columbarius*) (Sodhi et al. 1992), Cooper's hawk (*Accipiter cooperii*) (Rosenfield et al. 1995; Boal and Mannan 1998), and eastern screech owl (*Megascops asio*) (Gehlbach 1994) can be more abundant in towns and cities than in more natural areas. In some situations, urbanization creates habitat for native species where there was none before and can result in expanded distributions. For example, Mississippi kites expanded their range into grasslands due to the planting of trees in exurban developments (Parker 1996), and birds dependent on wetlands often find new habitat in sewage treatment ponds (Andersen, Sartoris and Thullen 2003). However, most instances of range expansion associated with urbanization involve non-native species (e.g., European starling).

Golf courses are associated with many urban and exurban developments and occupy >935,000 ha in the United States (Brennan 1992, as cited in Cristol and Rodewald 2005). Like other developments, construction of golf courses alters existing vegetation and replaces it with something else, usually well-manicured, lawn-like greens and fairways. Cristol and Rodewald (2005) summarized the findings of a collection of studies designed to determine whether golf courses could play a meaningful role in conservation. They concluded that, unlike areas in urban centers, golf courses could sustain high levels of bird species richness and abundance, even when compared to undeveloped areas. This pattern was especially strong in arid regions (e.g., the southwestern United States), where man-made ponds and vegetation sustained by irrigation mimicked riparian zones (Merola-Zwartjes and DeLong 2005). However, even if numbers of species supported on golf courses is similar to those supported in undeveloped areas, usually several species (i.e., those specialized to live in undeveloped areas) are absent on courses. Success of individual species on golf courses depends primarily (and obviously) on whether courses provide critical habitat elements, but also upon the regional context in which courses are positioned. Similar courses surrounded by developed lands supported fewer species than those surrounded by more natural environments (Cristol and Rodewald 2005). Not surprisingly, whether golf courses could sustain species of management concern depended on the habitat needs of the species in question, and the resources available on the course.

The presence of nesting birds in urban landscapes says little about their rates of survival or reproductive performance. How well a given species survives and reproduces in an urban landscape is dependent not only on the presence of resources it needs but also on how susceptible it is to predators, competitors, and potential problems it encounters. For example, rates of survival and productivity of birds potentially are influenced in exurban landscapes by risk of collision with human-made objects, electrocution, human disturbance, poisoning, and changes in food supply, rates of predation, and nest parasitism (Hansen et al. 2005; Chace and Walsh 2006). These potential problems are reviewed below.

Challenges Posed by Exurban Land Development

Birds that nest in developed landscapes live out their life cycles, or at least their nesting cycles, in environments in which they did not evolve. As a consequence, they often encounter urban-related elements or situations to which they are not well adapted, and sometimes die at high rates during these encounters. These urban-related sources of mortality, sometimes called "environmental challenges" (Mannan and Boal 2004), include collisions, electrocution, poisoning, human disturbance, and exotic diseases and predators.

Collisions

In developed landscapes, birds often fly into or collide with human-made objects, including power lines (Rusz et al. 1989), cars (Condoner 1995), and windows. Flying into windows is perhaps the most serious of these problems because birds cannot distinguish reflected images on a pane of glass from actual environments (Klem 1990). Estimates of the number of birds killed annually in North America from collisions with glass windows range from 100 million to 1 billion (Klem 1990; Dunn 1993; Klem et al. 2004). Furthermore, feeding birds at bird feeders, a tremendously popular activity in the United States (US Department of Interior and US Department of Commerce 2002), may contribute to this problem because feeders often are placed near windows.

Electrocution

Electrocution on poles supporting overhead electric lines was identified as a significant source of mortality for large birds, especially birds of prey, in the United States in the early 1970s (Olendorff 1972; Boeker and Nickerson 1975; Lehman 2001). Despite awareness and some efforts to reduce the problem (see Avian Power Line Interaction Committee 2006), incidents of electrocution continue to be reported (Manosa 2001; Wayland et al. 2003; Dwyer and Mannan 2007) and the scope of the problem remains largely unknown (Lehman 2001). Several species of large-bodied predatory birds (i.e., those most vulnerable to electrocution) nest in urban and exurban environments in the United States (see Adams 1994 for review). For example, Harris's hawks (*Parabuteo unicinctus*), great horned owls (*Bubo virginianus*), and red-tailed hawks (*Buteo jamaicensis*) are common year-round residents in Tucson, Arizona (Mannan et al. 2000), and estimates suggest that over 100 Harris's hawks are killed annually by electrocution in this city alone (Dwyer and Mannan 2007).

Predators

Conditions in urban and exurban developments can sometimes lead to an increase in the number of predators compared to undeveloped environments. Predatory species that often increase after development include predatory birds (e.g., Corvids, Marzluff et al. 2007; hawks and owls, Mannan and Boal 2004), and small to medium-sized mammals (e.g., cats, Crooks and Soule 1999). Many of these species consume songbirds or their eggs. For example, pet cats, if they are allowed to roam outside, are especially effective predators and may kill up to 1 billion birds per year in North America (Klem et al. 2004). This level of predation can depress reproductive success and richness of native bird species (Crooks and Soule 1999). Dogs are less effective predators on birds than cats, but their presence can disturb nesting birds and result in reduced nesting success.

Human Disturbance

Incidents of people intentionally harming birds or their nests in exurban and urban settings are uncommon, but do occur. For example, 28 Mississippi kites were shot in Ashland, Kansas, likely because they were diving at people while defending their nests (Parker 1996). Inadvertent disturbance of birds by people, however, can be a significant problem. People walking near birds' nests or through their territories can influence how frequently and effectively they forage and could potentially affect their rates of survival in an area (see review by Chace and Walsh 2006). Furthermore, repeated disturbances near nests by people during non-consumptive activities, such as bird-watching, often cause birds to abandon their nests, especially if the disturbances take place during incubation.

Poison

Inadvertent poisoning of birds in urban areas has not been widely reported, but it is a potentially serious threat (Mannan and Boal 2004). Use of chemicals to kill pest animals (e.g., rodents, insects) is a common practice in some urban areas. Birds that eat targeted organisms consume the toxin and can die from secondary poisoning. For example, peregrine falcons (*Falco peregrinus*) and Cooper's hawks have been reported killed by eating prey poisoned with strychnine and organophosphates (Cade and Bird 1990; Boal and Mannan 1999).

Management Strategies

Management strategies for conservation in exurban developments demand articulation of conservation goals. It is conceivable that conservation goals could vary among ecosystem types, but a common goal might be to preserve as much of the native biota as possible during and after development. Outlined below are suggested practices for conservation in exurban development that strive to meet this goal. Success in meeting conservation goals depends largely on the types of conservation strategies employed, the context in which they are applied, and how long they are maintained (Milder 2007).

Clustered Housing

The relative value of clustering homes, or conservation developments (Milder 2007), compared to spacing them uniformly in an area likely depends, partly, on the density of homes in the development. At very low densities (e.g., 1 house/50–80 ha), differences in impact between the two strategies might be minimal, especially if both strategies placed individual homes or clusters in areas that are the least environmentally sensitive. However, as the number of homes to be built in an area increases, clustering appears to be a logical strategy from a conservation viewpoint because larger patches of undeveloped land could be relatively free from the influences of urbanization (Fig. 6.1). Lenth et al. (2006) compared the density of songbirds and nest density and survival of ground-nesting birds between clustered housing developments and dispersed housing developments in a mixed-grass prairie in Colorado. They found that areas treated with both types of development supported more non-native and human-commensal bird species and fewer native bird species than

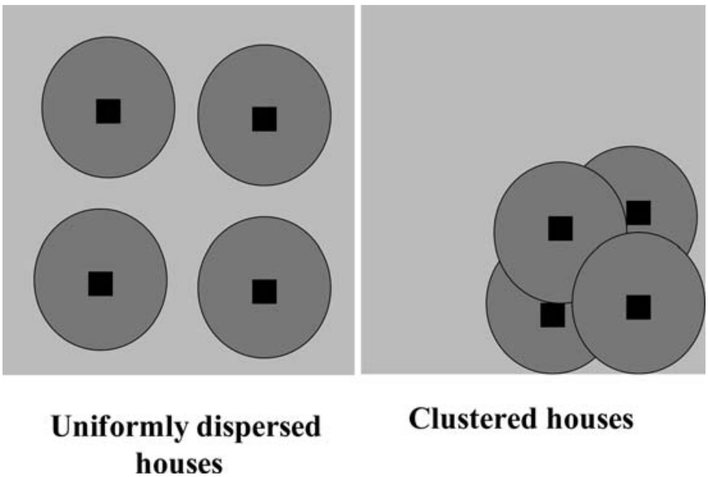

Fig. 6.1 The influence of development may extend up to 200 m beyond the footprint of houses themselves (Bock et al. 1999; Lenth et al. 2006). Clustering homes is thought to be a good conservation strategy because when houses (*black squares*) are clustered, the zone of influence around each house (*dark gray*) overlaps and the area of open space (*light gray*) that could have conservation value increases. Source: R. William Mannan

undeveloped areas. Their results call into question the value of clustering houses as a conservation strategy. However, Lenth et al. (2006) also found that areas with clustered houses and areas with dispersed houses were both dominated by non-native plant species. They suggested that the open spaces surrounding the clusters were small compared to the undeveloped areas used for comparison (80 vs 480 ha). Furthermore, use of the open spaces around housing clusters by humans and pets potentially reduced the value of the areas for native birds. Hence, clustering houses might still be a good conservation strategy, but only if guidelines are in place to help maintain ecological value. Perhaps the most important guidelines are to maintain native species of plants in the open spaces between housing clusters, and use native plants in landscaping around homes. Lenth et al. (2006) also recommended the following if clustering is to be a conservation strategy: (1) cluster homes as close together as possible, and far away from ecologically sensitive areas; (2) make the open space between clusters as large as possible; and (3) coordinate development on a regional basis so that open space in adjacent developments is as contiguous as possible.

Maintaining Connectivity

In addition to planning clustered developments so that open spaces abut one another, connectivity of open spaces can be enhanced by protecting vegetation in riparian zones. Buffers on either side of streams and rivers should be set aside, especially if they run through a cluster of houses (Fig. 6.2). Width of the buffers may vary depending on the size of the water course, but should be at least as wide as the associated plant community. A general strategy should be to keep buffers as wide as possible because the number of bird species supported tends to increase with buffer

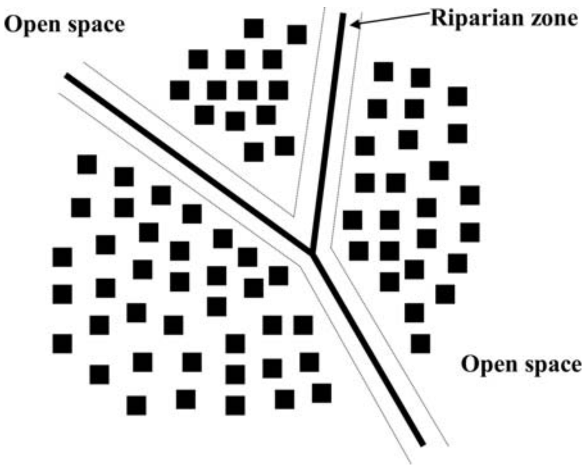

Fig. 6.2 Protecting riparian zones has the potential to decrease the fragmenting effect of development, even if houses are clustered. The riparian zones themselves serve as additional open space and provide some connectivity between open spaces separated by development.
Source: R. William Mannan

width (Peak et al. 2006). Protecting riparian zones not only enhances the potential for maintaining bird species associated with these distinctive environments, but also provides connections between patches of open space, increases the amount of open space, and provides corridors for movements for some birds and other animals (see Chapter 10 for a fuller discussion of riparian conservation).

Golf Course Design

If golf courses are planned for exurban developments, their value to birds can be enhanced by (1) maintaining as much native vegetation as possible (i.e., restricting the footprint of the course); and (2) positioning the course so that it is surrounded by open space, or is close to natural wetlands, or nesting and roosting areas (White and Main 2005). If the course is to support specific species or groups of species, their habitat needs should be considered in the design of the course. For example, if golf course ponds are to support wading birds and shorebirds, depth of water along the shoreline of the ponds should be very shallow to provide sites for foraging (White and Main 2005). If golf courses are to support woodpeckers (Rodewald et al. 2005), dead trees and older trees with dead limbs along fairways should be maintained when possible to provide nest sites.

Reducing Electrocution

The best way to eliminate the risk of electrocuting large birds in exurban developments is to bury the electrical distribution system underground. If the delivery system is above ground, then all differentially energized conductors closer together than about 102 cm should be insulated during installation on all poles (Avian Power Line Interaction Committee 2006). In existing developments, if insulation was not installed when the system was erected, poles most likely to be hazardous to large birds should be retrofitted (i.e., insulation installed) first. The potential for a pole to electrocute a large bird depends on the position of the pole in the environment, the pole-top configuration (Ferrer et al. 1991; Manosa 2001), and the species, age, and behavior of birds present (Dawson and Mannan 1994; Janss 2000; Avian Power Line Interaction Committee 2006). In rural environments, poles overlooking large, open areas are most problematic (Harness and Wilson 2001; Schomburg 2003). In urban areas, poles near nests may cause the most electrocutions (Dawson and Mannan 1994; Dwyer and Mannan 2007).

Reducing Window Strikes

Birds fly into windows because they cannot differentiate between reflections and real environments. Thus, any technique that reduces reflections reduces mortality.

The simplest technique is to place a physical barrier (e.g., screens, netting, awnings) outside the window to prevent birds from seeing the reflection (Klem et al. 2004). Another technique is to attach opaque silhouettes of almost any shape (e.g., hawks), separated by 5–10 cm, to the outside of the window thereby breaking up the reflection (Klem et al. 2004). During construction of buildings, if windows are angled down 20–40° from vertical, the reflection birds will see will be of the ground. This technique reduces mortality from window strikes. Finally, if homeowners employ bird feeders, they should place the feeders close to windows (˜1 m). Feeders placed 5–10 m from glass panes resulted in marked increases in mortality from window strikes (Klem et al. 2004).

Reducing Human Disturbance, Predation, and Poisoning

Most of the strategies for reducing problems for birds caused by human disturbance, predation by cats and dogs, and accidental poisoning are not the direct responsibilities of planners. For example, the best way to reduce predation by pet cats is to strictly enforce rules that restrict cat owners from allowing their pets to roam outdoors. Rules that encourage dog owners to keep their dogs on leash when outdoors also could reduce predation on birds and disturbance near nests. Also, careful monitoring and control of the use of toxins used to kill pests, combined with educational programs, should reduce the number of birds killed through accidental poisoning. All of these rules and programs are the jurisdictional domain of neighborhood associations, or (even better) a staff of a conservation organization hired to manage the open spaces in a conservation development (Milder 2007). However, planners can help reduce human disturbance of birds in the open spaces around clustered housing by establishing a limited number of well-defined trails in them (Lenth et al. 2006). Also, establishing fenced areas where dogs could run may reduce the impact of dogs roaming freely.

Conclusion

This chapter considered the ways in which bird populations respond to exurban development. The primary way in which exurban development affects birds is by altering their habitats, principally through changes in the structure and composition of vegetation. Some birds, usually non-native species, thrive in developed environments. However, native species often decline in abundance in developed areas due to the degradation of key resources and increased risk of electrocution, collision, poisoning, and disturbance or predation from family pets, especially cats. The chapter then summarized ways in which land development, when conducted in an ecologically sensitive manner, can reduce these impacts. Clustering houses, for example, can increase the amount of open space retained during development, and the conservation of riparian areas and other corridors can connect open spaces within and between developments. Homeowners can also do much to sustain bird populations by keeping pets indoors, positioning birdfeeders appropriately, lessening reflectivity of windows, and maintaining native vegetation on their lots.

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Chapter 7
Integrating Wildlife Conservation into Land-Use Plans for Rapidly Growing Cities

William W. Shaw, Rachel McCaffrey, and Robert J. Steidl

Abstract By definition, exurban development does not occur in isolation from other environments. Indeed, in many if not most situations, "exurban" is a categorization for a range of development types that occur somewhere between wild or rural lands and cities. Urban environments and the habitats found in cities and suburbs play important roles in the ecological health and biodiversity of adjacent and nearby exurban lands. In this chapter, we review the importance of wildlife and wildlife habitats in metropolitan areas and the influence of these urban habitats on adjacent exurban lands. We also describe how planning and science can work together to develop large-scale land-use plans that advance wildlife conservation goals. The Sonoran Desert Conservation Plan (SDCP), developed for Pima County, Arizona, serves as a case study for this type of conservation planning.

Introduction

In this book *exurban* is defined as areas "beyond the metropolitan fringe" (see Chapter 1). The term, however, is a convenient label for a range of land uses, from wild, undeveloped areas to urban environments. Exurban development, therefore, does not occur in isolation from other environments. Indeed, from the perspective of environmental planning, the inevitable ecological interactions among adjacent urban and exurban lands are important considerations.

Urban environments affect the ecological structure and function of adjacent exurban areas and vice versa. In particular, wildlife habitats that exist in metropolitan environments are inextricably linked to the wildlife and habitats in surrounding exurban landscapes, as described in Chapter 5. Unfortunately, this intimate connection is too often ignored in land-use planning decisions. To some extent, this is an artifact of the way in which planning authorities are organized into geographically

W.W. Shaw (✉)
School of Natural Resources, University of Arizona, Tucson, AZ 85721, USA
e-mail: wshaw@ag.arizona.edu

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defined jurisdictions. Highly urbanized cities typically have different land-use priorities than jurisdictions such as counties, which often have authority over suburban and exurban lands. But the lack of integration across jurisdictions also occurs because until recently, wildlife conservation within metropolitan environments was not appreciated widely. Thus, conservation was not an influential factor in land-use decisions.

In this chapter, we review the evolution and development of a subdiscipline of wildlife conservation – *Urban and Suburban Wildlife Conservation* – and the recent and rapid emergence of wildlife conservation as an important land-use planning goal for many municipalities. We then address the question of how wildlife conservation can be incorporated into large-scale land-use planning for a region that includes the full spectrum of land uses, including wilderness, livestock grazing, row crop agriculture, and exurban, suburban, and urban lands. With this background, we focus on the linkage between urban and exurban planning by examining the development of the Sonoran Desert Conservation Plan, a large-scale land-use plan that deliberately integrated these land-use categories into the framework for a comprehensive land-use plan.

Historical Background: Wildlife Conservation on Urban and Suburban Lands

Until fairly recently, most wildlife management and conservation dealt with exurban settings because prior to the 20th century most people lived in rural areas (Decker, Brown and Siemer 2001). As human populations increased, people moved to metropolitan areas. This signaled the need to develop wildlife management and conservation programs aimed specifically for suburban and urban lands. In the United Kingdom, where the urban shift occurred earlier than in the United States, ecologists began studying the ecology of urban areas in the early 1900s (Shenstone 1912). As development in and around London continued, Fitter (1945) published the first book on urban ecology, detailing the city's natural history and the changes brought by development. In the United States, wildlife biologists, such as Aldo Leopold, provided guidance for the nascent field of urban ecology. Although Leopold is best known for writing the first wildlife management textbook (*Game Management*1933) and his advocacy for wilderness protection, he also studied family farms in human-dominated landscapes and was an early proponent for finding ways to minimize the impacts of human activities on wildlife (Miller and Hobbs 2002). In concurrence with Leopold's work, the 1930s–1950s marked the beginning of a gradual shift in the field of wildlife management from a strict focus on game animals to the inclusion of non-game species and a more conservation-based approach to management (Hadidian and Smith 2001). This shift paralleled a budding interest among urbanizing Americans in attracting wildlife (particularly birds) to their backyards and an increase in studies examining the distribution of animals and birds in developed areas (DeStefano and DeGraaf 2003), such as Kieran's (1959) *A Natural History of New York City*.

The 1960s and 1970s witnessed a boom in ecological studies of urban areas as the American environmental movement amplified the need for conservation in metropolitan areas. These years brought a fundamental shift from the "old conservation," that focused on the exploitative use of natural resources to a "new conservation," that dealt with clean air and water, open space, outdoor recreation, and the quality of human environments (Dasmann 1966). Urban residents began to restore their environments and developed an interest in wildlife conservation and the incorporation of wildlife into cities (Decker, Brown and Siemer 2001). Federal laws that protect wildlife were passed, such as the Endangered Species Act of 1973 (ESA), and state agencies established non-game management programs. Because agencies funded traditional game management programs with proceeds from hunting and fishing permits, new revenue sources such as sales taxes, tax "check-off" programs, and lotteries were devised to fund non-game projects (Decker, Brown and Siemer 2001). In 1968, the US Fish and Wildlife Service sponsored its first conference on the urban environment, and the National Institute for Urban Wildlife was founded in 1973 (Adams 2005).

Although studies from this period continued their focus on ways to attract wildlife (the National Wildlife Federation instituted their popular Backyard Wildlife Habitat Program in 1973), Leedy's (1979) comprehensive literature review indicates an explosion of research on how wildlife fared in urban and suburban environments (DeStefano and DeGraaf 2003). In 1974, Emlen (1974) conducted his seminal study of Tucson, Arizona's urban bird community. He identified many of the patterns of species abundance and diversity that dominate urban ecology today (Fig. 7.1). His work led the way for a growing number of studies that singled out bird–habitat relationships in urban areas (Campbell and Dagg 1976; Lancaster and Rees 1979; Beissinger and Osborne 1982; DeGraaf 1991; Blair 1996; Germaine et al. 1998; Marzluff, Bowman and Donnelly 2001; Melles, Glenn and Martin 2003). Due to their high visibility and broad public appreciation, birds have been central to wildlife research and conservation in urban areas (Adams 2005). Research during this period also documented the value of wildlife watching, established urban residents' interest in wildlife, and identified opportunities for planning and management that increased

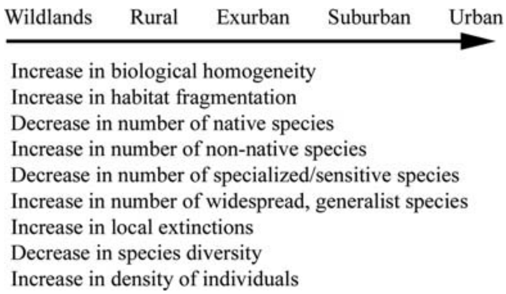

Fig. 7.1 General ecological patterns found along gradient from wildlands to urban areas. Source: Shaw, McCaffrey and Steidl

positive human–wildlife interactions (Lyons and Leedy 1984; Shaw, Mangun and Lyons 1985). Despite ecologists' increased attention to urban areas, many in the field saw developed areas as biologically impoverished. Instead, they suggested that research should target the conservation of undisturbed natural areas (Miller and Hobbs 2002). Thus, throughout the 1980s, the ecology of urban areas remained on the margins as applied ecologists focused on preserving endangered species and other pressing conservation issues (DeStefano and DeGraaf 2003). Further, during the 1980s, wildlife research in urbanized areas centered on mitigating conflicts that arose as human populations moved to areas inhabited only by wildlife (Loker, Decker and Schwager 1999).

The late 1980s and 1990s experienced the proliferation of urban wildlife research, especially among management agencies and universities. International symposia were organized (Adams and Leedy 1987; Shaw, Harris and VanDruff 2004) and professional societies such as The Wildlife Society created working groups that focused on urban wildlife. The critical role that urban and exurban environments play in conservation was also acknowledged during the 1990s. Ecologists recognized that a conservation strategy focused exclusively (or predominantly) on wildlands and wilderness areas was not sufficient to maintain the full range of biodiversity.

These responses were due largely to the escalation of urban development. By 2000, over 5% of the country's land had been converted to urban uses – more land than was protected in national and state parks and owned by the Nature Conservancy (McKinney 2002). More so, scholars were concerned by the pattern of development: a patchwork of urban areas intermixed with protected lands. Informed by island biogeography (MacArthur and Wilson 1967), researchers recognized that protected parks and reserves were too small and dispersed to ensure adequate conservation of biodiversity over the long term.

Recognition of the need to soften human-induced impacts, including the most modified lands of all – those found in cities – spurred an explosion of interest in urban ecology. This led urban ecology quickly from the periphery of ecological science to the mainstream as concerns about unprecedented suburban growth and the attendant loss of open space motivated research agendas aimed at informing regional planning and conservation (DeStefano, Deblinger and Miller 2005). Several universities hired faculty to teach and conduct research on a range of urban wildlife issues (Decker, Brown and Siemer 2001). In 1997, the National Science Foundation added two urban sites, Baltimore and Phoenix, to its long-term ecological research program (Kingsland 2005). By 2000, every state wildlife agency had a non-game management program, with some, such as Arizona Game and Fish Department, dedicating significant resources to wildlife management in urban areas (Decker, Brown and Siemer 2001).

Today, two areas of interest dominate the field of urban ecology: (1) reducing the impacts of urbanization by preserving and restoring habitats that promote native species conservation (McKinney 2002) and (2) developing methods to reduce human–wildlife conflicts and problems associated with "overabundant" wildlife (DeStefano and DeGraaf 2003). These themes spawn public involvement because they are ripe with conflict and ignite passions and controversy. Unlike remote areas, where conservation and management typically involve federal and state lands, most land in urban areas is privately owned or, if public, is used heavily by people (Shaw and Supplee 1987). Ecologists increasingly engage urban and suburban residents through direct participation in conservation or research programs, by communicating their research findings and by educating people about the various ways to mitigate the impacts of urbanization (DeStefano, Deblinger and Miller 2005). The Tucson Bird Count, a citizen science-based project that collects data on the abundances and distribution of birds around the Tucson area, is an example of such projects (McCaffrey 2005). The Tucson Bird Count uses data for research, local conservation initiatives, and land-use planning. In urbanized areas, developing a more ecologically informed public can be the most effective way of promoting conservation of native species and reducing human–wildlife conflicts (McKinney 2002).

Importance of Wildlife and Wildlife Habitats in Metropolitan Environments

The global urbanization trend challenges ecologists to work closely with planners in developing novel approaches that sustain biodiversity in and around cities and suburbs (Wood and Pullin 2002; Rosenzweig 2003; Turner, Nakamura and Dinetti 2004). Although vegetation in urban and suburban areas typically differs from natural areas in structure and composition (Melles, Glenn and Martin 2003), urban environments provide habitat resources for many species. An entire suite of species categorized as "urban exploiters" (Blair 1996) inhabit urban environments, often at higher population densities than in natural areas. Although many nonnative species are considered urban exploiters, some native species fall in the same category. Such is the case with the peregrine falcon, which nests on the ledges of buildings and on bridges (McKinney 2002). Another group of species known as "urban adapters" (Blair 2001) prospers in the "edge" habitats that dominate suburban landscapes. These species, such as the American robin and cottontail rabbit, flourish in areas where humans have removed many traditional predators and supplement their diets with anthropogenic food sources (McKinney 2002).

Environmental conditions vary widely across the range of land uses found in and near urban areas. Many of these land uses, from suburban locales to central cities, can provide habitat for wildlife species (Niemela 1999; McKinney 2002). Additionally, many cities, such as London and New York, have large parks within their urban centers. Given the variety of environmental conditions, many metropolitan areas, including some of the world's largest cities, such as Rio de Janeiro, Singapore, and New Delhi, support high levels of species richness (Miller and Hobbs 2002). In Portland, Oregon's Forest Park, located only a couple of miles from the city center, nearly all the plants and animals found in peripheral forests have been detected (Jonsson 1995). In some cases, cities can even serve as habitat for rare species

(McKinney 2002). For example, human-dominated environments support as many as 35% of the rare ground beetle species in Britain (Eversham, Roy and Telfer 1996).

Although cities do not support the same species assemblages as natural areas, cities are important for conserving biodiversity (Noss 2004). Armed with lessons garnered from urban-based research, ecologists are working with planners to develop and design urban and suburban lands in ways that sustain native populations and conserve biodiversity (Turner 2003; see Chapter 12). Wildlife corridors are a prime example, where urban/regional planners increasingly designate corridor systems that link urban habitat patches with surrounding suburban and exurban lands (Adams 2005). This enables wildlife to move outward (from urban habitats to wildlands) and inward (from wildlands to urban habitats) so that cities do not impede large-scale wildlife movements.

Even so, few planning projects have been conducted at sufficiently broad spatial scales to integrate conservation across the urban-to-rural gradient. This is due in part to political fragmentation and the lack of coordination between the numerous jurisdictions (central cities and suburbs) that comprise metropolitan regions. The remainder of this chapter reviews one recent effort to integrate urban and exurban planning on a large scale: Pima County, Arizona's Sonoran Desert Conservation Plan (SDCP). We describe the SDCP and the political and administrative factors crucial to its development. Chapter 12 presents the biological framework used to develop the SDCP.

Habitat Conservation Plans

There are many reasons for promoting conservation in land-use planning, but in the past other objectives outweighed conservation objectives in the planning process. This perspective is changing rapidly, however, and the ESA and its amendments has been one of the catalysts for change. In 1982, ESA was amended to authorize an "incidental take" (harming or destroying animals or their habitat) of an endangered species by private landowners and other non-federal entities. As part of the permitting process, petitioners must develop habitat conservation plans (HCPs) that minimize and mitigate the take. Habitat conservation plans offer a potential solution in situations where land-use restrictions (imposed by the ESA to protect listed species) limit economic activities, such as metropolitan growth and development. When HCPs ensure that the net impacts of development will not further jeopardize the listed species, a Section 10 permit is granted by the US Fish and Wildlife Service that allows development to proceed, despite incidental takes. Some believe this process has weakened protections provided by the ESA, whereas others view this alternative as a powerful incentive for proactive conservation at larger geographic and ecological scales.

In either case, HCP provisions in the ESA have drawn greater attention to conservation planning. Even so, HCPs have drawn criticism. Common complaints include inadequate scientific standards, the lack of scientific transparency and meaningful public involvement, and the need to adequately fund long-term monitoring and adaptive management strategies (Hood 1998; Kareiva et al. 1999). Critics also claim that the ESA is complex legislation and its implementation has often been controversial and inefficient. Despite these issues, there is still broad support for conserving biodiversity and promoting proactive planning through HCPs and multispecies HCPs (MSHCPs).

Yet the question remains: Is it feasible to develop a large-scale MSHCP that addresses criticisms of previous efforts? We answer this question affirmatively: the Sonoran Desert Conservation Plan (SDCP) is one contemporary, comprehensive large-scale land-use planning effort in which conservation of biodiversity plays a substantive role.

The Sonoran Desert Conservation Plan

In 1997, the US Fish and Wildlife Service listed the cactus ferruginous pygmy owl (*Glaucidium brasilianum cactorum*) as an endangered species under ESA when fewer than 20 of these diminutive owls were known to exist in Arizona, north of the Mexican border. Because owls inhabited lands on the suburban fringe of Tucson, the listing threatened to halt development in suburban/exurban areas of the city. The desire to continue regional development while conserving owls (and biodiversity more broadly) triggered support for land-use planning that included development of a MSHCP to address the regulatory issues and species protection required by the ESA.

Tucson, situated in Pima County (Fig. 7.2), has been among the fastest growing communities in the United States for decades. By 2000–2001, approximately 1 acre of natural desert was lost to urban development every 2 hours (Benedict, Drohan and Gavely 2005). The human population of Pima County is currently about 1 million persons. Nearly all the population is concentrated in the Tucson metropolitan area, leaving most of the county's 9,000 square miles as exurban wildlands or sparsely settled Native American lands. These areas support a remarkable diversity of flora and fauna.

It is noteworthy that prior to the SDCP, Pima County had never developed a truly effective comprehensive land-use plan. The threat to economic growth, created by the listing of the pygmy owl, served as a catalyst for development of the SDCP, which was subsequently integrated into the county's comprehensive land-use plan. The SDCP has become a model for integrating conservation of biodiversity into land-use planning by transcending the conventional treatment of urban, suburban, and exurban lands.

The SDCP process began in 1997 with the creation of the Science and Technical Advisory Team (STAT) to advise the county. More than a decade later, the planning process continues, although there have been notable and significant accomplishments. These include:

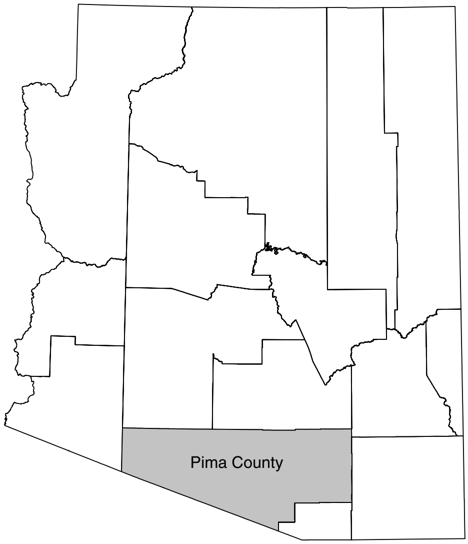

Fig. 7.2 Location of Pima County, Arizona. Source: Amanda Borens

- The County Board of Supervisors' unanimous adoption of the SDCP and its conservation guidelines as an integral part of the county's comprehensive land-use plan;
- Passage of a bond initiative in 2004 providing $174 million for open space including at least $112 million for acquisition of lands and easements to protect land with high biological importance;
- Purchase of land and easements that by 2008 had already protected over 77,000 acres of high priority conservation lands;
- Involvement of hundreds of citizens in educational workshops and public hearings;
- Involvement of more than 150 scientists as sources of information and as reviewers for the plan;
- Development of a comprehensive, county-wide geographic database that enables sophisticated environmental modeling.

The SDCP arose from a scientific process that categorized lands according to their value for conserving biodiversity – the Conservation Lands System (CLS) (Fig. 7.3) – and the land-use guidelines associated with the CLS (Table 7.1) (see Chapter 12). In brief, the categorization of land was based on modeling potential habitat for a range of vulnerable species based on a number of environmental characteristics. While the scientific analysis of lands was pivotal to land-use planning, guiding administrative and political processes and building and sustaining public support were instrumental in the plan's success. These key elements are described below.

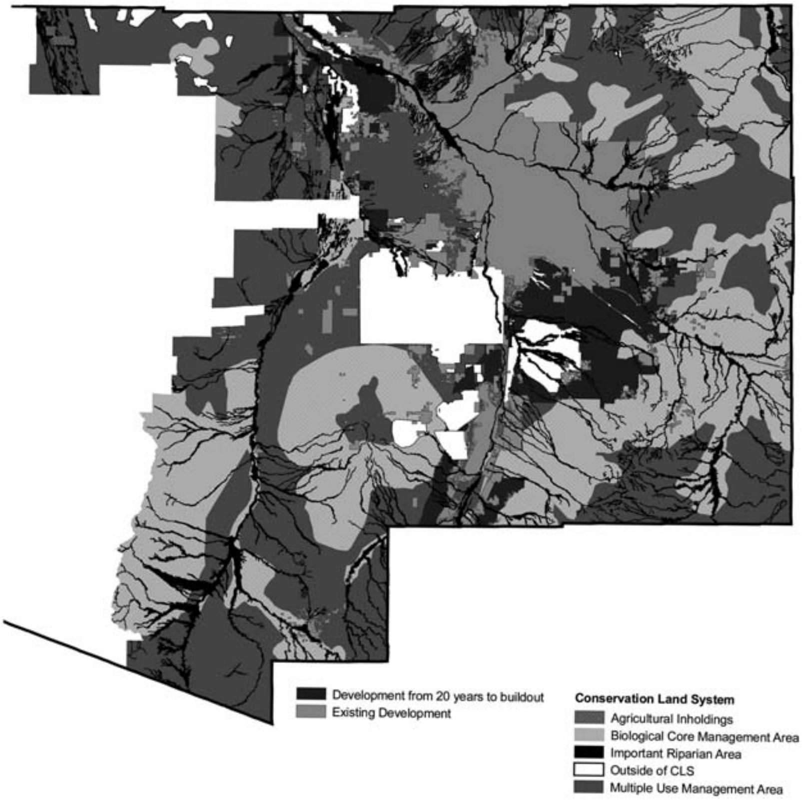

Fig. 7.3 Conservation lands system, Pima County, Arizona. Source: Steidl, Shaw, Fromer

Table 7.1 Land-use guidelines for primary conservation lands categories. Sonoran Desert Conservation Plan, Pima County, Arizona

Conservation land category	Percent of total acreage conserved as natural open space
Important riparian areas	> 95
Biological core management areas	> 80
Multiple use management areas	> 66.7

Managing the Social and Political Dimensions of the Land-Use Planning Process

Conservation planning is inherently complex and dynamic. Not only are environmental characteristics constantly in flux, the needs and priorities of society are equally variable. We suggest ways of responding to these dynamics by pointing to “lessons from the field.” They intend to inform and improve efforts by others, regardless of location, the assortment of land uses, or ecosystem structure. We list and discuss some of these lessons below.

Lesson 1: Conservation Planning Can Provide a Reliable Basis for Well-Balanced Land-Use Planning. Critics of conservation planning in urban areas invariably question whether society can (or should) bear the costs associated with implementing, evaluating, and monitoring plans. Observers also consider whether environmental concerns should preempt other worthy planning goals. The SDCP has demonstrated that urban development and conservation of biodiversity can be complementary and meet a wide range of urban planning goals. For example, riparian lands are critical for conserving biodiversity in the southwestern United States and in other regions of the country. But in addition to conservation, riparian areas provide a logical foundation for innovative land-use planning that meets multiple needs. Riparian areas can be used to establish an interconnected system of open spaces that support outdoor recreation, provide some of the most aesthetically valuable areas in cities, preserve critical archeological sites, and sustain crucial processes that govern groundwater recharge. Preserving these riparian lands also keeps development away from flood prone areas that are unsuitable for homes and other structures. In sum, there are many benefits of protecting riparian areas that extend well beyond the benefits to biodiversity.

Lesson 2: The Goal of Conservation Planning Should Be Conservation, Not Compliance with the Bureaucratic Requisites of Environmental Legislation. When faced with ESA issues, cities often develop an HCP or MSHCP in order to obtain a Section 10 permit and protect individual species listed under ESA. This perspective focuses on compliance rather than effective conservation. In contrast, development of the SDCP was driven by the goal of establishing a land-use system that ensures the long-term persistence of the full spectrum of biodiversity native to the region. There are several arguments for taking this broad approach to conservation. First, there should be no disadvantage to our approach because a well-designed plan that accomplishes the SDCP goal (conserve biodiversity) should surely qualify for a Section 10 permit (focused on a subset of species). Second, by looking beyond the species-level mandates of ESA, planning, conservation, and monitoring benefit from economies of scale by becoming more economically efficient as they increase in scope. For example, approximately 60% of species considered “vulnerable” in Pima County depend on riparian environments. Monitoring the status of these species individually is extremely costly, whereas monitoring function and structure of carefully chosen elements representing the overall riparian environment is less costly and produces biological insights unavailable through monitoring at smaller scales.

Lesson 3: Science Is Both Process and Knowledge. Knowledge about ecological processes and biological structure is always incomplete. However, science contributes more than knowledge to land-use planning. Foremost, science provides a process of transparency and accountability plus a rigorous foundation for synthesizing existing information and for identifying areas where uncertainty must be reduced by generating new knowledge. Early in the SDCP process, for example, we recognized that predicting potential habitat for vulnerable species across the planning area would be more effective if models were based on a high-resolution map of plant communities (especially riparian communities) in key planning areas. Therefore, the county commissioned a process to develop a new, high-quality map of riparian vegetation.

Ultimately, science performs multiple functions in land-use planning, including the following:

- Rigor, consistency, and replicability. Although some decisions need to be made with imperfect information, establishing a rigorous basis for decisions and explicitly documenting strategies employed allows those decisions to be re-evaluated when new knowledge is available or if planning goals change in the future;
- Setting goals. Different planning alternatives can only be compared meaningfully if examined relative to their success in meeting a set of carefully considered goals for conservation and other objectives established for the planning process. These goals should be established carefully and, at a minimum, span a range of ecological scales from single species (fine filter) to the entire planning area (coarse filter);
- Transparency and accountability. The entire planning process, including scientific deliberation, should be open, explicit, and well documented;
- Expert evaluation and validation. Periodic review by experts from outside the community is both a crucial source of new perspectives and validation of the approaches taken;
- Peer involvement and review. By deliberately engaging hundreds of local biologists, the SDCP process benefited from diverse biological expertise and fostered political support from local scientists.

Lesson 4: Separate Scientific and Political Processes. The role of science in land-use planning is to provide information and a reliable structure for prioritizing and allocating lands to different competing uses. To accomplish this objective, science advisors must be isolated from the political and advocacy elements that are integral parts of the planning process. In the case of the SDCP, a citizens steering group, comprised of various interest groups, was formed to ensure their input to the process. Further, there was a non-governmental coalition of environmental groups (Coalition for Sonoran Desert Protection) that participated in the steering committee and functioned as political advocates on behalf of the plan. This structure made it possible for the science team, comprised of volunteer environmental scientists, to focus exclusively on applying science in designing and recommending a land-use system that would accomplish the conservation goals established for the process.

Similarly, all of the preliminary biological assessments and inventories as well as the modeling and mapping of important biological areas were conducted independently of land ownership issues. This was a deliberate strategy to insulate the biological assessment process from the economic issues inherent in land ownership. In short, the biologists focused purely on ecological information with the goal of providing this scientific information to inform decision makers who must also consider ownership and other socioeconomic issues.

Lesson 5: Beyond Reserves – Working Landscapes Are Crucial Elements in Land-Use Planning for Conservation. Conservation has often focused on protected natural areas. But lands used for low-intensity activities, such as responsible ranching, can be important elements of a conservation plan. Indeed, Pima County includes substantial lands in parks, refuges, and forests that function as conservation lands. One critical element of the SDCP was to provide a way to maintain or enhance connectivity among these lands by preserving intervening private or state trust lands that are under development pressure. Most of the lands acquired by Pima County to implement the CLS will remain as working landscapes (primarily ranches) rather than pure biological reserves. This strategy complements another of the county's planning goals: protecting the cultural heritage associated with ranching while keeping these lands largely open and natural for conserving biodiversity. These acquisitions, coupled with the zoning limitations of the CLS (Table 7.1), provide a strategy to ensure that private lands with high biological value remain in low-intensity uses.

Conclusion

In concluding the chapter, it is important to recognize the positive benefits that conservation brings to urban, suburban, and exurban dwellers as local wildlife provides numerous opportunities to engage and appreciate nature. Many of these opportunities are home based. Data provided by the US Department of the Interior (2006) and other federal agencies support this claim. They indicate that in 2006, 68 million Americans over 16 years of age (nearly 30% of the population) participated in wildlife watching activities, 55 million put out food to attract wildlife, 44 million reported enjoying wildlife, and nearly 20 million photographed wildlife. All of these activities took place near homes.

These positive experiences foster political and economic support for conservation because people's exposure to nature affects their (positive) environmental views (Savard, Clergeau and Mennechez 2000). Enhancing biodiversity in urban areas means that people engage nature more often. This fuels a stronger appreciation of – and willingness to – protect nature (Shultz 2001). Although occasional human–wildlife conflicts occur, ecologically literate residents can be a positive force for environmental planning. Residents of urban and suburban areas place a higher value on conservation than rural residents and vote accordingly: legislators from more urbanized states and districts are more likely to support strengthening ESA (Kellert 1996). Thus, the potential impact of a well-informed public in supporting conservation is enormous (Gould 1991) and the demand for access to nature in cities is substantial.

These actions demonstrate a crucial challenge of wildlife conservation in urban areas: integrating conservation and management of wildlife with issues of public perception and risks to their well-being. Urban conservation involves educating people and fostering a conservation ethic as well as promoting the ecological integrity of habitat for plants and animals. Conserving habitat in urban areas helps protect biodiversity, but also connects people with nature. For people interested in conserving biodiversity, these efforts provide a motive to support conservation in urban, suburban, and exurban areas.

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Chapter 8
Into the Wild: Vegetation, Alien Plants, and Familiar Fire at the Exurban Frontier

Lynn Huntsinger

Abstract The spatial expansion of human populations threatens or alters ecosystems on much of the country's privately owned exurban land. These impacts affect the many ways that plants, animals, and environments interact and influence one another. This chapter considers exurban impacts to plant habitat, plant species, plant community structure, ecological processes, and social conditions within, nearby, and at a distance from development. The properties of major vegetation eco-regions in the United States are described and how and why exurban development alters ecological processes over varying spatial and temporal scales is explained. Issues such as fire suppression, land fragmentation, and the introduction of nonnative vegetation are discussed as artifacts of exurban land development. The chapter also draws on the research literature to discuss why specific development densities and configurations are best suited for particular vegetation regimes and points to the mitigation techniques that have proven most successful.

Introduction

As primary producers of ecosystems, plants capture solar energy that sustains life, while also serving as the foundation of ecosystem biodiversity. Vegetation provides habitat and food for wildlife, protects and feeds the soil, and stores and cycles water and other nutrients. Exurban development changes vegetation within and adjoining it, but also can change conditions far from the development site. Direct displacement and alteration of vegetation and indirect effects on ecological processes and species composition are characteristic impacts. Long-term effects may be cumulative and affect entire landscapes and distant areas. Fire and introduced species associated with exurban development are extraordinarily costly and far-reaching. This chapter

L. Huntsinger (✉)
Department of Environmental Science, Policy, and Management, University of California, Berkeley, Berkeley, CA 94720, USA
e-mail: Huntsinger@berkeley.edu

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explores what is known about the effects of exurban development on vegetation. The specific impacts of exurban development vary with the ecosystem and the characteristics of the development, so while this chapter presents general concepts, it cannot capture every situation. Instead the focus is on concepts of broad applicability to generic forest, rangeland, and desert ecosystems. These concepts have much in common with development impacts on wildlife but, unlike animals, plants cannot move from one spot to another except through reproduction and growth.

Before discussing the influence of exurban change, it is important to consider what kinds of land uses might precede exurban development. Presumably exurban expansion occurs on privately owned land that is rural in character (Fig. 8.1). While some of this land may truly be "vacant," it is more likely used by the owner for farming, grazing, forestry, hunting, and/or recreation. Vegetation often has already been exposed to management for various goods and services and has changed and adjusted as a result. For example, plant communities may have developed based on irrigation ponds and canals, and a spectrum of exotic species may have been introduced intentionally or inadvertently. Trees and shrubs may have been cleared for grazing, forests thinned or genetically improved for timber production, game brought in for hunting, and fields created and plowed for farming. Exurban development ends these uses and introduces new factors that shape plant communities.

Fig. 8.1 The term "ranch" takes on new meaning in an exurban environment. Photograph by Lynn Huntsinger

For decades, maintaining biological diversity through protection of particular species and habitats has been a primary focus of conservation. Ecologists now realize the need to maintain the integrity of an ecosystem, rather than only elements of it. "Ecological integrity" means that ecosystems are self-sustaining over long periods of time. Thus, conserving the ecological integrity of an ecosystem means maintaining not only biodiversity but also the processes that create structural and biological diversity and enable the persistence of plant communities. These processes include the many ways plants, animals, and environments interact and influence one another.

This chapter considers exurban impacts to plant habitat, plant species, plant community structure, ecological processes, and social conditions within, nearby, and at a distance from development.

Plant Habitat

Plant habitats are places where populations of plants normally are found. Habitats are determined by the soils, climate, water dynamics, and topography of an area, contemporary as well as historical influences, and the interactions among species at a site. For example, in a forest, clearing trees creates habitat suitable for small-statured plants that need abundant sunlight. Creation of a pond or watercourse creates habitat for plants that need consistent access to water, often referred to as riparian vegetation (see Chapter 10 for a discussion of riparian habitats). A history of plowing for crop production changes the kinds of seeds and soils found on a site and may influence vegetation long into the future, creating habitat for plants that grow well in previously plowed areas. The suburban landowner, by regularly mowing the lawn and adding fertilizer, hopes to create habitat for lawn grasses—though the wily dandelion has found a way to occupy the same habitat.

Plant communities are groups of plants that share a habitat. The concept of community can be applied across a wide range of scales, from the plant community along the shores of a small pond to the Amazon rain forest. The species in a plant community interact with each other and with the environment and exist in recognizable forms that develop repeatedly over space and time, such as oak woodlands, pine forests, desert grassland, or sagebrush grassland. Plant communities are named for the characteristic plant species within them or for characteristic environmental features.

The location of exurban development often is correlated with high levels of biodiversity because both are influenced by biophysical factors, particularly the presence of water. Unusual rock outcrops or landscapes with abundant visual complexity, which attract development, often harbor unusual habitats (Fig. 8.2). The ecological importance of a habitat can be much greater than is suggested by its size (Naiman and Décamps 1997). Consequently, the effects on biodiversity may be disproportionately large relative to the size of the exurban development (Hansen et al. 2005). Rare habitats include those on unusual or endemic soils, where only long-adapted natives can grow. The few small wetlands in a desert area, or the meadows in an otherwise heavily forested landscape, are relatively rare habitats that also are desirable places for humans to live.

A plant community that becomes isolated in evolutionary time develops species that are genetically different from those growing elsewhere. These habitats may contribute significantly to the compositional and structural complexity of a region (Dale et al. 2005). An example of a relatively rare habitat is the vernal-pool habitat that develops temporarily in spring on soils with a hardpan that slows or prevents water drainage. The unique chemistry of the water, the harsh and variable growing

Fig. 8.2 Although this vacant ranch is now within a preserve, the setting illustrates the convergence of attractive scenery and riparian vegetation that leads to high interest in exurban development but also relatively high levels of biodiversity. Photograph by Lynn Huntsinger

conditions, and the geographic isolation of individual pools lead to the development of unique, very localized, species (Solomeshch, Barbour and Holland 2007). Exurban development changes plant habitats profoundly (Table 8.1). Rural land uses such as forestry or livestock grazing are heavily constrained by the environmental conditions native to a site. Exurban development can bring far more resources to bear on changing habitat, using intensive fertilization, pest and weed control, water application, seeding, planting, and manipulation of existing plants. Because of this manipulation, and the displacement of habitat by paving, construction, and associated disturbance, habitats often are completely eliminated and replaced with others within a development. Nearby habitats are influenced directly by road construction, changes in management, and the introduction of new species that are able to naturalize and spread into the undeveloped land (Table 8.1). Further, additions of water and nutrients may exceed levels that can be used by plants in the local climate, and the excess may create polluted runoff that affects other habitats. Additions of water and fertilizer typically alter and often reduce biodiversity (Dale et al. 2005).

Plant Species

Species and networks of interacting species have broad, ecosystem-level impacts (Dale et al. 2005). One species may play a more obviously crucial role in an ecosystem than others, as when it occupies a large area, or provides habitat for pollinators, or is a crucial link in a complex food web (Dale et al. 2005). One species may modify habitat so that another can use it, by building soil or fixing nitrogen. Endemic or rare species are restricted to very small areas, yet they provide functions that are critical to other species. The ultimate impacts of species change to biodiversity are difficult to predict and may have unexpected results because of the complexity of plant interactions with each other and with the environment (Power et al. 1996). Sometimes the processes associated with a single species can turn out to be critical

Table 8.1 Impacts of exurban development on vegetation

	Within the development	Surrounding area	Distant but linked areas
Structure	Vegetation structure altered directly by pruning, removal, additions, clearing of defensible space, construction, and paving	Fragmentation of previously continuous habitat into spatially separated and smaller patches. Additional edge and more patchy environment, loss or creation of corridors for species migration, less core habitat. Pollination may be influenced by changes in patchiness or connectivity and introduction of new species. Roads and trails become vectors for the spread of invasive plants, plant pests, and diseases	Reservoirs to hold water, levees and channelization, and draining of wetlands may all be caused by the need to supply water to exurban developments and to protect them from flooding. Road, pipelines and power lines fragment habitat
Ecological processes	Suppression of most ecological processes, including disturbance regimes, nutrient cycling, species interactions	Ecosystem processes, feedbacks between environment and plants, interactions between plants, nutrient cycling, disturbance regimes may be changed or suppressed by management or the introduction of new species	Vegetation adapted to water-based disturbance regimes or access to wet soils and riparian areas will be altered. Air quality change may affect plant communities
Plant species	Massive displacement of wild with domesticated plants, new species are introduced, and others are controlled or reduced. Plant pests and diseases, and herbivores, may be introduced or controlled	Spread of invasive species, plant pests and diseases, and new herbivores. Plants that can live under natural conditions may naturalize in the surrounding areas, changing the character of plant communities and altering ecological processes. New diseases and herbivores, or herbivore predators, may also affect the surrounding vegetation. These changes are continuous and do not have a foreseeable end	The spread of invasive species, plant pests and diseases, and new herbivores may extend over huge area

Table 8.1 (continued)

	Within the development	Surrounding area	Distant but linked areas
Plant habitat	Significantly altered because of large inputs of chemicals, water, and materials. Changes in water availability, soils, wind and thermal patterns, erosion, fire, flooding, localized pollution. May lose small habitats entirely, new ones created. May extend and increase supply of green growth or biomass through year	Risks to nearby homes makes prescribed burning, use of herbicides, tree thinning, more costly and sometimes impossible. Changes in water use and availability as streams are allocated, diverted, or controlled. Tree thinning, fuel breaks, vegetation manipulation may extend to nearby areas and influence habitats. Suppression of disturbance regimes changes habitats	Roadside habitats created, riparian habitats altered
Social and economic	Landowner goals for residential living are dominant and may require complete change in vegetation; management for defensible space; pets. New residents may not recognize or comply with social norms of behavior. Absentee ownerships may make community management strategies less feasible	New constituencies favoring one type or another of management and protection for surrounding lands. Loss of community, infrastructure, political voice, and conflicts with new residents makes forestry, ranching, farming, and hunting more difficult and more regulated. This leads to habitat and vegetation change. New groups seek to influence traditional uses and management of public and private lands. Local economy may come to depend on commuter and/or retiree economy. Loss of infrastructure and community may accelerate conversion to exurban use	Change in the relative influence of different groups on local and eventually more distant planning and political processes. Need for services may extend impacts

to ecosystem functions (Dale et al. 2005). Exurban development creates widespread change by introducing new species or changing habitat, adding barriers to movement or dispersal, introducing new herbivores, and changing competitive dynamics among species (Table 8.1).

Ecosystems vary in the number and density of plants and plant species they contain. The absolute number of species or density of plants is not necessarily an indicator of the status of an ecosystem or plant community. Redwood forests in California, for example, have comparatively few species, despite being a relatively intact native plant community. The density of plants may be very low in desert areas, reflecting limited soil and water resources. However, one general statement is that the native species present on a site have adapted to the site and to each other over evolutionary time, creating a persistent plant community. In turn, the wildlife species, soil conditions, water, nutrient cycling, and other ecological processes linked to this particular complex of plants will change if the plant community changes. For this reason, the proportion of native species on a site is sometimes considered an indicator of ecosystem health.

Exurban developments favor species that are adapted to human-altered environments. Nonnative and weedy species generally increase (Hansen et al. 2005). New residents bring in exotic species for landscaping or gardening and control native species that are not desirable to the owner. Humans act as unwitting vectors for invasive plants whose seeds are carried on clothing or pet fur. Introduction of nonnative species can have profound affects on plant communities, because the relationships among plants and environment that has evolved over time can be severely altered, in turn changing species composition and ultimately, wildlife habitats and site characteristics. For example, a new species that uses water more rapidly than native desert species can prevent natives from obtaining the water they need. Highly aggressive plants out-compete the natives, shading them or excluding them from their habitat. Nonnative plants may assume a focal role in an ecosystem and change community composition and ecosystem processes in their roles as competitors or vectors for pathogens and disease and through effects on water balance, soils, productivity, and habitat structure (Drake et al. 1989).

In some areas, rural land uses have already changed plant communities significantly. Yet these communities may have achieved relative stability over time by adjusting to or persisting despite rural land uses over the last 200 or so years. Exurban development will inevitably introduce new species into these and other nearby plant communities, causing new kinds of change. The extent and impact of this change is unknown. Increased fire frequency and air pollution during the last several decades in southern California facilitated the widespread conversion of coastal sage shrubland to exotic grassland systems (Talluto and Suding 2008). Effects on biodiversity are cumulative and often nonlinear and continue to emerge for decades after development occurs (Maestas, Knight and Gilgert 2003; Hansen et al. 2005).

In addition to introduction of new species, exurban development fosters vegetation change by altering water availability. The new and/or better-watered plants have characteristics that attract some wildlife species and increase their numbers. Plants may remain green when native species are dry during the summer or in drought, or produce fruits and leaves that are particularly tasty and nutritious. One common animal that can prosper from exurban practices is the deer. In much of the United States, local deer species adapt well to exurban food sources and battles ensue as landowners struggle to protect their landscaping from the rapacious herbivores. Pocket gophers enjoy the softer, irrigated soils of irrigated landscaping. Each plant species responds differently to changes in habitat, and regardless of the type of change, some species will benefit and others will decline. Three levels of development in coastal California did not alter overall numbers and diversity of woodland birds, but the species present did change (Merenlender, Heise and Brooks 1998). Specifically, more nonnative species were associated with the more intensively developed areas. A survey of rangelands conducted in Colorado found that private ranchlands had plant communities with higher native species richness and lower nonnative species richness and cover than did exurban areas or protected areas (Maestas, Knight and Gilgert 2003).

Structure

Plant communities have structure that creates habitat and affects species composition. Vertical layers of vegetation, canopy, shrub, and herb layers – comprise vertical structure. Across a landscape – varying proportions of rock outcrops, shrubs, trees, grasses, and watercourses create a horizontal landscape mosaic of habitat patches of varying sizes, termed horizontal structure (Giusti, McCreary and Standiford 2005). In grasslands, vegetation is short and flexible. Shrubs introduce a woody component, adding height and complexity. Trees add further height, large trunks, and extensive canopies. Each increase in vertical complexity adds additional habitats for plants as well as wildlife in the landscape. Trees and shrubs provide shady habitats for plants, for example, or arboreal habitat for mosses and lichens.

Horizontally, a continuous forest provides one kind of vegetation structure with relatively few low-growing species and extensive, contiguous canopy. A patchy forest provides a mix of treed and open areas where grasses and shrubs can grow. The roads, clearings, houses, and pipelines associated with exurban development interrupt horizontal structure and create new habitats, fragmenting contiguous areas into smaller patches (Table 8.1). This results in greater amounts of "edge" habitat and smaller amounts of "core" or interior habitat, benefiting edge species while reducing core plant and animal species. The edges and cores of plant communities can have quite different conditions and habitats, and the abundance of edge and interior habitat varies with patch size. Fragmentation of plant communities may enhance susceptibility to a variety of disturbances, including windthrow, pest epidemics, invasion by nonnative species (Franklin and Forman 1987), and increased grazing pressure from native or nonnative herbivores.

Housing and pavement obviously eliminate vegetation structure, and plantings create new structure. A road creates patches where sunlight can reach plants, but reduces the connectedness and extent of contiguous canopy in a forest, thereby fragmenting the habitat. Roads fragment deserts and rangelands and act as vectors for nonnative species (Gelbard and Belnap 2003). Corridors, or linkages among plant communities that are often recommended for wildlife, also provide opportunities for the spread of invasive plant species (see Chapter 5 for a discussion of fragmentation, corridors, patches, and edges). Fuel breaks constructed to protect developments facilitate the spread of nonnative species. A statewide study in California found that nonnative plant abundance was over 200% higher on fuel breaks than in adjacent wildland areas. There was a significant decline in relative nonnative cover with increasing distance from the fuel break (Merriam, Keeley and Beyers 2006).

Exurban development can have other direct impacts on vegetation structure. In addition to the complete replacement of native communities with residential landscaping, remnant native vegetation may be thinned, cleared, or pruned, sometimes for fire prevention. Particular plants may be encouraged to grow with watering or protection from herbivores and fire. Indirectly, impacts to surrounding vegetation structure can be strong. For example, the need to suppress wildfires near developments may change vegetation with the infilling of trees and shrubs into more open woodlands or grasslands. Unfortunately, together with the increased likelihood of fire with increased human activity, over time this will in turn increase fire hazard to the community.

Ecological Processes

Ecosystem processes are critical to the persistence of plant communities and are affected directly and indirectly by exurban development (Table 8.1). Ecosystems are shaped by processes such as herbivory, competition, interrelationships of plants and environment, pollination, and nutrient cycling. Exurban development alters biogeochemical cycles that can change the pace or direction of ecosystem change for decades or centuries (Dale et al. 2005) (Table 8.1). For example, deposition of nitrogen from auto exhaust favors nonnative grasses in northern California, eliminating the habitat of the rare, endemic Bay checkerspot butterfly (*Euphydryas editha bayensis*) (Weiss 1999). Nonnative species can alter hydrologic processes and nutrient cycling (Vitousek 1986; Lyons and Schwartz 2001). An overall loss of nitrogen in an ecosystem resulting from the takeover of a sagebrush site by nonnative cheatgrass (*Bromus tectorum*) has been documented (Evans et al. 2001). Clearing of vegetation releases carbon and nitrogen, and changes soil moisture regimes.

Species interactions can change or stabilize plant communities. For example, in some environments competition between plants leads to the development of plant communities dominated by the tallest species or suite of species capable of occupying a particular habitat. These communities, sometimes termed "climax communities," can be quite stable in the absence of disturbance. On the other hand, in arid environments a lack of soil nutrients or water overwhelms the effects of competition among plants, and the community that develops is determined more by the ability of a particular species or a suite of species to use the available habitats. Internal regulating forces and relationships, such as competition and nutrient availability and cycling, maintain a plant community within certain bounds (Perry, Oren and Hart 2008). To cross those bounds and become a different plant community is often represented as crossing a threshold of some sort, where return to the original plant community is unlikely to happen without external intervention. The plant community settles into a configuration within a new set of boundaries, sometimes represented as similar to the way a ball rests in a cup.

Various disturbances can disrupt the ecosystem's internal regulating processes, including competition and nutrient cycling (Dale et al. 2005). Disturbance is often a natural event in western ecosystems, and plant communities are well adapted to it. Fire is perhaps the most classic example, but flooding, severe drought, windstorms, plowing, clearing, and even cessation of herbivory are disturbances. Some plant communities depend on native disturbance regimes—particular patterns and frequencies of disturbance—to maintain stability. For example, in some shrub communities, there are many ecological processes and adaptations that enable swift recovery from a common disturbance such as wildfire. After the fire a suite of specially adapted fire-following species occupies the site, some of which require fire to germinate or to create suitable habitat. Shrubs are quickly able to reseed or resprout and reoccupy the site within a few years. The shrub plant community is resilient to fire, in that wildfire does not move it beyond the bounds that define it. The plant community may look different after burning and take a while to recover its former appearance, but it does not change to a different plant community for any significant length of time.

Ecological feedback processes create resilience and persistence despite disturbance. Resilience is the capacity of an ecosystem or plant community to recover structure and function after disturbance (Walker and Fortmann 2003). In a forest community that experiences frequent fire, the understory has little to burn, limiting the possibility of fire getting into the canopy layer and killing the trees. The forest is quite resistant to fire, or resilient, because of this feedback cycle, where fire begets less severe fire. On the other hand, changes in the frequency and type of fires or other disturbances can destabilize plant communities (Keeley, Lubin and Fotheringham 2003), because the ecological processes that enable persistence may only function within the native fire regime. For example, a forest may recover very quickly from a fire that does not burn into the canopy. However, when fire suppression decreases fire frequency, trees become more tightly packed and smaller trees carry the next fire into the canopy, resulting in high tree mortality. Exurban development generally entails fire suppression, disrupting fire feedback processes and leading to a loss of resilience to fire.

Land-use changes that alter natural disturbance regimes or initiate new disturbances are likely to cause changes in species abundance and distribution, species composition, and ecosystem function (Yarie et al. 1998). Flood control or water appropriation for exurban development may disrupt ecological processes in plant communities that are adapted to frequent flooding or particular patterns of water availability, changing habitat characteristics, species composition, nutrient cycling and habitat characteristics, among other things. Fires that are too frequent may prevent the woody component of a shrub-dominated community from coming back, and create habitat for invasive species.

The introduction of a new species can affect resilience by derailing native response processes. Even if a disturbance regime is not changed, the presence of a nonnative species can disrupt response to disturbance. For example, if a nonnative invasive plant is able to take over the site after a fire, the native species that would otherwise come in may be unable to establish. This can cause permanent change to the plant community. In Sierran forests, Keeley (2006) found that because of the presence of new species, wildfire, and even prescribed low intensity fire to which Sierra forests once would have been quite resilient, now serves to spread invasive species and further change ecosystems. A critical problem for ecologists today is that ecosystems have changed, and the processes that maintained stability in the past may not work in present and future conditions.

As opposed to feedbacks that maintain stability within bounds, cycles may be initiated that, if not dampened or mitigated, can lead to costly and self-perpetuating changes in vegetation at the landscape scale. A relentless positive feedback can lead to great change, as with the introduction of cheatgrass (*Bromus tectorum*) to intermountain sagebrush rangelands (Menakis, Osborne and Miller 2003). Cheatgrass successfully makes use of available habitat opened up by land clearing, overgrazing, wildfire, and other disturbances to the existing vegetation, maintaining site occupancy by quickly using up available water resources early in the spring. The annual growth habit of the species results in an abundant dry biomass over the summer that leads to frequent fire, much more frequent than is believed to occur under natural fire regimes, thereby reducing the native shrubby component and opening up more areas to cheatgrass, which in turn leads to more fire. Ultimately, the vegetation changes to a cheatgrass-dominated grassland. This grassland may continue to expand into other plant communities by fostering fires that open up more habitats for cheatgrass, affecting the distribution and character of plant communities at the landscape scale.

Changes in ecological processes may be slow to reveal themselves. The effects of increased fire hazard resulting from the introduction of new species, or infilling of native species due to fire suppression, or the cessation of forestry and agriculture in areas surrounding development may not manifest for decades. The impacts of new pests on desert species, or a lack of reproduction in slow growing and slow changing desert environments, may take a long time to detect. Yet these changes can have far-reaching and persistent effects. The loss of pollinators due to decline in habitats that support the reproduction of native bees and wasps may not ever be recognized. Instead, the disappearances of the plants that depend on them are attributed to something else. Impacts may also take a long time to develop. The cumulative effects of development may lead to gradual change, as when increased nitrogen from automobile exhaust alters the composition of plant communities over time.

Exurban development can be seen as a form of disturbance, but it is not a form to which existing plant communities are adapted. Millennia of exposure to certain kinds of disturbance, including drought, flooding, and fire, has resulted in some western plant communities being quite resilient to certain frequencies and types of each, with feedback processes that maintain stability. There has been no such opportunity for the evolution of stability-maintaining feedbacks with exurban development, including the introduction of new species and changes in site characteristics that accompany it. The impacts take us into uncharted territory, and our ability to anticipate long-term outcomes is limited.

Social and Economic Impacts

Private rural lands are an important buffer between public lands and urban development, but exurban development on the edges of public lands disrupts that buffer (Talbert, Knight and Mitchell 2007). Exurban development affects many social and economic conditions, which in turn alter vegetation (Table 8.1). Public lands add value to development, but this means that for the foreseeable future the new development will influence, and be influenced by, the management of public lands. Once houses are introduced into the mix, vegetation management priorities and options are changed, essentially forever. Ecological processes such as fire can no longer be allowed to occur, and invasive plants, pets, human fire starts, and other exurban impacts will more directly affect nearby public lands. Prescribed burning and grazing are often lost as management options (Fried and Huntsinger 1998).

A shift away from historical uses has already been described in terms of its impacts on plants, but the loss of farm, ranch, and forestry enterprises can also establish a feedback cycle that can lead to even greater loss of rural land and foster more exurban development. Exurban expansion into farms, forest, or rangeland fragments rural lands and results in development surrounded by privately owned production land. Suburban neighbors may object to timber harvest, animal management, and crop management practices, and conflicts and vandalism increase costs to rural enterprises. Exurban residents may be unaware of or unwilling to follow the social norms of behavior and interaction that have been a part of rural communities for decades (Ellickson 1991; Yung and Belsky 2007). Producers draw on a community of other producers for support, shared labor, and information. As rural enterprises disappear, this community grows smaller and farmers, ranchers, and forest owners become more isolated.

Further, ranches and farms require access to infrastructure, including veterinarians, packing houses, processing facilities, and agricultural advisory services (Huntsinger and Hopkinson 1996). Forestry enterprises require equipment and mills, as well as skilled labor. As lands are developed, there are fewer rural enterprises to support this infrastructure. With each forest, farm, or ranch that ceases to exist, the remaining enterprises become more vulnerable to conversion (Liffmann, Huntsinger and Forero 2000) (Fig. 8.3). This feedback cycle can eventually lead to the loss of rural enterprises over a wide area. In one study of exurbanizing communities, ranchers had seen an average of 10 neighboring ranches sold for development and stated that this was an important reason they might sell their ranch (Sulak and Huntsinger 2002).

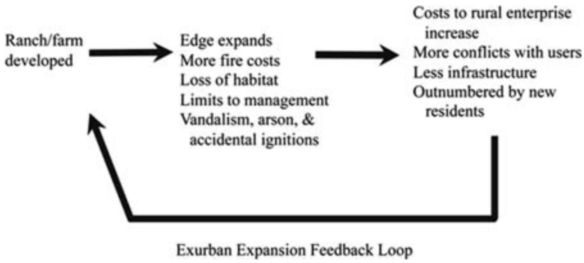

Fig. 8.3 Development feedback loop. As rural enterprises are converted to exurban development, pressure to sell on the remaining enterprises increases. Source: Lynn Huntsinger

For historical reasons, privately owned rural lands generally have more water and better soils than publically owned land. In addition, private rural lands offer habitats unavailable on public or urban lands. For example, privately owned wetlands provide migratory waterfowl in conjunction with rice production in the central valley of California. In the Sierra Nevada, where public and private lands are interwoven, public forests have been profoundly changed by fire suppression, while ranchers historically have maintained relatively fire-resilient open woodlands through grazing, brush control, prescribed burning, and tree thinning (Sulak and Huntsinger 2002).

Another form of "exurban expansion" is the purchase of production-oriented properties for urban refugees who then manage the properties for amenity values: a private reserve, vacation home, estate, or even "trophy ranch." A shift in ownership emphasis leads to a shift in ecosystems. In southwestern Montana, Gosnell, Haggerty and Byorth (2007) found that new owners managed water differently than long-time owners, influencing the region's fisheries in positive and negative ways. In the Rocky Mountain region, Gosnell and Travis (2005) found that about half of the ranches sold were going to amenity buyers, who often had quite different views about land and vegetation use and management than the rural populace. In some high-amenity developments, properties are often vacation or second homes. Absentee owners are less likely to take part in the community and in collaborative efforts at vegetation management and fire-hazard reduction and may be difficult to contact. Amenity buyers add a new political dimension to local communities and a different set of goals for land management.

Exurban residents may quickly outnumber rural residents and change the economics and politics of a region (Gosnell and Travis 2005; Sheridan 2007). While the rural community may value its historical connection with and shaping of the landscape, new residents may be attracted to exurban development because of a perceived lack of people and human impacts in an area. Exurban and rural residents may have very different expectations of the "country life" and how vegetation should be managed (Masuda and Garvin 2008). In-migrants may bring with them particular "aesthetic" or "consumption" views of a landscape that long-time residents view as political threats. In one example these tensions ignited a political firestorm over a proposal by the environmentalist-dominated county government to incorporate landscape-scale aesthetic and environmental principles into county planning (Walker and Fortmann 2003) (see Chapter 13 for further discussion of rural attitudes toward land use and regulation).

An increased population can also mean an increased positive presence on the land. Local conservation areas will have a larger body of volunteers for restoration work. Fire agencies will have more eyes on the land to watch for smoke. Lake Tahoe, in Nevada and California, has experienced a tremendous build-up of fuels in its forests. However, large fires are rare in part because the large number of people in the area report fires quickly. One California rancher reported that in an area where residents appreciated grazing for reduction of fire hazard, exurban residents would notify him when a calf was in trouble or a fence was breached (Fried and Huntsinger 1998).

Forest Considerations

Vertical structure and species composition are key elements of ecological integrity in native forests (Yongblood, Max and Coe 2004) and, although readily measured and managed, they can be difficult to retain in urban settings (Sanders 1984). For example, a 48-year study of changes in forest canopy in a 16 ha remnant forest patch in the New York Botanical Garden showed that overstory canopy composition had been significantly altered by changes in disturbance regime (Rudnicky and McDonnell 1989). In addition, activities by local residents can contribute to the loss of standing and down woody material (Matlack 1993), as well as changes in vegetation. Snags are commonly removed in areas with high recreation use or near houses and roads because of concerns that they may fall. Logs and snags are often gathered as firewood as well. Remnant native vegetation is sometimes manicured to be more pleasing to the eye or easier for people to navigate by reducing the density of the overstory and removing dead woody material (Tyrväinen, Silvennoinen and Kolehmainen 2003). In forested areas, edges caused by development and roads tend to be sunnier, warmer, drier, and more favorable to invasive nonnative species at the expense of many native species.

In some exurban environments, efforts are made to save individual trees within the development. Such trees are cut off from the network of ecological processes that sustain them. Soil changes due to watering or soil compaction may eventually kill the trees. In addition, the trees are cut off from nutrient-cycling processes that formerly took place underneath and around them. Pollinators, native to the former herbaceous vegetation, may not be able to locate scattered trees surrounded by development. Without nearby habitats suitable for the growth of new trees, the preserved trees will eventually simply die off.

On the other hand, remnant native forests can contribute significantly to maintaining native species in an urbanizing landscape, especially if there is some degree of connectivity to larger areas of forest and regulations restricting site alteration (Heckmann, Manley and Schlesinger 2008). Despite an increase in non-native species, remnant forests equal to or greater than 0.1 ha in size in the Lake Tahoe basin retained much of their compositional and structural character along a development gradient, including large tree density, total canopy cover, and plant species richness (Heckmann, Manley and Schlesinger 2008). One substantive difference was the removal of downed woody material by local residents in remnant forests. Remnant forests with high ground cover by native plants, high canopy closure, and low ground disturbance may be less susceptible to invasion by nonnative plants (Mandryk and Wein 2006; Merriam, Keeley and Beyers 2006).

Higher levels of human activity bring a variety of risks to the forest. In California, patterns of sudden oak death seem to be related to the prevalence of human recreation (Cushman and Meentemeyer 2008). Human activities such as construction, trenching, paving, sewage effluent disposal, insecticidal spraying of trees for mosquito control, and road de-icing can promote disease by injuring trees (Ferrell 1996). Soil compaction from various human activities, including keeping horses and other animals, can also degrade tree health by reducing leaf growth and changing root morphology (Lambers, Chapin and Pons 1998).

The greatest challenge for exurban development in western forests is coping with fire hazard. Many exurban developments are adjacent to public lands, where forest management is seemingly always controversial and is not under the control of the community affected by it. Western forests generally have been subjected to fire suppression for more than a century, resulting in ecological and human safety problems, such as altered forest structure, increased tree density, increased accumulation of dead wood, increased insect outbreaks, lowered biodiversity, and vulnerability to catastrophic fires (McKelvey and Johnson 1992; Ferrell 1996; McKelvey et al. 1996; Keeley, Lubin and Fotheringham 2003; Jensen and McPherson 2008).

Within developed areas, landowners may choose quite different levels and types of management for fire-hazard reduction and may or may not collaborate and plan together to reduce the possibility of a conflagration. There is a typical pattern of attitudes toward trees held by exurban residents: when they first move into the forest they want to protect every tree. After living in an area for a while they begin to see the danger of too many trees more clearly. The management of the Lake Tahoe Basin is a case in point: management for fire-hazard reduction has been and remains highly controversial, with some residents wanting fewer trees, some wanting more, and much disagreement on the types of fuels reduction that are appropriate. The scientific debate is also vociferous, with some arguing that fuel-reduction programs increase invasion by nonnative plants and destroy wildlife habitat and others arguing that there is no alternative, as fires are inevitable and the kinds that happen after decades of fire suppression are far more damaging to air quality, wildlife habitat, and plant communities than fuel treatments such as thinning, prescribed burning, and brush crushing.

Unfortunately, forest fuel-reduction programs have the potential to enhance forest vulnerability to alien invasions. In part this is due to the focus on reestablishing native fire regimes in a landscape that differs from pre-Euro-American landscapes in the abundance of aggressive nonnative species (Keeley 2006). The common introduction of nonnative plants may disrupt the ability of the forest to recover after a fire, harvest, or thinning treatment.

Rangeland Considerations

The author defines rangelands as woodlands, shrublands, and grasslands. Disturbance and fragmentation in shrublands at the edges of exurban or urban development lead eventually to the complete replacement of the native vegetation and most of the fauna by exotic plants and a combination of generalist native and exotic animals. The first fragmentation event is often road construction, with associated housing developments. Fuel breaks may be established and pose a special invasive plant risk because they promote alien invasion along corridors into wildland areas (Keeley 2006). Later, habitat remnants may be subdivided by additional development. But these isolated events are just the beginning. As described by Soulé, Alberts, and Bolger (1992), trails soon appear, and vagrants and neighborhood children remove the plant cover for camping sites and "forts." The edges of the remnant are nibbled by expanding gardens and back yards. These incursions are essentially irreversible in scrub and chaparral-type associations because the vegetation is slow to reestablish following removal. The proportion of core habitat in a fragment decreases over time, and before long no point in the remnant is more than a meter or two from some kind of artificial opening. These internal disturbances represent secondary fragmentation that occurs within the larger scale fragmentation of the area.

In a study of the effects of fragmentation in a shrub habitat in California, effects on plants and wildlife were found to go hand in hand. Extinctions after fragmentation occur quickly, with the least common species disappearing first. The size of the remnant was the major predictor of extinction, with larger reserves generally superior for conserving species. In chaparral habitats in southern California, it was found that in habitat remnants in the 10–100 ha range, only the most abundant chaparral-dependent animal species survive for long, and most of these are doomed within a century. Plant species also disappear, in large part because of chronic and cumulative habitat disturbance and perhaps also because of changes in the frequency of fire. In conclusion, Soulé, Alberts and Bolger (1992) argue that much more needs to be learned about managing habitat remnants.

Exurban residents may plant species capable of naturalizing and moving out into wildlands. The shrubs French broom (*Genista monspessulana*) and Scotch broom (*Cytisus scoparius*) were originally planted by homeowners for their hardiness and showy yellow flowers. They have now spread throughout the west coast and created new plant communities, thus changing the appearance of landscapes, shading out native species, and altering soil characteristics to favor weedy, invasive species (Vitousek et al. 1997).

Many shrubland ecosystems, such as intermountain west sagebrush steppe and California chaparral, have natural, high-intensity crown fire regimes that do not mix well with exurban development (Keeley 2006). A major contributor to increased fire-suppression costs and increased loss of property and lives is the continued urban sprawl into wildlands naturally subjected to high-intensity crown fires. Different shrublands have different kinds of fire regimes, however, requiring different fire-management tactics, yet in most cases, our knowledge is far from adequate (Keeley 2002).

Shrub invasion can occur in western ecosystems as a result of fire suppression, ultimately increasing fire risk. In the San Francisco Bay area, fire suppression and reduced grazing have resulted in plant community change in the open spaces surrounding the urbanized areas of the San Francisco Bay. There has been significant conversion of grassland to shrubland dominated by coyote brush (*Baccharis pilularis*). A significant increase in biomass resulting from the change from grass-dominated to shrub-dominated communities was evident. Using fire modeling to examine the effects of shrub increases on fire hazard showed that the replacement of grass-dominated areas with shrub-dominated landscapes has increased the probability of high-intensity fires (Russell and McBride 2003).

On the other hand, frequent fires can obliterate the woody component of some shrublands. For example, if fire occurs too often in sagebrush steppe, sagebrush is unable to recover. Invasion by cheatgrass, as discussed previously, facilitates this conversion. In chaparral, fires create opportunities for invasion of nonnative species. There is considerable argument about the appropriate fire regimes in the various shrubby regions of the west, but it is clear that fire regimes vary among ecosystems (Jensen and McPherson 2008). In addition, the increasing presence of nonnative species complicates predictions of fire outcomes.

Desert Considerations

In desert ecosystems, water is the key to life. Natural and artificial ponds and waterways may be focal habitat for plant communities that depend on consistent access to water. Areas with water are rare and should be focal points for conservation. These areas contain key habitats, have a high diversity of species in need of conservation, and are highly attractive to people for recreation and residence. Ranches and farms typically center on water, and these areas are highly attractive for exurban residences.

As development occurs in desert areas, land is re-contoured, vegetation is planted or removed, road networks are built, and buildings are erected. New landscapes and plant communities attractive to residents are created. In arid and semiarid ecosystems, these designed, engineered ecosystems are often characterized by plantings with high water demand, so water must be brought in from elsewhere. Assessing the impacts of development on a wash in central Arizona, Roach et al. (2008) found that the construction of canals created new flowpaths that cut across historic stream channels, and the creation of artificial lakes produced changed nutrient cycling. Further hydrologic manipulations, such as groundwater pumping, linked surface flows to the aquifer and replaced ephemeral washes with perennial waters. These alterations of hydrologic structure are typical by-products of urban growth in semiarid regions. Washes are usually disturbed or transformed into drainage structures, changing flood disturbance regimes characteristic of these waterways and eliminating habitat for desert vegetation (Stiles and Scheiner 2008).

Desert plant communities are slow to recover from the impacts of volunteer roads, campsites, and plant removal, all of which can be associated with exurban development. Slow-growing desert plants such as ironwood (*Olneya tesota*), creosote bush (*Larrea tridentate*), and saguaro cactus (*Cereus giganteus*) may be harmed directly by construction and roads. Plant theft and vandalism also increase with an increased human presence and more roads. Erosion from roads and soil compaction increases, as planned roads are augmented by volunteer roads and off-road vehicle tracks. These can serve as vectors for nonnative species introduction. Nonnative species that produce biomass and can support fires are especially dangerous to desert ecosystems.

Species within deserts can respond to fragmentation in varied and potentially contradictory ways. For example, contrary to expectations, low-density exurban development benefits some species by providing water, forage, and shade; these benefits disappear as housing density increases (Bock, Jones and Bock 2008).

Conclusion

One of the most important conclusions to be drawn from this review is that planning should consider ways to reduce the introduction and spread of nonnative plant species. Nonnative plant species change the outlook for neighboring vegetation in unpredictable ways. The changes wrought by the introduction of nonnatives can be widespread, altering habitats, structure, species composition, and ecological processes. The patterns of vegetation response and stability of the past become less useful in predicting the outcomes of development. Retaining as much of the native flora and ground cover as possible can help reduce the spread of nonnatives. Research in forests, rangelands, and deserts supports the notion that invasive plants invade more quickly when gaps in tree or plant cover are created, especially when this exposes open ground. Encouraging or requiring use of native species for landscaping within developments would be ideal, but seems unlikely to be implemented or enforced.

A second important conclusion is that buffering public lands with low-density enterprises such as agriculture, grazing, or forestry lands is a good idea (Fig. 8.4). These working landscapes ideally act as a buffer, providing a barrier to new nonnative species and limiting the direct impacts of the activities of exurban residents. In addition, such lands can help prevent the spread of wildfire to residences, because crop, livestock, and forestry enterprises manipulate vegetation in ways that, if properly managed, can reduce fire hazard. In addition, prescribed burning and grazing are still available as vegetation management tools on many of these lands.

A third point is that whenever possible, development should be kept away from waterways and wetlands. This reduces the possibility of flooding and also protects habitats that are often peak areas for wildlife activities, and important small-scale plant habitats. In arid lands, water is of particular importance, and the associated habitats are relatively rare. Waterways, whenever possible, should be buffered from the direct impacts of development and if possible, native flood disturbance regimes should be allowed to continue. Vegetated riparian buffers contribute terrestrial biomass to the aquatic food chain, regulate water temperature, control floods,

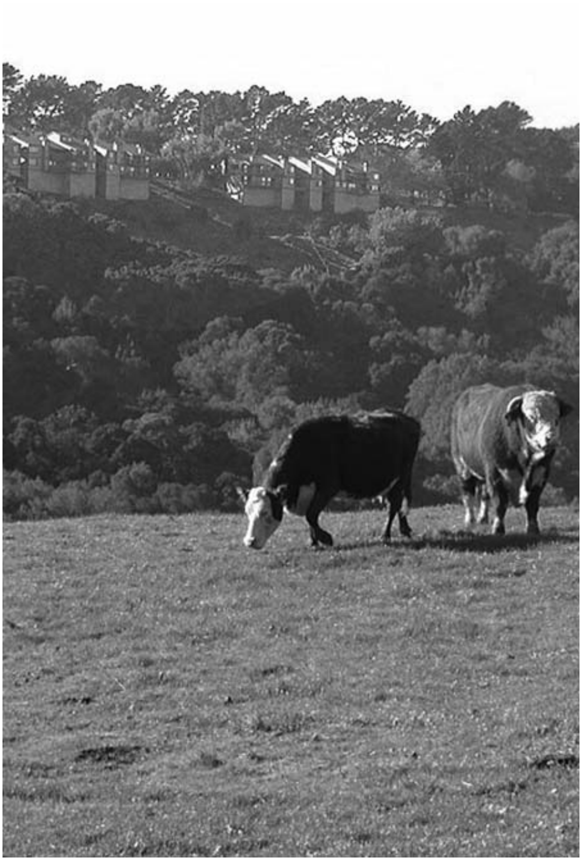

Fig. 8.4 Rural working landscapes can buffer wildland and urban environments. Photograph by Lynn Huntsinger

provide wildlife habitat, and reduce erosion, sedimentation, and pollution (Perlman and Milder 2005).

Fourth, for western ecosystems, planners should make the assumption that wildland fire is likely to occur. The costs of fire fighting and suppression should be taken into account when determining where exurban development should take place. It is unlikely that "natural" fire regimes will ever be restored in areas near or intermixed with development because of the risks to residents and property, air quality concerns, and the changes in the vegetation that have occurred because of fire suppression. If employed, prescribed burning should be strategically designed to insure the most efficient fire-hazard reduction and to minimize the amount of landscape exposed to unnaturally high fire frequency (Keeley 2006). Leaving some overstory canopy and minimizing exposure of bare ground may be less likely to promote nonnative plants (Merriam, Keeley and Beyers 2006).

Fifth, development should strive to protect as much core habitat as possible. Various development strategies are proposed to minimize fragmentation and edge effects. The ability of conservation development to protect biodiversity and ecosystem services depends on the size of remnant undeveloped areas, the amount of change to natural disturbance regimes and ecological processes, and the relationship of the exurban development to the rest of the landscape—whether remnants are connected with larger wildlands, or whether the development abuts public lands, and so forth. Ultimately, undeveloped fragment size affects the total number of individuals present in a continuous patch of vegetation. Larger patches have more individuals, which allows for larger populations and a lower extinction rate for the remnant vegetation. Smaller patches have larger edges and lack buffer zones, so that their limited expanse is exposed to repeated impacts from people (Stiles and Scheiner 2008).

Although it has been suggested that developments can be designed to reduce impacts, for example by clustering dwellings, Lenth, Knight and Gilgert (2006) found no evidence that cluster development had any impact on the proportion of nonnative species found in remnant areas compared to more typical dispersed development. Although the proportion of land area in clustered developments further than 200 m from development was nearly twice that of dispersed housing developments, nonnative vegetation dominated both clustered and dispersed developments (Fig. 8.5). The habitat patches left undeveloped by clusters were significantly smaller than those of undeveloped areas, and patches were often not connected. Suburban edge effects may extend up to 200 m into grasslands and shrublands (Bock, Bock and Bennett 1999; Odell and Knight 2001). Most of the open area in a typical clustered development is within this zone, and as a result, edge species dominate. Finally, the open spaces of clustered developments may not be managed in ways that promote conservation values.

Fig. 8.5 This cluster development retains patches of open lands. Photograph by Lynn Huntsinger

The value of clustered housing developments can be enhanced by planning that connects clusters with each other or with other wildlands (Lenth, Knight and Gilgert 2006). When possible, the location and configuration of open areas should be planned on a regional scale, aggregating open-space areas and minimizing the construction of roads and power lines. It is also possible that clustering homes may foster stronger community relationships, enabling collaborative community efforts in the long run. Providing places where people will naturally meet each other helps to develop a sense of community. Developed areas have an important role in the maintenance of native ecosystems and the ability to maintain ecological integrity will depend as much on the activities, practices, and politics of the local population as on management conducted by land management agencies (Heckmann, Manley and Schlesinger 2008).

An assessment of conservation-oriented limited development projects in the eastern United States found that they were protecting threatened conservation resources, including rare biodiversity and ecosystem functions. They also resulted in significantly more conservation benefits than other types of conservation developments, including typical cluster developments (Milder 2007). On average more than 85% of each site was protected as interior habitat, and project design and management generally addressed the conservation, restoration, and stewardship needs of site-specific conservation targets (Milder, Lassoie and Bedford 2008). Despite containing relatively little development, most are financially self-sustaining and many realize a profit. The sale of a relatively small amount of subdivided land ready for construction can finance the protection of a much larger amount of undivided land. In addition, many of these developments benefit from federal, state, and/or local tax incentives for land conservation (Milder 2007; Wright and Anella 2007). More study of these kinds of options is needed.

Finally, it is important to remember that ongoing changes in plants, vegetation structure, and climate make the exurban environment a true frontier, in the sense that our ability to look beyond the boundaries of the present and anticipate the future is limited. Turning back to the past for answers about how plant communities will respond to future impacts is of limited use. To cope with this changing and new world will require tough decisions, with special attention to decision-making processes and to who is included in them. Planning should seek to maintain options for vegetation management in order to be able to cope with the unanticipated changes of the future.

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Part III
Water Resources, Wetlands, and Storm Water Management

Chapter 9
Impacts of Exurban Development on Water Quality

Kathleen A. Lohse and Adina M. Merenlender

Abstract This chapter details the impacts of exurban development on water quantity and quality in the United States. The chapter begins by reviewing studies that document the consequences of urbanization on water quality, with emphasis on exurban development. We show how watersheds are contaminated by a range of organic and inorganic compounds as land use along the rural-to-urban gradient intensifies. These studies indicate the need to evaluate anticipated land-use changes carefully so that watershed conservation is improved. The chapter then describes the use of modeling methods that link land-use change with watershed conservation. A case study of California's Russian River Basin demonstrates the use of coupled land-use impact/land-use change models as decision-support tools that enable assessment of future land-use change, including exurban land development.

Introduction

Sustaining water resources has emerged as one of humanity's greatest challenges (National Research Council 2004). It requires managing existing threats to surface and groundwater as well as planning for future impacts due to land-use change and other global conditions (Butcher 1999; Fitzhugh and Richter 2004). Other chapters in this volume detail the ecological consequences of exurban land development and how best to address them. This chapter follows suit by examining how exurban land development affects water quantity and quality.

Two themes are explored in this chapter. First, we explain how and why land development along the rural-to-urban gradient introduces a range of contaminants to watersheds. The rural-to-urban gradient captures the higher residential densities found in more urbanized areas (<1 acre per dwelling), intermediate density suburbs,

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K.A. Lohse (✉)
School of Natural Resources, University of Arizona, Tucson, AZ 85721, USA
e-mail: klohse@email.arizona.edu

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and exurban (rural) areas where densities are much lower (5–40 acres per dwelling). We distinguish land uses by residential density because the intensity of land use indicates much about the impacts on water quantity and quality. As Chapter 11 illustrates, the amount of land covered by impervious surfaces (rooftops, pavement) increases as residential densities increase. This augments the volume and speed of runoff which affects watersheds and stream quality. Indeed, a growing field of research looks specifically at the relationships between land-use intensity, water quality, and associated impacts on aquatic life and human health. The research we summarize provides the most current understanding of these relationships. Second, we describe the use of an analytical model that enables policy makers to assess how anticipated exurban development will likely affect water quality and aquatic life. These models go a far way in assisting planners, watershed managers, and conservationists as they weigh the future outcomes of exurban land development. We describe how the model was used in northern California's Russian River Valley.

Review of Urban and Exurban Land-Use Impacts on Water Quality

Agricultural and urban land uses are widely known to impair water quality in streams and other water bodies (US EPA 2000). However, land-use change beyond the metropolitan fringe is increasingly recognized as an emerging mode of development in critical need of ecological and water quality assessments (Theobald 2001, 2004). Indeed, exurban development is the fastest growing land use in the United States (Heimlich and Anderson 2001; Theobald 2003; Brown et al. 2005) and is expanding in Canada and Europe as well (Dubost 1998; Azimer and Stone 2003). For example, recent nighttime aerial analyses of the conterminous United States found that exurban development covers 14.3% of the total land area and claims 37% of the population. In contrast, urbanized areas account for only 1.3% of the land area yet house 54.7% of the population (Sutton, Cova and Elvidge 2006). These differences in residential densities signal the need to investigate exurban land development explicitly. More so, urban and exurban developments are fundamentally different types of growth (Newburn and Berck 2006). Development codes typically require that higher density (<1 acre per dwelling) urban development is tied to sewer and water infrastructures, but exurban development (5–40 acres per dwelling) is nearly always serviced by private wells and septic systems. Thus, exurban residential development is not bound to existing or planned sewer and water service areas (SWSA). These differences extend the possible range and associated environmental impacts of rural-residential development such as sedimentation but also temperature, organic wastewater contaminants, and nutrient loading from septic systems well beyond the urban fringe (Hansen et al. 2005; Newburn and Berck 2006; Lohse et al. 2008). The different factors governing urban and exurban developments, combined with their distinct land-use impacts, mean that planners and watershed managers should identify the effects of exurban versus urban development.

The scientific literature identifies the impacts of urbanization on water quality characteristics including nutrients, organic pollutants, metals, and sedimentation. The conversion of land to exurban and urban housing also alters hydrology and is detailed in Chapter 11. Here we focus on differences in housing densities that range from exurban to urban.

Water Quality Assessments and Sources

Assessments. Section 305b of the Clean Water Act requires that states, US territories, and other jurisdictions assess the quality of surface and groundwater and report findings to the US Environmental Protection Agency (EPA). Water bodies are then classified according to water quality and their ability to meet designated uses, including aquatic life, fish consumption, primary and secondary contact recreation, drinking water supply, and agricultural use. To meet drinking water standards, for example, surface or groundwater quality must not exceed the specified maximum contaminant level (MCL) established by the EPA for each regulated water quality constituent. Similarly, surveys of bed sediments are used to estimate the probability of adverse effects to aquatic and human life as required by the Water Resource Development Act of 1992. The contaminant concentration in bed sediment expected to adversely impact benthic (or bottom-dwelling) organisms is called the probable effect concentration (PEC).

Based on these standards, the EPA reported that 35,000 miles of river were impaired by urban runoff and sewers as of 2000. An additional 28,000 miles were impaired by municipal point sources, and 129,000 miles of river were impacted by agricultural land use. Figure 9.1 shows that pathogens (bacteria) were the leading cause of river impairment, followed by siltation, nutrients, and metals. Figure 9.1 also indicates that 26% of the 21,000 surveyed sediment sites fell into the EPA's Tier 1 category, where observed contaminant concentrations are likely to adversely affect aquatic life and possibly human health. The most frequently observed contaminants in Tier 1 were toxic organic compounds, namely polychlorinated biphenyls (PCBs) (20%), followed by pesticides, mercury (Hg), and another class of toxic organic compounds, polycyclic aromatic hydrocarbons (PAHs). Another 49% of the sites were classified as Tier 2, indicating possible, but infrequently expected, adverse effects on aquatic ecosystems or human health. Metals were the most frequently encountered contaminants in Tier 2 (58%).

Sources. Contaminants are divided into point and nonpoint sources. Point sources refer to the discharge of contaminants from specific locations such as municipal discharge from wastewater treatment plants. Because nonpoint contaminants are more diffused, they are separated into atmospheric and fluvial sources. Atmospheric deposition is commonly associated with organic pollutants such as PCBs and PAHs and metals such as lead (Pb) and mercury (Hg) derived from coal combustion, burning of leaded gasoline and other petroleum products. Nonpoint sources

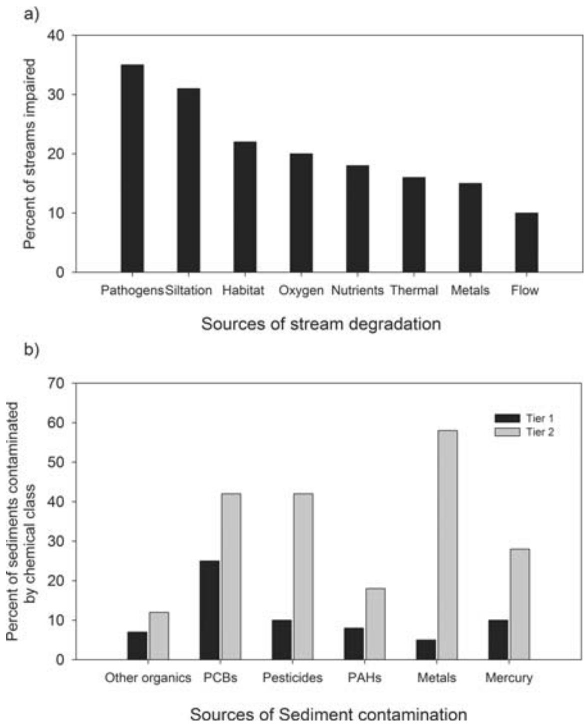

Fig. 9.1 (**a**) Percent of streams impaired by different sources of contaminants or alternations including pathogens, siltation, habitat alteration, oxygen depleting substances, nutrients, metals, and flow alteration (adapted from the US EPA 2000); (**b**) Percent of sediments contaminated by organics, PCBs, pesticides, PAHs, metals, and mercury (adapted from the US EPA 1997)

from watershed-derived fluvial transport include runoff from agricultural fields, mine drainage, or urban areas via pavement, lawns and golf courses, and leaking septic tanks. Table 9.1 highlights sources of select contaminants and the predicted enrichment factor associated with conversion (land-use intensification) from rural to suburban and from suburban to urban land uses. Below, we examine how land-use intensification affects the occurrence of different contaminants, including organic compounds such as biological pathogens and toxic organic compounds, inorganic compounds including nutrients and metals, and sediments. We then suggest best management practices that minimize sources of contaminants derived from residential housing developments.

Organic Contaminants

Organic contaminants include biological pathogens and other toxic organic substances. Pathogens consist of a diverse group of bacteria, viruses, protozoa, and parasitic worms responsible for many waterborne diseases such as gastroenteritis, malaria, river blindness, cholera, and typhoid fever (World Health Organization 2008). Although fatalities associated with waterborne pathogens remain low in the

Table 9.1 Contaminants, sources of organic pollutants, nutrients, and metals, probable effect concentration (PEC) for sediments (in μg/g or μg/kg sediment) or maximum contaminant level (MCL) for drinking water (in mg/L), and predicted enrichment factor (EF) from conversion from rural (R) to suburban (S) to urban land use (U). Percent commercial, industrial, and transportation (CIT) or impervious surface area (ISC) is used as an index of urban intensity. Drinking water standards are specified because regional water quality standards vary for rivers and streams (from Chalmers, Van Metre and Callender 2007)

Contaminants		Sources	MCL PEC	EF (R to S)	EF (S to U)	Threshold CIT or ISC > PEC or EPA
Organic pollutants						
Pathogenic	*E. coli*, enteric bacteria, viruses	Septic, domestic animals, wildlife, or agriculture	0 MCL; 400 MPN/100 ml*			10–20% ISC*
Toxic organic	Polyaromatic hydrocarbons (PAH)	By-products of fossil fuel combustion in automobiles, power plants, and heating facilities. Creosote and roofing tar, coal-tar and asphalt sealant	0.0002 mg/L; 22,800 μg/kg	6.1	5.2	13
	Halogenated hydrocarbons					
	PCB	Solvents, cleansers, and degreasers but also pesticides, electrical equipment, and commercial products	0.0005 mg/L; 676 μg/kg	2.2	3.7	31
	DDT	Pesticides, insecticides	572 μg/kg	1.8	3.2	Not exceeded
Inorganic contaminants						
Nutrients	Nitrate-N	Fertilizers, atmospheric deposition, food import, waste	10 mg/L			

Table 9.1 (continued)

Contaminants	Sources	MCL PEC	EF (R to S)	EF (S to U)	Threshold CIT or ISC > PEC or EPA
Nitrite-N		1 mg/L			
Total phosphorus	Fertilizers	–			
Metals					
Arsenic (As)	New/old timber treatment, ag. chemicals and natural sources; mining by-product	0.01 mg/L; 33,000 μg/kg	–	–	–
Cadmium (Cd)	Tires, tire wear, and galvanized metals	0.005 mg/L; 5 μg/g	1.9	3.3	25
Chromium (Cr)	Metal plating	0.1 mg/L; 111 μg/g	–	–	–
Copper (Cu)	Break pads, residential algaecides, wood preservatives, landscaping materials	1.3 mg/L; 149 μg/g	1.7	3.1	14
Mercury (Hg)	Industrial waste, mining, fuels	0.002 mg/L; 1.06 μg/g	1.7	3.1	23
Lead (Pb)	Old housing (leaded paint and fuel)	0.015 mg/L; 128 μg/g	1.9	3.4	3
Zinc (Zn)	New urban surfaces, rooftops, wood preservative	459 μg/g	2	3.5	10
Sediments	New construction, roads, etc.				

* For water quality criterion in Georgia (Schoonover and Lockaby 2006).

United States owing to safe drinking water and sanitation practices, in "developing" countries, waterborne diarrheal diseases (including cholera) and malaria claim 1.8 million and 1.3 million lives, respectively, each year (World Health Organization 2008). Toxic organic substances include a plethora of human-derived compounds that vary in weight, toxicity, and persistence in the environment (Miller and Miller 2007). Two common classes of toxic organic groups that are known to threaten human and ecosystem health include polycyclic aromatic hydrocarbons (PAHs) and halogenated hydrocarbons (PCB). These are discussed below.

Biological Pathogens. Biological pathogens, such as bacteria, protozoa, and viruses, have emerged as primary stressors in surface waters (US EPA 2000) and have been found recently in groundwaters (Embrey and Runkle 2006). The 2000 EPA report mentioned above identified pathogens (bacteria) as the leading cause of river degradation, impairing approximately 91,431 river miles (35%) of the rivers studied (Fig. 9.1). A national survey of groundwater aquifers (Embrey and Runkle 2006) also showed high occurrence of coliform bacteria which were detected in 33% of the wells sampled. Rather than depth-to-well, hydrogeologic characteristics and proximity to contaminated sources, such as wastewater treatment plants, appeared to be better predictors of pathogens in groundwater. These findings raised awareness of groundwater's vulnerability to pathogens and the need to understand factors that control the transport of bacteria and viruses.

The impact of urbanization on pathogen sources, transport, and fate is an area of active research, with investigators using different tools and techniques to address these questions (see Field and Samadpour 2007 for a detailed review). Studies increasingly use *Escherichia coli* because it is a reliable indicator of fecal contamination (Doyle and Erickson 2006). However, the use of *E. coli* alone as an indicator organism is questionable because pathogens have been isolated from ecosystems where only low concentrations of fecal coliforms were found (American Water Works Association 1999; Field and Samadpour 2007). More studies are using molecular techniques to develop microbial tracking tools that identify sources (e.g., human, domestic animal, wildlife, and/or bovine) and the pathogenic nature of the bacteria (Field and Samadpour 2007).

To our knowledge, few published studies have examined the occurrence of fecal coliform along gradients of urban intensity. However, one published study found that in the state of Georgia, fecal coliform concentrations in urban watersheds were significantly higher during base and storm flow than in nonurban watersheds. In these water systems, fecal coliform typically exceeded EPA review criterion of 400 most probable number (MPN)/100 ml (Schoonover and Lockaby 2006). Land-use impact models developed from this study suggest that fecal coliform will exceed EPA review criterion when development exceeds 10 and 20% impervious surface cover. Studies in other environmental settings are needed to determine whether these patterns hold across different hydroclimates. Research also needs to flesh out the effects of transport versus source processes in controlling the delivery of bacteria and viruses to surface waters.

Even though we do not have a firm grasp on the sources, transport, and fate of bacteria, watershed managers and planners can follow best management practices that reduce bacteria sources and delivery to streams. These are categorized as nonstructural and structural methods. Nonstructural practices for low-density residential development include routine septic inspection and pump-outs and management of pet waste as well as manure from domestic animals. For urban areas, management of pet waste and regular inspection of sewer lines for leaks reduce unexpected releases of feces into rivers and streams. Structural best management practices include buffers, constructed wetlands, sand filters, infiltration trenches, low-impact development, and stream fencing. Examples of low-impact development include permeable pavers, retention areas, grass swales, rain gardens, and minimizing impervious surfaces to increase runoff infiltration, storage, filtering, evaporation, and onsite detention (*public communications*, Low-Impact Development [LID], www.EPA.gov/owow/nps/lid/). Although these practices reduce bacteria in surface water, further studies are needed to evaluate their effectiveness.

Halogenated Hydrocarbons. Halogenated hydrocarbons are hydrocarbons that contain one or more atoms of chloride (Cl), bromide (Br), or fluoride (F). These are one of the largest and most important groups of toxic organic contaminants and are linked to adverse effects on aquatic life and human health including cancer, reproductive health, and nervous and immune system problems (Miller and Miller 2007). Sources of halogenated hydrocarbons include solvents, cleansers and degreasers, pesticides, electrical equipment, and commercial products. Trichloroethylene (TCE) and chloroform are examples of halogenated hydrocarbon solvents. Prominent examples of halogenated hydrocarbon pesticides are dichloro-diphenyl-trichloroethane (DDT) and 2,4-dichlorophenoxyacetic acid (2,4-D). Polychlorinated biphenyls (PCBs) are also chlorinated hydrocarbons often used in electrical equipment. Although polychlorinated biphenyls (PCBs) have been banned in the United States since the 1970s, high levels are still found in river and lake sediments owing to their continued use in equipment, their slow degradation rate, and persistence in the environment (Miller and Miller 2007). Dichloro-diphenyl-trichloroethanes (DDTs) were also banned in the 1970s and take a long time to break down and tend to accumulate and bio-magnify in biota. The persistence of these chemicals was highlighted in a recent national survey of surface and groundwaters. The study detected banned (DDT, PCB) and newer organochlorine compounds (chlordane, dieldrin) in fish and bed sediments in most streams in the United States. In addition, at least one type of pesticide was detected in 90% of the surveyed streams and in 50% of the groundwater wells (Gilliom 2007; Gilliom et al. 2007).

A few studies have evaluated the relationships between land-use intensification and particle-associated and water-associated halogenated organic compounds. They indicate that concentrations of halogenated hydrocarbons increase with the percentage of commercial, industrial, and transportation land use (CIT) in a watershed. Along a rural-to-urban gradient in the northeastern United States, for example, Chalmers, Van Metre and Callender (2007) found higher concentrations of halogenated hydrocarbons in sediments in areas with a higher percentage of CIT land use. Land-use impact models generated from this research suggest that converting from rural to suburban land uses results in a twofold increase in DDT and PCBs;

conversion from suburban to urban land uses leads to a three to fourfold increase (Fig. 9.2) (Chalmers, Van Metre and Callender 2007). Despite the high occurrence of chlorinated hydrocarbons in stream sediments, surveys of urban and reference lake sediment cores (lakes are used as long-term historical records for the deposition of compounds) show that concentrations of DDT and PCBs are declining over time across the country. This suggests that sources of DDT and PCB in the environ-

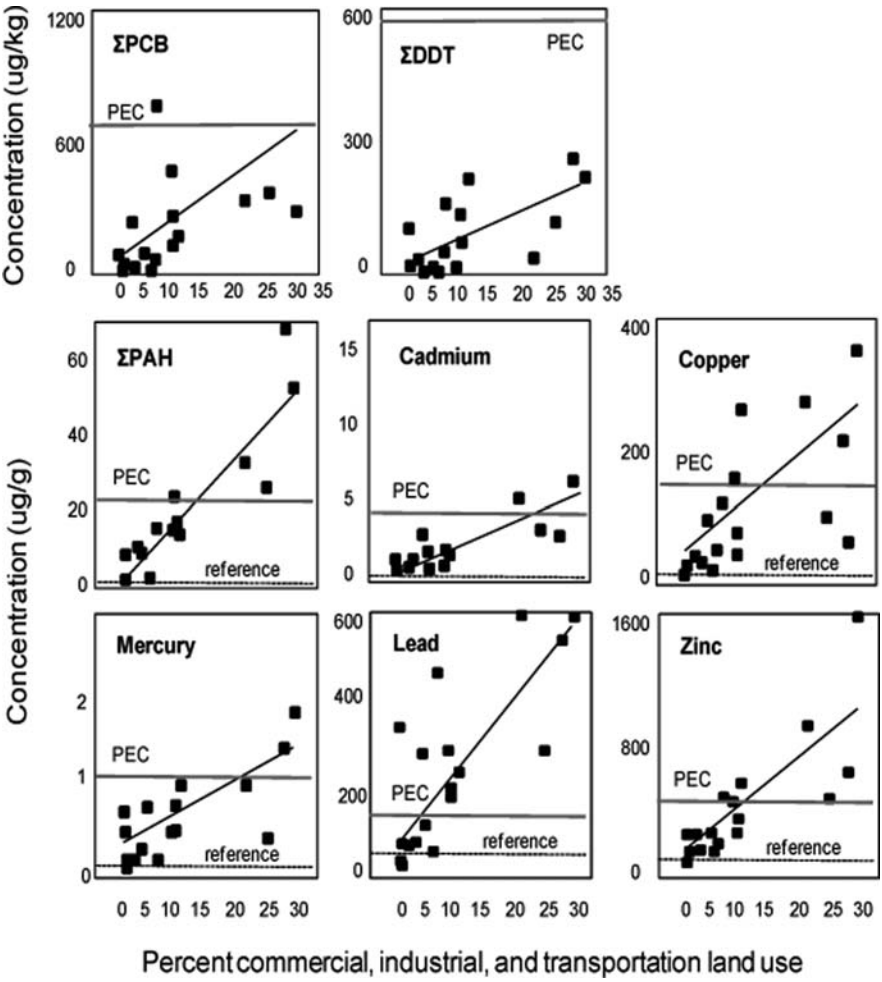

Fig. 9.2 Impact of percent of watershed in commercial, industrial, and transportation land uses (CIT) on metals and organic compounds in sediments in the northeastern United States. *Solid horizontal lines* indicate the probable effect concentration (PEC), and *dashed lines* indicate reference concentrations. The CIT threshold occurs at the interaction of the slanted regression line and the PEC line. Thresholds are exceeded beyond the intercept (adapted from Chalmers, Van Metre and Callender 2007)

ment are generally decreasing as they are phased out and eventually degrade (Van Metre, Callender and Fuller 1997; Van Metre et al. 1998; Van Metre and Mahler 2005). Nonetheless, these studies highlight the persistence of halogenated hydrocarbons in the environment; once released, these compounds persist for decades to centuries.

The occurrence of other halogenated hydrocarbons such as pesticides and herbicides in surface and shallow groundwaters is also high in undeveloped-to-urban areas. Pesticides were detected in 97% of the surface water and 55% of the groundwaters sampled in urban areas (Gilliom et al. 2007). Surprisingly, the same study also detected pesticides in 65% of surface waters and 29% of groundwaters in undeveloped watersheds. More than half the fish sampled in undeveloped watersheds contained organochlorines, indicating deposition and persistence of these compounds in the environment. In another study of six metropolitan areas, insecticide concentrations increased significantly with increasing urban cover in low-flow conditions, whereas herbicides increased with increasing urban cover in three of the cities (Sprague and Nowell 2008). Large agricultural influences in the other three cities appeared to explain herbicide patterns in stream flow.

Best management practices for reducing halogenated hydrocarbons in urbanizing areas include nonstructural and structural approaches. Examples of structural practices include reducing halogenated hydrocarbon pesticides and insecticides or using non-halogenated hydrocarbon pesticide and insecticides. Inspection of older electrical equipment and phasing out of older and/or leaking equipment that may contain PCBs are also advised. Structural practices include LID methods and others described previously in the "biological pathogen" section.

Polycyclic Aromatic Hydrocarbons. In contrast to PCBs and DDTs that appear to be declining over time, polycyclic aromatic hydrocarbons (PAHs) are on the rise (Van Metre and Mahler 2005). Polycyclic aromatic hydrocarbons originate from natural and anthropogenic combustion of organic material, including fossil fuels burned by automobiles, power plants, and heating facilities, and are potentially carcinogenic. They are also found in creosote, roofing tar, and asphalt sealant (Mahler et al. 2005). Indeed, coal-tar-emulsion-based and asphalt-emulsion-based sealcoats were recently identified as prominent sources of PAHs. These sealants are used by many homeowners to coat driveways and are applied to parking lots in businesses, apartments, condominium complexes, churches, schools, and industrial parks. Mahler et al. (2005) found much higher PAHs in runoff from parking lots sealed with coal-tar-based sealcoat compared to those covered with asphalt-based sealant. The average PAH concentrations in runoff from coal-tar-sealed parking lots were 3,500 mg/kg – 65 times higher than concentrations in particles from parking lots not seal coated (54 mg/kg). Average concentrations in particles from asphalt-based sealcoat were lower, 620 mg/kg. The concentration of total PAHs in sediments likely to adversely affect aquatic organisms, or the PEC, is 22.8 mg/kg (Mahler et al. 2005). Together, these findings suggest that streams receive PAHs from new development, associated vehicular traffic, and driveway sealants.

Since PAHs are produced as byproducts from partial combustion of fossil fuels and other products, several studies have examined atmospheric transport distances of PAHs and PCBs. In general, PAHs and PCBs tend to decline with distance from urban areas due to lower emission rates. However, persistent gas-phase PAHs, often alkylated PAHs, increase from urban to rural locations (Gingrich and Diamond 2001). These persistent gas-phase compounds can travel as far as 50 km, whereas more reactive gas-phase and particle-phase compounds often travel shorter distances, <5 km (Gingrich and Diamond 2001). Impacts of the atmospheric transport of PAHs are visible at the urban fringe (areas experiencing rapid urban sprawl), where rapid increases in PAHs in lake sediments have been linked to increased automobile commuting (Van Metre, Mahler and Furlong 2000). These findings suggest that urban and exurban growth adversely impact water quality within a watershed due to significant increases in traffic to-and-from urban centers.

Like PBCs and DDTs, polycyclic aromatic hydrocarbons have also been strongly correlated with the percent of commercial, industrial, and transportation (CIT) land use in a watershed (Fig. 9.2). Based on their land-use impact model from the northeastern United States, Chalmers, Van Metre and Callender (2007) predict that PAHs will increase by a factor of six when a rural site becomes suburban, and increase by a factor of five when the suburban sites becomes urban. Their model also predicts that the PEC for PAHs will be exceeded at 13% CIT. Research in other regions of the country is warranted, but this study provides evidence for upward trends in PAHs with land-use intensification. Based on these findings and the upward trend in PAHs in urban lake sediment cores (Van Metre and Mahler 2005), it is expected that PAHs will likely surpass chlorinated hydrocarbons as a threat to human health and aquatic biota in streams and lakes in the coming decades.

Polycyclic aromatic hydrocarbons are emerging as threats to human and aquatic health. The sources of PAHs include atmospheric deposition from incomplete combustion of fossil fuels as well as watershed sources such as asphalt sealants. Reducing atmospheric sources of PAHs such as vehicular traffic remains challenging and will require transportation alternatives and stricter controls on urban sprawl. On the ground, planners, watershed managers, developers, and individual homeowners can apply best management practices to reduce watershed sources of PAHs by reducing or eliminating driveway sealants and/or finding alternative sealants. Structural practices described above can also reduce delivery of PAHs to streams.

Other Organic Compounds. Many organic compounds, such as pharmaceuticals, hormones, and other organic wastewater compounds, are not currently regulated by the EPA and cannot be readily removed by wastewater treatment or septic systems. A recent national survey of 139 streams revealed that organic contaminants including pharmaceutical, hormones, and other organic wastewater compounds (OWC) were detected in 80% of the rivers sampled (Kolpin et al. 2002). Most frequently detected compounds included coprostanol (fecal steroid), cholesterol (plant and animal steroid), *N*,*N*-diethyltoluamide (insect repellant), caffeine (stimulant), triclosan (antimicrobial disinfectant), tri(2-chloroethyl)phosphate (fire retardant), and 4-nonylphenol (nonionic detergent metabolite) (Kolpin et al. 2002). The impact of these individual compounds and their interactions with aquatic and human health remain unclear, thus indicating the need for further research.

Nutrients

Nutrient concentrations have increased in rivers throughout the United States and the world (Howarth et al. 1996; Mueller and Spahr 2006). Nonpoint sources of nitrogen (N) and phosphorus (P) dominate surface waters (Howarth et al. 1996; Carpenter et al. 1998; Caraco and Cole 1999) and are highly correlated with population density and net anthropogenic inputs to watersheds. Dominant sources of nitrogen (N) include fertilizers, atmospheric N deposition, food and animal feed imports, and biological N fixation in leguminous crops. Because P and sometimes N can limit productivity of surface waters, one of the main impacts on nutrients occurs through the process of eutrophication whereby lakes, reservoirs, and sometimes rivers have excess algal or plant growth which leads to degradation of water bodies. High levels of nitrate (>10 mg/L nitrate-*N*) in surface and groundwaters can also have human health consequences because it interferes with the ability of blood to carry oxygen, particularly in infants.

A growing body of research indicates that nutrient concentrations and loads in rivers increase with land-use intensification. A national survey of streams and rivers (Mueller and Spahr 2006) found that concentrations of all nutrients (total nitrogen, total phosphorus, nitrate, orthophosphate) were significantly higher in partially developed watersheds than in undeveloped watersheds, but significantly lower than in more developed agricultural, urban, and mixed land-use watersheds. Other studies have shown similar patterns at smaller spatial scales (Groffman et al. 2004; Lewis and Grimm 2007). The impact of exurban development on nutrient loading to rivers is most apparent in mountainous headwater catchments experiencing rapid development, such as those in Colorado. In these water systems, exurban development is linked to increases in dissolved inorganic nitrogen in streams during spring melt; 19–23% of this nitrogen is believed to come from septic systems (Kaushal, Lewis and McCutchan 2006). Increased nitrate export from these headwater catchments indicates limited biotic capacity to take up N, suggesting that they are particularly sensitive to development. Kaushal, Lewis and McCutchan (2006) indicate that because much of the world's population relies on water originating from mountainous areas, even modest levels of nutrient enrichment cascade to downstream water supplies and potentially affect a growing number of people.

Metals

Trace metals are found in very low concentrations in nature, and include arsenic (As), silver (Ag), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), zinc (Zn), and others. Several of these metals are essential for plant and animal lives at low concentrations but become toxic at higher concentrations (Miller and Miller 2007). Trace metals enter terrestrial and aquatic ecosystems through atmospheric deposition and point and nonpoint sources. Atmospheric deposition is an important source of trace metals, particularly for Hg and Pb. Indeed, some studies suggest that nearly all the Hg in water, sediment, and fish is explained by atmospheric deposition (Sorensen et al. 1990). Point and nonpoint sources of trace metals include mining byproducts, chemical waste, coal and industrial waste, metal plating, and plumbing materials.

Like organic compounds and nutrients, trace metals are highly correlated with population density and percent commercial, industrial, and transportation land use (CIT) (Fig. 9.2). For example, the sum of trace elements (Cu, Pb, Hg, Zn) in streambed sediments is highly correlated with population density (Rice 1999), and anthropogenic Pb and Zn concentrations can be accurately predicted by population density (Callender and Rice 2000). However, the spatial distribution of Pb and Zn depends on the timing, or period of development; removal of leaded gasoline in the late 1970s led to declines in lead, and increased vehicular travel kept Zn concentrations high in runoff and sediments. Consistent with these spatial observations, declines in lead are observed in long-term lake sediment records, whereas high Zn concentrations are found in recent exurban development because of high vehicular traffic (Mahler and Van Metre 2006). Chalmers, Van Metre and Callender (2007) suggest that metal concentrations double when a rural site is converted to suburban land uses, and triple again when the suburban site is intensified and becomes urban (Table 9.1and Fig. 9.2). Finally, concentrations of metals are predicted to exceed PEC standards between 3% CIT for Pb and 10–25% CIT for Zn, Hg, Cu, and Cd.

Best management practices include reducing sources of metal by lowering vehicular use and traffic. Elimination or use of alternative, nonmetallic, chemicals for timber treatment and preservation also reduces metals in watersheds. In addition, structural practices that reduce delivery of metals to streams include, for example, LID methods. Finally, more transformative planning options that reduce metals in watersheds include transferring development rights in undeveloped watersheds to more developed watersheds already impacted by metals and other contaminants.

Sedimentation

Numerous studies have linked in-stream sedimentation to upland landscape elements and land-use change in watersheds (e.g., Richards, Johnson and Host 1996; Wohl and Carline 1996; Sutherland, Meyer and Gardiner 2002; Opperman et al. 2005). Agricultural and urban land uses are often considered key drivers that increase fine sediment production and delivery to streams (Waters 1995; Pimentel and Kounang 1998). Compared to land with native plant cover, croplands often have significantly higher rates of sediment production, even on moderate slopes due to the amount of bare soil exposed to rain and sheet wash (Dunne and Leopold 1978; Chang, Roth and Hunt 1982; Pimentel and Kounang 1998), and indirectly to higher rates of runoff that speed incision and bank erosion (Chang, Roth and Hunt 1982). Construction in urban areas emits large quantities of fine sediment, and bank erosion produces sediment over long time periods (Trimble 1997; Pizzuto, Hession and

McBride 2000). Less is known, however, about the impacts of different land uses (especially in exurbia) on sediment production and delivery to streams. We address this issue in the case study described below.

Summary of Urban Land-Use Impacts

Urbanization dramatically increases the occurrence of organic pollutants as well as nutrients, metals, and sediments in streams (Chalmers et al. 2007; Table 9.1). Predictions indicate that in most cases the intensification of rural (exurban) lands to higher density suburban uses doubles the concentration of contaminants, with the exception of PAHs which are estimated to increase sixfold. The subsequent intensification of suburban land uses to urban uses (higher densities) is expected to increase contaminants three to fivefold. Once the quantity of commercial, industrial, and transportation land use in a watershed exceeds 15%, contaminants in sediments will likely exceed the probable effect concentration (PEC) and adversely impact aquatic and possibly human health (Chalmers, Van Metre and Callender 2007). Similar studies are underway in the rapidly urbanizing desert southwest – in Tucson and Phoenix – but research in other regions is sorely needed.

Planners and watershed managers should implement best management practices that reduce the buildup of contaminants resulting from land-use intensification. The most effective way of reducing watershed contamination is to avoid it in the first place. Developers and homeowners, for example, should avoid PAH-containing driveway sealants and advocate for PAH-free alternatives. Structural practices can reduce the delivery of contaminants to streams once they are introduced into the environment. Finally, there are more transformative options available to planners, conservationists, and watershed managers. One of these options involves the use of coupled land-use impact/land-use change models and the Transfer of Development Rights (TDRs) to protect sensitive land (see Chapter 13 for discussion of TDRs). This approach is described below.

Land-Use Impacts and Watershed Planning: The Russian River Basin, California

The research summarized above shows the relationship between land-use intensification and increases in watershed contamination. While best management practices lessen degradation somewhat, planners, developers, and watershed managers benefit from understanding the specific impacts of various land intensification scenarios. In many cases, however, policy makers and analysts have limited knowledge of how different types of land use, especially low-density exurban housing, affect stream and groundwater quantity and quality. The problem arises because tools that detect and quantify exurban development, such as commonly used remotely sensed imagery (e.g., Landsat), cannot adequately distinguish differences in housing density. Consequently, exurban development is often excluded from models and risk assessments. This omission is critical in view of the pace and scope of exurban residential development in the United States and abroad. Additionally, the extent to which all types of land-use change will impact future water quantity and quality is often unclear. Together, these factors hinder predictions of how watersheds will respond to future land uses and other unforeseen interactions (Nilsson et al. 2003).

Coupled (or linked) land-use impact/land-use change models have emerged as powerful decision-support tools for watershed managers and planners. They inform stakeholders of the trade-offs associated with various land-use policies and guide conservation planning accordingly. Coupled models are especially valuable when manipulating the human–environmental system is difficult and outcomes uncertain (Peterson et al. 2003). Even so, the ability to integrate these models is challenged by entrenchment along disciplinary lines (hydrologists, geomorphologists, and ecologists on one hand, and planners and economists on the other) and requires a truly multidisciplinary approach (Nilsson et al. 2003). These barriers are overcome by emphasizing interdisciplinary environmental science and the use of new modeling methods and source data that improve reliability and accuracy.

While a full description of the coupled land-use impact/land-use change model is beyond the scope of this chapter (see Lohse et al. 2008 for a full discussion of the model and data requirements), we summarize the modeling procedure and demonstrate its contribution to land-use planning and watershed management. Development of the coupled land-use impact/land-use change model follows four interdependent steps: (1) quantifying relationships between land use and water quality/quantity (land-use impacts); (2) developing land-use-change scenarios that forecast likely outcomes; (3) developing economic valuation models; and (4) integrating these models (land-use impacts, land-use change, and economic valuation) to evaluate environmental and economic trade-offs. Data for the coupled models come from a variety of sources, but it is noteworthy that the use of parcel-level data enabled detection of the impacts on watersheds associated with different housing densities and other land uses. Thus, unlike other modeling and risk assessments, we were able to single out low-density exurban residential development.

Northern California's Russian River Basin, located in Sonoma County, is ideally suited for the case study. Like many regions rich with natural amenities, it is confronted with land-use conflicts and environmental risks as human development encroaches further into the countryside (Grantham et al. 2008). Ensuring adequate water quality and preserving fish habitat rank high on the list of concerns. Faced with these problems, planners and watershed managers seek answers to tough and controversial land development decisions. In this regard, the coupled land-use impact/land-use change model serves as a valuable decision-support tool.

The modeling exercise sought to analyze the impacts of three land uses (urban, exurban, and vineyard development) on levels of fine sediment in streams. We distinguished between urban (<1 acre per dwelling) and exurban (1–40 acres per dwelling) because housing densities of 1 acre per dwelling are the typical limit on residential development serviced by septic systems (Newburn and Berck 2006). Intensive agriculture in these watersheds consisted almost exclusively of vineyards.

Fine sediment is one measure of water quality that reduces habitat suitability for spawning salmonids. Data on fine sediment levels were included for 93 watershed reaches with an average of 54 spawning sites per reach. Finally, land-use conversion, or intensification, was defined as any transition of developable parcels to vineyard, urban, or exurban development during the period 1994–2002. Our future development scenario spanned the 2002–2010 period. We forecasted the amount of land-use change under a "business-as-usual" scenario; however, other scenarios can be investigated as well.

Figure 9.3 shows the study area and the amount of development in each of the 93 watersheds. Developed lands are placed into four categories, with lighter shades indicating watersheds with the least amount of development, and darker shades indicating the most development. Figure 9.3 also shows the anticipated change in water quality with future land development. These impacts are ranked on a four-point scale, with darker colors (vertical bars) indicating the most severe impact to spawning habitats (substrate quality). It is noteworthy that predicted impacts on water quality are frequently (but not always) found in areas with the highest levels of urban development.

The coupled models produced valuable information that promotes conservation-minded land development. We found that anticipated rural-residential and vineyard developments will influence water quality more than higher density urban land uses. Our estimates indicate that exurban residential land use and vineyards will grow tenfold during the target period (through 2010) when compared to higher density urban uses. Our forecasts found that urban development will concentrate in the most developed watersheds, which already suffer from poor spawning substrate quality. Our findings also suggest that conservation should target moderately and less-developed watersheds to meet the goal of protecting water quality for salmonid-spawning habitat. It is not surprising that future exurban residential development and vineyards pose the greatest threat to high-quality fish habitat in these watersheds. In contrast, conservation should not be directed to the most developed watersheds, where land prices typically are much higher; and land-use development, particularly urban development, has already led to significant habitat degradation.

Armed with these results, policy makers can influence the density and location of future residential development through local zoning and other regulatory devices. For example, implementing a Transfer of Development Rights (TDRs) Program can assist conservation by guiding the location of development. In this case, TDRs can be used effectively to curtail lower-density rural-residential development within moderate- and less-developed watersheds ("sending" areas in light gray of Fig. 9.3), while encouraging higher density infill development in areas already highly disturbed ("receiving" areas in dark grey watersheds of Fig. 9.3). The TDR can be buttressed with construction control techniques, best management practices for road construction and maintenance, and other low-impact development (LID) strategies that minimize impacts on sensitive watersheds.

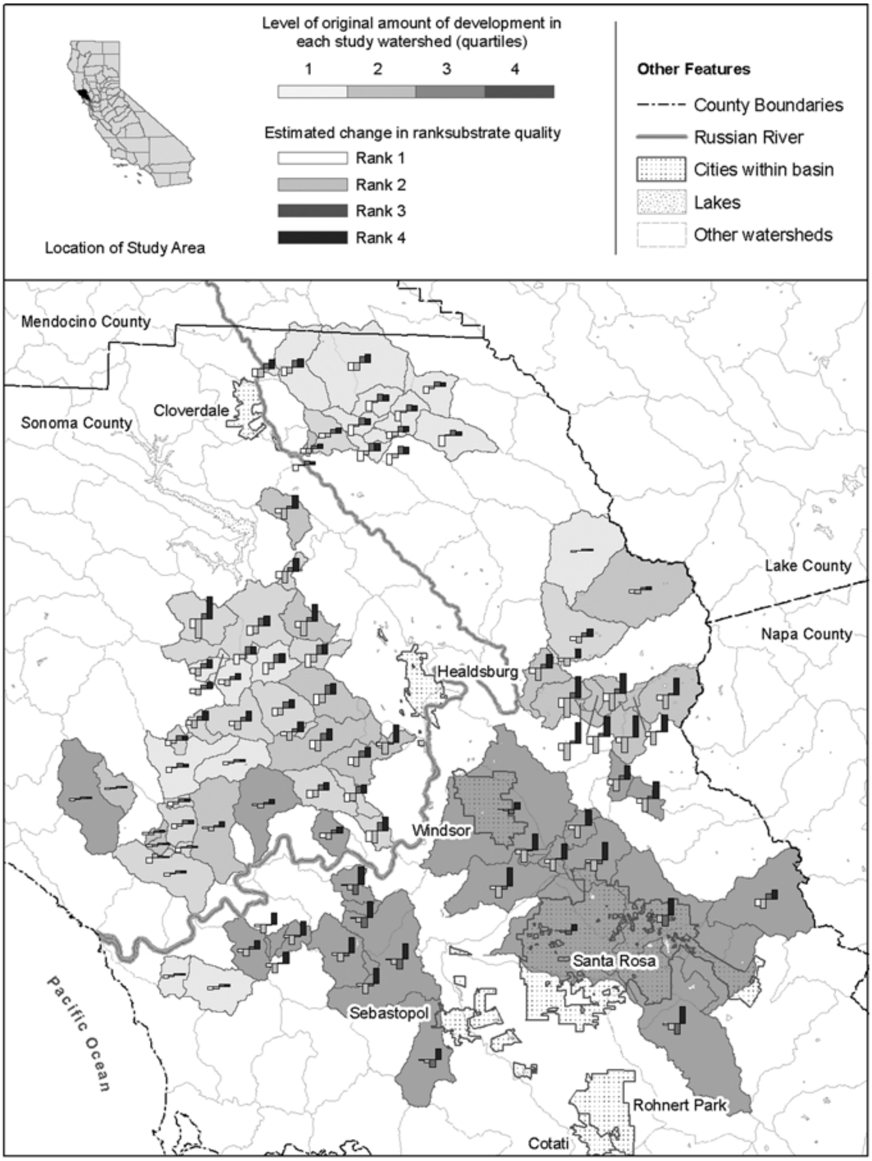

Fig. 9.3 Watersheds studied in the Russian River Valley of California. *Lighter shades* indicate less development; *darker shades* more development. *Vertical bars* indicate the severity of watershed impacts resulting from future development. Source: Kathleen Lohse and Adina Merenlender

Conclusion

This chapter examined the impacts of urbanization on water quality, with particular emphasis on the expansion of housing development beyond the urban fringe. A review of the literature indicates that land-use intensification along the rural-to-urban gradient increases the occurrence of organic pollutants, as well as nutrients, metals, and sediments in streams, with potentially adverse effects on stream biota and humans. The main drivers appear to be increased population density, road construction, and vehicular traffic which result in deposition and fluvial transport of metals and organic pollutants to streams and sediments. Exurban development and associated roads also extend possible land-use impacts by increasing nutrient and fecal bacteria inputs to streams through leaking septic systems and increased vehicular traffic, both of which result in increased nitrogen inputs to watersheds.

We used a case study from the Russian River Basin in California to illustrate how modeling methods can guide conservation planning and development. In the case study, we developed a land-use impact model to predict the consequences of urban and exurban developments on sedimentation in streams that support rare salmonids. We then coupled this model with a land-use change model to predict where conversion to exurban and urban developments would take place. With both models, we differentiated between exurban and urban residential land uses because they represent different types of growth and impose distinct impacts on substrate quality in streams. We showed that exurban development has a greater potential for affecting water quality because of its ability to "leapfrog" into previously undeveloped areas, an outcome that transfers easily to other environmental settings.

There is little doubt that water quantity and quality will become an increasingly important issue worldwide as population growth, land development, and other anthropogenic factors impinge on natural environmental systems. This suggests that conservation-minded land-use planning will become even more important in the years ahead. Coupled land-use impact/land-use change models are one way of improving land-use planning because they can be used to evaluate alternative land development scenarios. The importance of scenario planning (and engaging communities in the process) is widely recognized (Hopkins and Zapata 2007), especially the ability to connect conservation and land-use planning. By doing so, scenario planning can minimize unintended consequences as future development alters and or threatens ecosystem functions that support aquatic and human lives.

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Chapter 10
Preparing for Human Expansion into Exurban Riparian Areas

Ann Audrey, Mark Briggs, and Kendall Kroesen

Abstract Water, vegetation, and wildlife concentrate in the wetlands and riparian areas of the exurban environment. This chapter describes the impacts of exurban development on the life forms and functions of these vulnerable systems. Strategies for reducing negative impacts are also discussed, including the selection of appropriate development density, spatial distribution, infrastructure construction and location, and wastewater and storm water management. The role of conservation and mitigation efforts in maintaining wetlands and riparian habitat is described, including land set asides, native plant protection, restoration of degraded habitat, and the mitigation of on- and off-site development impacts.

Introduction

The lush vegetation and allure of water in riparian areas is attractive to wildlife and people. Riparian areas perform myriad functions that benefit both. But riparian areas have been hit hard by human development. Over half the available river runoff in the world is used by humans and over three-quarters of the largest rivers in the northern latitudes are heavily fragmented by human alterations. In the lower 48 states, nearly all of the largest rivers are severely altered (for power or navigation) and in the United States only 2% of waterways still have high water quality. This has severed the connection between streams and floodplains with devastating consequences for natural resources important for humans and wildlife (National Research Council 2002).

When riparian areas constitute significant obstacles to development, watercourses may be rerouted, lined with concrete, or run underground through pipes to increase the supply of developable land. These modifications allow development

A. Audrey (✉)
City of Tucson Office of Conservation and Sustainable Development,
Tucson, AZ 85726-7210, USA
e-mail: ann.audrey@tucsonaz.gov

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to move ahead but result in the loss of riparian habitat and natural hydrologic function. This chapter focuses on accommodating human expansion into exurban riparian areas while maintaining riparian characteristics and functions that are pivotal to both human and ecological well-being. Seeking this fragile balance echoes the words of Aldo Leopold who many years ago wrote:

> When we see land as a community to which we belong, we may begin to use it with love and respect. There is no other way for land to survive the impact of mechanized man, nor for use to reap from it the esthetic harvest it is capable, under science, of contributing to culture (Leopold, 1966, pp: xviii–xix).

Leopold's sentiments foreshadowed the work of many others in the last half of the 20th century, from Rachel Carson (1962) to E. O. Wilson (1992), who weighed in on the intersection of the natural world, science, and ethics. This chapter supports that work by attempting to bridge the gap between the science of riparian ecology and the challenge of making land-use decisions that affect riparian areas.

The intended readers of this chapter are "planners," broadly defined as those people and entities who, through elected office, government work, business endeavors, nonprofit efforts, or other mechanisms determine the interface between human activities and exurban riparian areas. This interface is referred to here as "development," which for present purposes typically means residential and commercial development related to urban and suburban expansion. The term "exurban riparian area" is used here to refer primarily to streams and rivers and the relatively high-water-use vegetation that grows along their banks.

The idea of managing riparian areas stretches the concept of "management" because they are among the most dynamic and least manageable environments on Earth. Human modification that initially affects one dimension of riparian areas, such as floodplain breadth, will likely affect flood velocity, sediment transport, channel depth, and plant and wildlife diversity. Human management of these environments has led to dramatic impacts ranging from desertification (e.g., California's Owen's Valley) to the Mississippi River flowing at a higher elevation than the city of New Orleans.

It appears inevitable that a portion of today's wild rivers and their associated riparian areas will be surrounded by tomorrow's exurban development. Theobald (2005) predicts that exurban development will expand 14.3% by 2020 compared to 2.2% for urban and suburban housing, and Compas (2007) predicts that a significant portion of residential development will take place in or near riparian areas. This is not surprising as riparian ecosystems that are intact and whose ecological condition has not been compromised significantly offer a variety of benefits to residents and visitors, including flood control, groundwater recharge, water quality protection, plant-based resources, wildlife habitat, navigation, aesthetics, recreation, and others. All these benefits can be diminished, even lost, once riparian areas are degraded by human activities.

With foresight, expansion of human settlement can be designed to accommodate people while minimizing negative impacts to important riparian areas. By its nature, this balance includes some loss of riparian resources because development cannot occur without impact. Watercourses in developed areas need to be crossed and some land holdings will be undevelopable if impacts are avoided altogether. Ultimately, this is an exercise in making trade-offs between development and loss of riparian habitat, certainly an unenviable position for those involved with decision making. But the more informed planners are, the better equipped they will be to make these difficult decisions.

This chapter sets forth a series of principles in preparation for human settlement of exurban riparian areas. These principles guide planners through a proactive process of building knowledge and conducting planning in a regional institutional context that anticipates and prepares for both near- and long-term growth.

Guiding Principles

Riparian systems across the country vary dramatically with climate, elevation, geologic conditions, latitude, and with continual (though not necessarily constant) changes in such independent variables as sediment load and discharge. Yet there are characteristics, values, and threats common to many of these systems. Understanding this information in a given region provides a strong baseline for planning and is critical to making decisions about the future of specific riparian sites within these regions.

To achieve the best possible outcome during development, case-by-case decision making should be embedded in long-term regional analysis and planning. Regional planning, in turn, should anticipate future growth pressure on riparian areas and proactively prepare by prioritizing riparian protection needs and describing appropriate locations for different types of development. A set of guiding principles goes far in promoting conservation while accommodating growth.

Principle 1: Review the Science

Characteristics and Functions of Riparian Areas. Riparian areas have been described as “the vegetation, habitat, or an ecosystem that is associated with bodies of water (streams or lakes) or is dependent on the existence of perennial, intermittent, or ephemeral surface or subsurface water drainage” (Arizona Riparian Council 1986). Although the characteristics of riparian areas differ spatially and temporally, they share the presence of unidirectional fresh water flow, the distinct life forms that live alongside it, and a startling degree of complexity. Intact riparian areas are complex because they concentrate dynamic physical elements in a relatively small space.

Riparian ecosystems are generally associated with streams and rivers. Flow in these settings may be perennial, intermittent, or ephemeral. Perennial streams and rivers have a constant flow while intermittent streams flow part of the year, usually in response to both groundwater discharge and storm water runoff. Ephemeral streams flow only in response to storm water runoff. Perennial streams may be "gaining" or "losing" streams. That is, streams may experience increased flow due to groundwater discharge into surface flows. In contrast, infiltration of surface flow into the ground may decrease stream flow. In heavily forested areas significant amounts of rainfall may infiltrate into highly organic soils, and many intermittent or perennial streams may be generated by discharging groundwater. In more arid areas stream flow frequently consists of ephemeral runoff that enters losing streams (washes) and sinks into the ground as it moves along the channel (National Research Council 2002). This infiltration is sufficient to support riparian ecosystems along desert washes.

Many rivers flow perennially in response to large networks of upstream ephemeral, intermittent, and perennial streams that feed into them. This upstream network of "lower order" streams generally receives both storm water runoff and groundwater discharge, all of which contribute to perennial flows downstream in "higher order" rivers (National Research Council 2002). In more arid areas intermittent and perennial rivers may depend on groundwater for their perennial flow, augmented at times by storm water. Lowering of groundwater resources through pumping or erosion can reduce or eliminate perennial surface flow in these situations (Logan 2002). Regardless of the river, groundwater discharge points in rivers often produce areas of greater biodiversity. This is due to consistent water availability, more stable vegetation, and less varying water temperature.

Riparian ecosystems take on many forms and are characterized by a variety of plant communities. Riparian ecosystems can be narrow, with abrupt transitions between the riparian and upland plant communities, or broad, with the riparian zone extending for hundreds of meters from the stream channel. Changes in elevation appear to be the most significant factor associated with the distribution of riparian plant communities and their species composition (Szaro 1989).

One of the key characteristics of riparian areas is the diversity of landforms found within them. Movement of water creates networks of channels separated by islands. Moving water deposits sandbars, creates terraces and leaves oxbow lakes on wide floodplains. These landforms are built of sediments that are transported through, or deposited on, the riparian area. Sediment enters a riparian system in lower order riparian zones, often in upland areas. It is transported through middle-order streams and then deposited in lowland floodplain zones (Ward, Tockner and Schiemer 1999). The storage of overbank flow is related to landform diversity. When flood flows spread across floodplain soils that are not normally saturated, some water infiltrates and other water is trapped and detained in low-lying areas. Some infiltrated water may later discharge from riverbanks into surface water flows or reach the aquifer. Other water may be taken up and transpired by vegetation. The overall effect of varied landforms, soils, and vegetation in riparian areas, and the attendant storage of flood flows, is attenuation of downstream flooding via spread, storage, and velocity reduction of storm water. This is a key function of riparian floodplains.

"Biochemical transformations" occur in riparian areas as the constituents in water cycle through sediments, soils, and organisms. This means that riparian areas play an important role in dealing with pollutants. Nonpoint source pollution is the major source of water pollution in the United States (U.S. Environmental Protection Agency 2007). Much attention is paid to waterborne pollutants in large rivers, but much of the transformational filtering of pollutants occurs in ephemeral and smaller streams. A relatively high percentage of the water in these streams interacts with the riparian area, whereas in large rivers much of the water does not contact riparian resources. Moreover, prior to reaching large rivers, much water has passed through smaller riparian streams and experienced remediation of water quality (National Research Council 2002). Thus, the health of a vast network of riparian streams is important for water quality in larger rivers.

Riparian areas are some of the most biologically productive ecosystems in North America (Johnson and Jones 1977; Johnson and McCormick 1978). This is particularly true in arid areas. In the western United States, riparian areas claim less than 1% of the total land, yet in Arizona and New Mexico 80% of all animals use riparian areas at some point in their lives (Chaney, Elmore and Platts 1990). Riparian areas are also among the most endangered ecosystems, along with the wildlife that depends on them. For example, 70% of threatened and endangered vertebrates in Arizona depend on riparian habitat (Johnson 1989).

The physical characteristics of riparian areas can vary immensely. Riparian areas may meander across a wide floodplain as with many Midwestern rivers or be deeply entrenched in a bedrock canyon such as the Colorado River in the Grand Canyon. Topography, soil, climate, and many other factors determine the physical characteristics of a riparian area. Riparian vegetation along with aquatic fauna (e.g., beavers) can affect the floodplain, which in turn cycles back to affect physical conditions in the riparian area.

Threats to Riparian Areas. Human alterations to riparian areas rarely produce positive ecological benefits, though negative effects are numerous. Development can change sediment transport regimes in a variety of ways. For example, hardscaping-covering the earth with concrete, asphalt, roofs-cuts off sources of sediment and increases the flashiness of runoff which, in turn, increases the erosive power of flow to evacuate channel alluvium, often leading to channel incision and other channel morphologic changes that are often deleterious to existing riparian biota. Flood control efforts in developing areas often include channelization, which is a form of engineering that reduces the frequency with which stream flow inundates surfaces immediately adjacent to the channel. Channelization typically involves straightening the channel and constructing levees along the channel course. As a result, the channel is artificially narrowed, connection with the rest of the floodplain is lost, and channel slope is increased. These morphologic changes often produce increased flow velocities along the affected reach, which, in turn, increases flow energies and the capacity of flow to evacuate sediment. This can produce channel degradation, often to the point of initiating channel incision.

Incision into valley alluvium leads to the formation of terraces (abandoned alluvial floodplains no longer affected by annual floods). Thus, incision changes the topography of the channel from broad and shallow as occurs when excess sediment is stored to narrow and deep (Wolman and Leopold 1957; Burkham 1976; Schumm, Harvey and Watson 1984; Harvey and Watson 1986). As flows are confined to the narrow incised channel, the stream becomes even more efficient at scouring its bed and banks (Elliott 1979; Van Haveren and Jackson 1986). Channel incision can significantly affect the amount of water available to riparian flora and fauna. As channel incision proceeds, the probability of floods inundating the valley floor decreases (Elliott 1979) and precipitation on the watershed spends less time in the fluvial system due to the lack of lateral dispersion onto adjacent floodplains (Glinski 1977). A decrease in travel time can also reduce aquifer recharge rates. Degradation of the channel bed also lowers the local water table to roughly the depth of incision in the main channel (Van Haveren and Jackson 1986). As a result, moisture availability is lessened, which can reduce the extent and distribution of native riparian flora and fauna. While channelization protects local infrastructure, flooding often increases downstream.

Sediment transport between rivers and banks facilitates the creation of floodplain soils, which are among the richest soil types and contribute significantly to agriculture. Severing the link between water and floodplain and altering sediment transport can have long-term negative effects on soil fertility (National Research Council 2002).

Dams also threaten riparian ecosystems. Seventy-five thousand dams have been built on the streams and rivers of the United States (Graf 1999). Riparian areas in lands inundated by dams are lost completely. Downstream effects are equally significant. These include sediment starvation, loss of flood flows, reduction of total flows, and general reduction of physical and biological functions. Dams are typically built in rural areas, some distance from human development. Regional planners are not often involved with planning dams, but they warrant careful attention nonetheless. Foremost, planners should pay close attention to development near existing dams and to areas downstream from them.

Exurban development that increases residential density reduces the survival and reproduction of many native species (Hansen et al. 2005; Smith and Wachob 2006). Native species density and diversity is often higher in riparian areas than in surrounding uplands, so development near, or in, riparian areas is of particular concern to native wildlife. Development both reduces and fragments wildlife habitat. It generally results in the creation of "islands" or "patches" of vegetation that support less biological diversity than undisturbed configurations, with consequences described in Chapter 5. For example, riparian areas act as corridors to facilitate animal movement, including both long-distance migration and local movements. These movements facilitate gene flow and therefore help maintain the genetic diversity of wildlife populations. Loss of connectivity can make areas impossible to repopulate once local populations have been lost.

Even when riparian floodplains maintain "normal" hydrologic function, development can introduce invasive plant and animal species. Bladed roadsides are notorious corridors for migration of invasive plants, and some nonnative decorative plants used in landscaping are invasive in riparian areas. Invasive plants often do well in disturbed areas, which are abundant in areas under development. Floodplain sediments moved by flooding can easily be colonized by invasive plants with an affinity for riparian areas.

Over the extended time frames that planning uses, riparian areas in some regions are changing due to global climate change (see Chapter 3). Global climate change appears at the regional and local scale, with enormous potential for driving major changes in terrestrial ecosystems (Intergovernmental Panel on Climate Change 2007). Recent and ongoing changes in regional climates suggest the importance of caution, research, and foresight when planning for the continued health, function, and aesthetic values of riparian areas.

The difficulty, expense, and uncertain outcomes of undertaking restoration of degraded riparian habitat are other long-range issues associated with planning beyond the metropolitan fringe. In riparian areas impacted by development, restoration efforts may range from difficult and costly to impossible to undertake in areas where floodplain characteristics have been altered substantially. It is always preferable to preserve riparian areas in place, rather than resorting to subsequent restoration that attempts to return necessary structures and functions.

For a more detailed account of riparian area characteristics, functions, threats, and management, readers are referred to the National Research Council's *Riparian areas: Function and Strategies for Management* (National Research Council 2002). While the Council's publication is worthwhile, no written introduction to riparian areas can substitute for on-the-ground research and monitoring of local riparian ecosystems in areas subject to future development. The following sections suggest a careful, long-term approach to planning for human settlement that is encroaching on exurban riparian areas. This approach also informs decisions concerning the proposed development of specific sites.

Principle 2: Understanding the Regional Planning and Regulatory Context

Regional Planning Context. Exurban lands may be designated as future growth areas by nearby towns and cities that seek physical expansion, often times through annexation. As such, both public and private regional-scale planning efforts provide an important context for making decisions about exurban riparian areas. Ongoing communication and information sharing between regional planning entities are essential. This interaction assists in understanding which plans take precedence over others, the similarities or differences in baseline planning data, compatibility or conflicts between plan recommendations, timing of plan implementation, and numerous other issues that arise when different entities plan for the same geographical location. Ongoing communication should result in identifying and developing synergies between these multiple planning endeavors.

Regional planning should be tailored to the unique characteristics of regions. This means that riparian planners should conduct their own research on target areas, investigate previous and ongoing planning efforts, and initiate communication with allied planning agencies at all levels of government. Numerous nongovernmental organizations (i.e., the Nature Conservancy, World Wildlife Fund) are also active in local environmental conservation. The studies and plans listed below are not exhaustive but exemplify the diversity of sources that inform planning for riparian conservation in exurban areas.

Studies that involve storm water management and flood control play a critical role in riparian conservation planning and contribute significantly to public health and safety (see Chapter 11). As development extends into exurbia, rooftops, roads, parking lots, and other impermeable surfaces overlay natural soils and vegetation. Studies reveal how these human modifications affect drainage patterns, alter runoff volumes, and evaluate changes in the quality, volume, velocity, and timing of water flow in watercourses. They also detail other potential impacts on exurban riparian areas caused by development.

Studies that target the movement of wildlife often complement planning for exurban riparian conservation because many species utilize riparian areas for some or all of their survival needs. However, the movement of wildlife across the broad landscape is increasingly hampered by human-built structures such as buildings, roads, and fences. Scientific studies (sponsored by governmental and nongovernmental organizations) document the impacts of these obstacles and identify how and where animal species move across the landscape, where they forage, seek shelter, and breed. Such information proves valuable in riparian conservation. Some species have been granted special conservation status at the state or the federal level. Their actual or potential presence in a region requires detailed analysis of the habitat, if and how species use it, and protections needed if development occurs. Preparation of detailed planning documents that address special-status species is required by various regulations (discussed below). Riparian areas play important roles in the life cycles of many special-status species and should be managed consistent with these plans.

Transportation plans look well into the future as they propose transportation networks in undeveloped areas. These transportation improvements may well affect riparian areas in many ways. Roads that cross or run parallel to watercourses often create impacts during construction and subsequent use. Streams and rivers are affected through the modification of channel bed and bank configuration, soil stability, stream flow attributes, sediment transport, stream water quality, and other characteristics. Vegetation is also affected as streets and roads alter biodiversity, especially through the introduction of nonnative species. More than anything, roads improve accessibility to outlying areas, which increases the human presence in riparian areas that were previously inaccessible.

Comprehensive plans are well known to planners but warrant a brief discussion because of their potential use in riparian conservation. These long-term plans are used by jurisdictions to identify overarching visions and goals for a community's future. One element of these plans addresses how the jurisdiction will manage natural environments, and riparian areas are often included. These sections of the comprehensive plan bring forward the community's perception of natural environments and emphasize the role that values play in guiding longer term development. It is noteworthy that if exurban riparian areas are slated for future annexation, the jurisdiction's comprehensive plan provides an overview of how currently undeveloped riparian areas will be managed. As Chapter 12 demonstrates, a community's long-term plan can be instrumental in promoting conservation on a variety of fronts, including riparian areas.

Master plans are not nearly as visible as comprehensive plans but have grown in popularity, especially in the western United States. Unlike comprehensive plans, which embody the aspirations of the community at large, master plans are prepared by developers and target specific large-scale, phased developments. These developments, in effect, constitute "new towns" that will house thousands of families and include a diversity of land uses (e.g., residential, commercial, and public). Master plans mimic comprehensive plans in that they include all elements of community life, a variety of land uses, transportation, infrastructure, flood management and control, recreation, and environmental conservation. These plans typically provide information about the management and conservation of riparian areas. These developments are subject to regulatory review by the jurisdiction in which the land is located and should comply with applicable riparian protection ordinances or standards.

Planners should also consult strategic plans that guide the development and management of natural resources in parks, preserves, forests, and other public open spaces. These plans are prepared by federal, state, and local agencies and are widely available online. Even though public land may not be subject to development, these plans are important because they document native flora and fauna, watercourse conditions, and other characteristics found in nearby exurban areas. Watercourses that connect public and private lands are especially valuable in planning for exurban riparian areas.

Regulatory Context. Many layers of regulations apply to riparian areas. These regulations originate at federal, state, and local levels of government. Planners and allied land development professionals should understand where different regulations originate and how they apply locally. While specific regulations vary, there are similar regulatory categories that apply to most areas. A thorough description of regulations applicable to riparian areas is available from *Riparian Areas: Functions and Strategies for Management* (National Research Council 2002). The brief summary of regulations below draws from this reference.

At the federal level, Section 404 of the Clean Water Act (CWA) addresses how materials may be moved (dredge-and-fill) within the jurisdictional limits of "waters of the United States." The U.S. Army Corps of Engineers is the federal agency that administers Section 404 of the CWA in regions across the country, including issuing permits and in some cases requiring mitigation for damages that result from dredge-and-fill activities. Section 303(d) of the CWA addresses creation of standards called Total Maximum Daily Loads (TMDLs) for point and nonpoint source pollution into waters that fail to meet state water quality standards. Establishing TMDL standards is a joint effort by the U.S. Environmental Protection Agency (EPA) and individual states.

The National Pollution Discharge Elimination Permit (NPDES) program addresses the water quality impacts of the release of storm water into waters of the United States. Water quality sampling and the implementation of Best Management Practices (BMPs) to improve the quality of storm water releases may be mandatory for jurisdictions subject to NPDES requirements. The NPDES program is administered by a state's environmental quality department if it has been delegated authority by the EPA.

Other federal legislation includes the National Environmental Policy Act (NEPA). The NEPA applies to projects in which federal actions may be detrimental to the environment. If a federal nexus exists on a project, analysis of the possible negative effects must be conducted and alternatives identified. Additional federal regulations that potentially affect riparian areas in some geographic locations include the Surface Mining Control and Reclamation Act, Coastal Zone Management Act, and Federal Power Act.

The federal government's Endangered Species Act (ESA) deserves special mention because riparian areas are home to many protected species. The ESA prohibits federal agencies from taking actions that potentially harm protected species or their habitat. Through Section 10 of the ESA, private lands may undergo development in areas that might impact protected species if agreed-upon conservation measures are instituted, as detailed in Habitat Conservation Plans (HCPs). The U.S. Fish and Wildlife Service (FWS) reviews and approves HCPs, which are prepared by local entities in anticipation of various kinds of development. Chapter 7 describes the use of HCPs in conversation planning.

State governments sponsor their own regulations. Foremost, states authorize local governments to regulate development in floodplains. Local jurisdictions typically prepare regulations that limit development and designate floodplain areas subject to regulation. Obtaining federal flood insurance is contingent on local and state regulations meeting a minimum federal standard for the "regulatory floodway and floodplain." Restricting certain types of development within floodplains prevents or reduces impacts on riparian vegetation. These state-level mandates are at times supplemented by local floodplain regulations that address impacts on riparian vegetation.

In addition to floodplain regulations, 49 of the 50 states have some regulations or guidelines that address impacts on forest buffers along streams. These specify widths of forested areas that should be protected to maintain a range of important functions for adjacent watercourses, including water quality treatment, reducing erosion, and absorbing runoff to attenuate flood peaks. Buffer widths vary from state to state, ranging from as little as 15 feet in Georgia to a range of 50–450 feet in Massachusetts. Other state-based regulations provide protection for various shorelines, riverfronts, deltas, and bays.

Although local regulations vary across the country, they are often instrumental in riparian conservation. In some cases, local regulations specify allowable land uses adjacent to water, including setbacks from the water's edge, with the aim of protecting riparian habitat. Through ordinances, codes, development standards, zoning, guidance documents, and other mechanisms, local governments target protections to local riparian areas. Protections often limit the impacts allowed to riparian vegetation, buffer zones, stream banks, and other features of riparian areas. Local jurisdictions can also require mitigation on-site, off-site, or through in-lieu fee programs that enable the purchase of riparian areas.

Principle 3: Conduct Long-range Regional Planning for Exurban Riparian Areas

Planning for growth in exurban riparian areas is not a static exercise that identifies appropriate development for a specific parcel of land. Rather, it is a strategic undertaking that anticipates growth pressures for generations to come. The famous adventurer and ecologist Aldo Leopold's suggestion that we should "think like a mountain" (incorporating ecological and biophysical relationships into planning) is certainly appropriate when planning for development along rivers (Leopold 1966, p. 137). When planning is conducted far in advance of anticipated growth, there is ample time to study the exurban area and the biophysical character of the river and its associated riparian ecosystems. Such an approach is the foundation for developing land uses that meet the social needs of community residents while retaining many of the natural functions and values of the river itself. Achieving this balance requires an understanding of the river system, including the composition of biophysical processes, current overall ecological condition, and how and why ecological conditions have changed. Some of these factors will be known, others will not. For instance, the river's flow characteristics (e.g., historic flood peaks, daily averages) may be known, particularly if the river is gauged, yet other factors (e.g., changes in channel morphology, bottomland biota, water quality) may not be as well understood.

Perhaps the only certainty is the inevitability of scientific unknowns. Considering these questions early in the planning process provides the time needed to investigate the river's overall ecological condition and the processes that form it. Therefore, one of the main questions for planners to consider is: to what extent and in what ways can development occur without compromising the physical processes that underpin and support the long-term viability of a river and its associated riparian areas? The goal is to ensure that riparian environments retain as many of positive attributes as possible. Scientific studies are essential for achieving this long-term goal.

Values. Riparian conservation invokes a range of values that complicate the planning process. On the one hand, issues of land value, returns to investment, and infringement on private property rights ignite controversy and often polarize stake holders along ideological lines. Scientific studies and analysis often go a far way in resolving these conflicts. On the other hand, few will argue that riparian areas are ripe with aesthetic value. Indeed, the scenic character of riparian areas often motivates the purchase of nearby land and sets the land development process in motion. The preference for riparian lands occurs because, by definition, they have different qualities than surrounding "uplands." From the Latin *ripa*, or "bank," riparian refers to the singular conditions encountered as one moves from the upland forest, savanna, or desert into a zone of increased moisture availability. Riparian plant and animal communities and other resources found along watercourses generally have much greater diversity than nonriparian areas. They can be visually intricate forests or thickets where the likelihood of encountering wildlife increases. Thus it is understandable that the popular pastime of wildlife watching, like the more traditional pursuits of hunting and fishing, often takes place in rich riparian ecosystems (Caudill 2003).

Riparian areas are places of shelter and shade. This effect is best exemplified by desert oases, but entering any natural riparian area provides something of the oasis effect. Temperatures decrease, wind is mitigated, the visual environment is more “closed in.” There can be the feeling of safety from heat or deliverance from less productive expanses. Riparian areas are places of movement and human imagination. It is no surprise that important works of visual art often depict rivers and streams. Great stories, from *Huckleberry Fin* to *Heart of Darkness,* are set in the moving medium of rivers and along their banks. The value placed on riparian areas, therefore, not only underscores their attraction as places to live and engage nature but also demonstrates the need for sound conservation planning.

Prioritizing Riparian Areas. By its nature, future development in exurban lands will impact riparian areas. Where should development occur and where should it be avoided? One way of responding to these questions is to rank riparian areas according to their relative “importance.” Ranking is a difficult exercise because all riparian areas have intrinsic value. Even so, it should be recognized that development will move forward, with or without the aid of rankings. Thus, conservation is best served by providing defensible rankings that assist decision making. The list below contains criteria that facilitate ranking. The list is illustrative rather than exhaustive and in no way constitutes a recommendation that these criteria be used. Instead, evaluation criteria should reflect conditions unique to localities. Examples of ranking criteria include the following:

- Stream order and length of watercourse;
- Hydrologic and geomorphic conditions of watercourse;
- Role of a watercourse in regional flood control and storm water management strategies;
- Groundwater recharge potential of watercourse;
- Ecological conditions such as vegetation quality, wildlife species, connectivity, habitats, and the like;
- Condition of adjacent forest buffers and the watershed as a whole;
- Analysis of how the above factors might change with development;
- Length of currently conserved reaches along the watercourse (e.g., public, private, or nonprofit-based reserves, set-asides) and potential for additional conservation;
- Current zoning and proposals for zoning changes;
- Lengths of privately held and publicly held reaches of the watercourse;
- Legal and regulatory context affecting the watercourse, including water rights
- Proximity to transportation corridors;
- Current and potential recreational use and aesthetic qualities.

In addition to the analysis and ranking of riparian areas, the long-range plan should recommend ways in which ecologically friendly development can proceed. Issues at hand include how best to reduce impacts on riparian areas, guidelines for mitigation when needed, and delineating locations where restoration or enhancement of riparian areas is required.

Principle 4: Mobilize Conservation Resources

Conservation sustains exurban riparian functions that benefit many stakeholders including land developers and private property owners. Mobilizing resources among stakeholders increases the likelihood of successful conservation. There are many resources available for conservation, especially for private land owners (developers and home owners). As noted in *Riparian Areas: Functions and Strategies for Management* (National Research Council 2002, p. 244):

> "A growing number of inducements are available to encourage private landowners to protect riparian areas. These inducements take the form of direct payments to landowners not to develop riparian lands, payments to encourage use of environmentally compatible practices, payment or tax benefits for placing a conservation easement on the property, funding for restoration demonstration projects, stewardship education and technical assistance, and outright purchase of the lands. To be effective, incentives generally must at least equal the value of other use options available to the landowner."

The long-term riparian plan can assist conservation by identifying key areas for preservation and vehicles and organizations suitable to undertake such efforts. The combined efforts of government, nonprofit organizations, and the private sector, working proactively at the exurban scale, have the potential to protect irreplaceable riparian resources for the benefit of society and the environment.

Principle 5: Assess and Make Decisions about Specific Sites

The starting points for assessing a specific exurban riparian site are (1) understanding the general characteristics, values, and threats to riparian areas in the region and (2) recognizing the site's priority in the long-range riparian plan. The procedures involved in making these assessments were described above. The next step requires gathering and analyzing data specific to the site and for adjacent lands as well. Numerous types of data are needed, ranging from current and historical ground-based and aerial photographs to ecological, hydrological, and economic profiles. These data are used in a number of ways, depending on site characteristics and objectives of the riparian conservation plan. For example, if the site will be incorporated with an adjoining preserve, issues such as nesting endangered birds or nonnative plant infestations may receive more attention.

Guidelines. Detailing the specifics of on-site development is well beyond the scope of this chapter, but a few guidelines further the potential for balancing development with riparian conservation. First, decisions about where and how to develop land in or near riparian areas benefit from lengthy dialogue between jurisdiction staff and the applicant proposing development. The earlier this dialogue takes place, the greater the opportunity for creative solutions that fulfill the applicant's development goals while reducing negative impacts or, ideally, enhancing the riparian area.

Ironically, if the riparian area has been substantially degraded by grazing, erosion, nonnative species invasion, or other major disturbance, the proposed development provides the opportunity for improving the quality of riparian habitat with cooperation from the applicant. For example, if the applicant proposes to reroute a reach of watercourse dominated by nonnative species to the perimeter of the site in order to create more developable land area, the rerouting might be allowed if the applicant provides a net improvement in riparian conditions. These conditions include constructing the new reach with shallowly sloped dirt banks and revegetating the new channel with an improved density and diversity of native plants that are maintained to prevent occupation by nonnative species. This accomplishes development goals while providing improved habitat that acts as an ongoing native seed source for downstream reaches of the watercourse that previously received large pulses of invasive plant seeds.

Second, given ample time, imagination and creativity can lead to a viable balance between conservation and site development. If the site involves commercial development, for example, creative design can avoid encroaching on a riparian area by shifting the development footprint or changing its shape to avoid the watercourse. Alternatively, the footprint can be reduced by building upward (adding additional stories), rather than spreading development outward. Similar tactics can be used to mitigate the impact of residential development. Using residential cluster development precludes encroachment into riparian areas, and clusters can be positioned in interesting and innovative ways. Such efforts are fruitful because riparian areas are aesthetically and economically attractive to homeowners. They often locate in residential developments that feature quality riparian habitat and low-impact trails within the riparian area.

Even so, residential and commercial developments potentially impose enormous impacts on exurban riparian areas, and planners should consider multiple ways of reducing and counteracting these impacts. Increased runoff, for example, is common with all kinds of development. It is often approached as an engineering problem that necessitates removal of excess water as quickly as possible, often by shunting it toward retention/detention areas at the low point of the site. An alternative to removing this valuable water resource is to creatively put runoff to work by harvesting water at multiple locations and using it to support native riparian vegetation. Ideally, water-harvesting depressions are positioned adjacent to, but not within, the riparian area, thereby increasing the area of riparian vegetation without enlarging the floodplain. These water-harvesting areas serve as retention/detention ponds that are constructed in natural shapes rather than conventional rectilinear basins. Such multipurpose strategies save space and maximize benefits, including supporting riparian vegetation, creating an opportunity for biologically based water quality treatment of urban runoff, providing supplemental irrigation if needed, increasing the diversity of appropriate native plant species, and improving on-site heat island mitigation.

Road crossings are another common form of encroachment that accompanies development. In this case, bridges can avoid ecological intrusion by allowing the relatively unobstructed flow of water and fish and the movement of wildlife beneath the bridge. Bridges sidestep many problems introduced by culverts (constructed of round or oval metal pipes or rectangular concrete openings) that tend to constrict water flow and deter wildlife movement. Developers and jurisdictions should consult with wildlife experts to determine the wildlife species most likely to use a site and the conditions that either impede or encourage crossing under a bridge or through culverts.

Third, think carefully about the use of vegetation in riparian areas. Residential and commercial developments sometimes use nonnative plants in landscape design. This often introduces nonnative seeds to adjacent riparian areas, which, in some cases, compete with and displace native plants. An alternative strategy is to use an all-native plant pallet in developments adjacent to riparian areas. This provides a continuous supply of native seed sources to the riparian area. Native plants are also inherently well adapted to the seasons and precipitation, thereby requiring little or no supplemental irrigation.

Finally, gain community support for riparian conservation by featuring them as prime recreational spots. There are numerous examples of successful riparian conservation that cater to public access, and they often become favored community amenities with trails constructed through them for ready visitor access. To get the benefits of close access to riparian areas while avoiding unnecessary impacts, trails should be built on land contours. Where they must go across contours, they should be designed to carefully deflect water running down the trail to avoid erosion. To minimize human encroachment, trails should be kept away from high-value habitat and places occupied by special-status species.

Mitigation. When development pressures are severe, many jurisdictions require mitigation. Mitigation takes many forms and should be designed to maximize benefits to the impacted riparian area. Although replacing disturbed vegetation is an example of a commonly used mitigation strategy, the emphasis of mitigation should be on minimizing or compensating for development's impact on the physical processes that underlay and support the biotic characteristics of the riparian ecosystem. In this sense, thoughtful and sound mitigation should *never* focus solely on a single variable (e.g., replacing vegetation volume in a disturbed area with an equal volume in an undisturbed area), but needs to consider how the impacts of development affected streamflow, channel morphology, water availability, water quality, the riparian water table and other physical parameters critical to maintaining the viability of the riparian ecosystems in the long-term. Where vegetation needs to be replaced, plantings should be placed contiguous to remaining on-site riparian habitat. The species planted should be the same as those removed from the impact area unless the riparian area is severely degraded. In this case, a nearby intact riparian site serves as a reference for determining appropriate density and diversity of native plants. If mitigation plantings must be placed away from the riparian area, they should (at a minimum) be clustered in as large an area as possible and consist of appropriate understory, midstory, and overstory riparian species so that they re-create the vertical structure typical of riparian areas. Standard landscape maintenance practices are not appropriate for mitigation areas. Plants should be left in their natural form, leaf and twig drop left in place to mulch the soil, and seeds allowed to germinate and grow.

Storm water retention/detention basins are excellent locations for mitigation plantings, especially if they can be placed adjacent to remaining riparian habitat. To accommodate the mitigation plantings, basins should be enlarged to accommodate additional plant volume. The sides of basins should be sloped gently to allow planting to occur there. The bottom of the basin can be shaped to create slightly elevated plateaus, which minimizes inundation of root crowns of plants. Basins often necessitate the removal of accumulated sediments to maintain appropriate storm water retention/detention capacity. Access ramps, sediment traps, and adequate maneuvering area can be designed into the basin is such a way that maintenance can be performed without disturbing the mitigation plantings.

If mitigation cannot be conducted at the site, alternatives are to conduct mitigation on nearby off-sites or to charge an in-lieu mitigation fee that can be used to restore or acquire similar habitat elsewhere. These are options of last resort since the loss of habitat occurs at the site and ideally is replaced there.

Principle 6: Learn from Existing and New Development Sites and Adapt Sites as Needed

In and around long-established urban areas, riparian areas range from being wholly preserved to completely destroyed by development. Some development sites are new, while others are much older. In any case, previous experiences can fine-tune development design for future sites. Lessons are likely to be specific to the unique hydrologic, ecologic, institutional, and social context of a region and site. Systematically assembling useful data from past projects will provide a body of information for many people to draw on. Useful data to collect site by site include:

- Percent and location of impacted riparian habitat;
- Aerial and ground-level photos taken before and after development;
- Upstream and downstream changes in the riparian area related to the development;
- Current natural characteristics of the riparian area;
- Riparian area conditions where site storm water discharges to the watercourse, at road crossings, and at other interfaces with development;
- Original mitigation plans and how they were implemented;
- Current conditions in the mitigation area.

On newly developed sites, coupling contemporary restoration techniques with monitoring of impacts adds to this body of knowledge. Monitoring changes on-site is accomplished easily by establishing several strategically located ground-based photo points and conducting repeat photography at periodic intervals once development is completed. Detailed scientific monitoring of flora and fauna, channel morphology, and other riparian characteristics can be designed to answer specific research questions with the cooperation of managers at the developed site. Site inspection of the riparian area is equally important. Inspections are conducted by site personnel at regular intervals and particularly after large storm events. These inspections reveal vegetation damage, erosion, wildlife mortality, and other problems that can be addressed with timely corrections. These periodic inspections also add to overall understanding of a site.

To benefit from lessons learned by others, keep active lines of communication open with public planning agencies, the development community, NGOs, agencies, universities, and other entities that observe and affect watercourses. To encourage active communication, planners should take the lead in organizing seminars, websites, and newsletters that provide venues for reporting on riparian conditions, innovative approaches to development, successful restoration techniques, and a range of other relevant topics. Conducting tours that showcase creative design, restoration, and mitigation is another valuable tool that promotes the sharing of information. This information should be used to update long-range riparian plans and benefit the environment and society.

Conclusion

Today's exurban areas will likely become tomorrow's suburbs, and even more remote open space will possibly become tomorrow's exurbia. Proactively preparing for this human settlement ensures that important riparian areas are identified and protected to the greatest extent possible. When development occurs, negative impacts should be minimized and opportunities to restore and enhance riparian areas maximized. Well functioning, healthy riparian areas provide a multitude of benefits, ranging from cleaning water runoff to soothing the human spirit. It is well worth the effort to prepare wisely for human movements into these areas. Such efforts build on Leopold's land ethic by balancing human needs with fragile riparian environments.

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Chapter 11
Storm Water Management in Exurbia

Evan Canfield and Richard H. Hawkins

Abstract In urban and suburban settings, storm water management and design is a well-developed and widely practiced profession, but the situation in exurban areas is far different. Beyond the metropolitan fringe, lower residential densities and smaller capital budgets limit storm water improvements, which heighten the need for sound storm water management by planners and private property owners. This chapter describes the impact that dissection of landscapes by infrastructure can have on storm water and stream stability in exurbia. It considers how, and why, roads and utilities and the siting of homes and exurban subdivisions impact drainage networks and contribute to flood hazards. Recommendations for dealing with storm water management in exurbia are also discussed.

Introduction

Storm water management is a growing concern as larger numbers of Americans move beyond the metropolitan fringe. Lured by the perceived benefits of open space and natural amenities, they convert near-pristine wildlands, rangelands, and agricultural lands as roads are carved and houses built. This land modification alters terrestrial hydrological processes and (often) calls for improved storm water management. In urban and suburban areas, storm water management is long standing, but this is not the case in many exurban areas where comparatively low residential densities and slim capital improvement budgets preclude the design and construction of more costly flood control devices. This chapter discusses the ways in which exurban land development affects storm water management and stream stability. We also describe ways in which planners and private property owners can improve storm water management in the absence of costly infrastructure. We begin

E. Canfield (✉)
Planning and Development Division, Pima County Regional Flood Control District, Tucson, AZ 85701, USA
e-mail: evan.canfield@rfcd.pima.gov

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by defining exurban development and then explain the fundamentals of storm water management. This is followed by a discussion of problems that arise from exurban development and ways of mitigating or avoiding them all together.

The Exurban Context

For present purposes, exurbia is defined as the low-density urbanization – or civilization – beyond the urban fringe, often with attachments to, and dependence on, nearby urban centers. It is semirural living enhanced with urban conveniences and access to urban culture. This occurs in a variety of regulatory settings and planning arenas, although a prime motivation is often to avoid regulations. Indeed, exurbia tends to be scaled to escape regulations common to urban and suburban living. While covering a wide variety of conditions, the common theme of exurbia is an overall lower housing density.

Exurbia is common and popular in our society and propelled by both noble and profane motives: the quest for solitude and quiet, wildlife interactions, natural environments, avoidance of social conflicts and regulation, and the desire to keep animals. These are all conditions difficult to supply in urban settings. In many cases, however, economics is a major force: cheap land, lower taxes, and escape from regulation, often with a significant "do-it-yourself" attitude. Regardless of the motive, remote locations and isolation discourage incidental monitoring and awareness.

Chapter 1 described several types of development occurring in exurbia. For present purposes, we consider two types of development: dispersed housing on multiacre lots and the increasingly common high-density developments located outside the suburban fringe. The conventional mode of exurban development consists of lots in the 1–10 acre range, containing a single-family dwelling, which at times is premanufactured. By choice, they are frequently clustered with periodic spacing but may also be irregularly arrayed or even isolated dwellings. Transportation infrastructure supporting these developments is poorly planned and often privately built and maintained. There is usually no drainage infrastructure, except as it arises to address transportation needs. In essence, people in these "wildcat (unplatted) developments" enjoy the benefits of affordable land and low taxes at the expense of poor infrastructure support. Hobby farms and ranchettes are another common dispersed housing type. In general, these will be on larger lots than wildcat developments.

Site-built homes on large lots are less common but are growing in popularity. These are dispersed developments that share many of the characteristics of wildcat developments. From a storm water perspective, they are essentially subdivisions located well outside the urban core. These are increasingly common in Texas, where they are often clustered around lakes (Cowley and Spillette 2004). These communities cater to a more affluent clientele who want to live on 1–20 acre lots and enjoy the benefits of rural living. Even so, they expect some infrastructure, such as reliable transportation networks. However, roads may be private and drainage infrastructure is often lacking.

As described in Chapter 1, retirement communities and starter homes are increasingly common features in exurbia. While located well outside the urban fringe, these communities are essentially urban developments from a storm water perspective. However, the technical support needed for planning these developments, such as accurate floodplain maps, is less likely to be available. Furthermore, unlike urban developments, they lack the connectivity with existing storm water infrastructure.

The following discussion of storm water in exurbia focuses on the problems unique to exurbia, the regulatory framework, and strategies to address these problems. For the most part, it will focus on the dispersed housing unique to exurbia.

Storm Water

Storm water management is concerned with the disposition of excess rainstorm runoff: its rates and volumes and the downstream effects, including impacts on water quality. The related term *drainage* is often used synonymously but suggests the singular attention to removing water from originating sites. In some regions of the country, snow melt water is an issue. Although runoff rates are usually quite modest: snow cannot melt as fast as rain can fall. The use of storm water as a resource is a beneficial facet of storm water management.

In urban and suburban settings, storm water management and design is a well-developed and widely practiced art and profession, with a distinct maintenance element included. It deals with capacities of gutters and channels, the diversion and direction of flows, and temporary storage or disposition with ponds and pits. Pumping may also be involved, and rainwater harvesting is becoming a popular option in many places.

Utilities that address storm water management commonly are called "flood control" utilities. This may be because traditionally these utilities built structures such as dams that minimized the potential for downstream flooding by retaining floodwaters. These utilities also frequently employ nonstructural measures, such as floodplain mapping, to limit the impact of flooding.

Problems

The problems (and solutions) of urban and suburban storm water management are also found in exurbia, but with less intensity. The impacts of development include the following:

- increasing the volume of runoff with increased impervious surfaces such as rooftops and roads (Roesner, Bledsoe and Brashear 2001; Gregory et al. 2006; Kennedy 2007);

- increasing the rate at which water travels across the landscape as those same impervious surfaces allow water to move more rapidly (Gilbert and Clausen 2006; Hood, Clausen and Warner 2007);
- destabilizing watercourses (Booth 1990; Chin and Gregory 2001; Kang and Marston 2006).

Predicting and developing methods that address these problems goes back thousands of years (Delleur 2003).

By its nature, exurbia is a diluted form of suburbia. In practical terms, this means that the urgency for formal responsible water management and drainage, required when neighbors are nearby and built-up areas are dense, is not as pressing in exurbia. Potential damages and benefits are diminished, although long-term degradation of stream networks can occur from even low-density development (Dougherty et al. 2007). However, exurbia is not free from interactions, problems, environmental impacts, and opportunities.

We suggest that planners should be alert to the following items: (1) impervious or "footprint" effects from buildings; (2) siting of homes and other structures; (3) roads and infrastructure placement; (4) associated land uses; (5) water development, including water harvesting; and (6) attitudes toward flood control.

Building Footprints Effects

It is fundamental that houses and outbuildings protect their interiors by shedding water from rooftops. The disposition of this water is necessary, and gravity leads it down slope. Typically, when considering the outcomes of development, the impact of increased impervious surfaces is profound (Shuster et al. 2005). Constructed impervious surfaces such as roads and rooftops increase the volume of runoff and the rate at which water moves. For this reason, virtually every method of quantifying flood volumes and peak discharges specifically requires quantifying impervious area (Haan, Barfield and Hayes 1994).

An assessment of urbanization determined that when exurban lands are "urbanized," the 100-year postdevelopment discharge doubles (on average) and the 2-year discharge increases 57 times (Joint Task Force of the Water Environment Federation and ASCE 1998). After urbanization, therefore, smaller floods become much more common. What had previously been a 2-year flood event may occur several times in a single year (Hollis 1975). Thus, impervious cover dramatically increases the amount of water that flows in smaller rainfall events. These impacts are illustrated in Fig. 11.1.

However, there is less impervious cover in exurbia because source areas (roofs, yard pavements, and driveways) typically occupy only a small portion of the total land. On a 2-acre lot, for example, the impervious cover is only about 12% (U.S. Department of Agriculture Natural Resource Conservation Service 1986), and the percentage of coverage decreases as lot size increases. On larger lots, the effects of impervious cover can be moderated on-site, but impervious cover becomes more important on smaller lots.

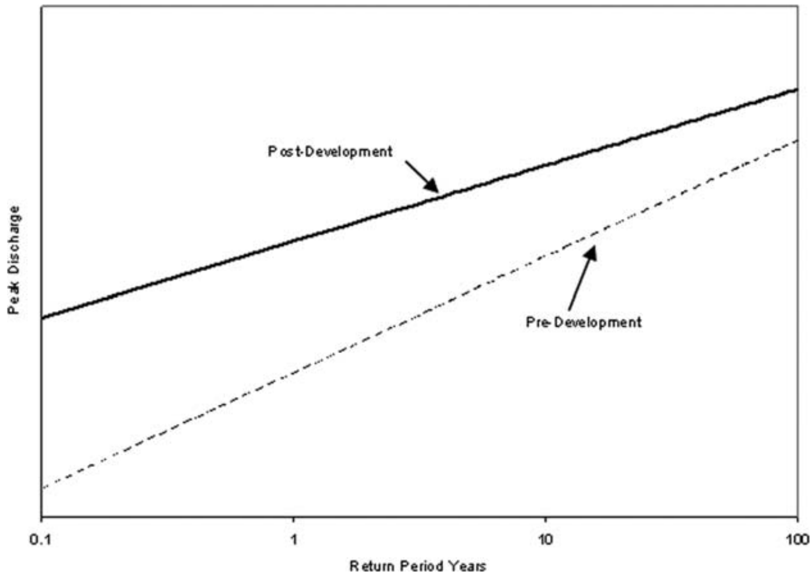

Fig. 11.1 Conceptual representation of the impact of urbanization on peak flow. Increases in impervious areas cause more frequent flooding. This causes more nuisance floods, which may not carry the life-threatening consequences of 100-year flooding. Source: Evan Canfield and Richard Hawkins

A 1-acre lot may produce considerably more unit runoff than a 2-acre lot for either large or small precipitation events (Figs. 11.2 and 11.3, respectively), because a typical 1-acre lot has about 20% impervious cover, while a typical 2-acre lot has only about 12% impervious cover (USDA-NRCS 1986). As these figures illustrate, even in relatively permeable (low-runoff soils), the likelihood of runoff occurring increases in a smaller event. In fact, an increase in the number and magnitude of small nuisance floods, rather than large life-threatening floods, is the primary hydrological impact of exurban development.

Traditional runoff management requires some structural methods to limit the impacts of increased runoff from developed areas. Usually this involves retention (i.e., retaining or holding flood waters) or detention (i.e., slowing and reducing the peak from flood waters). Since the increase in runoff rates from the footprint of home sites is comparatively small, traditional suburban runoff management techniques, such as retention ponds, are difficult to justify in exurbia. While effective in urban settings, modern and highly regarded measures such as low-impact development (LID) design (Prince George's County Maryland 1999; McCuen 2003; Hood, Clausen and Warner 2007) may be neither necessary nor appreciated in exurban areas.

However, where there are impervious areas such as cross-roads with gas stations or convenience stores, the relatively high densities of impervious cover from large parking lots or paved areas can generate problems for downstream property owners or destabilize natural channels. As such, in permitting such facilities, planners should require developers to manage on-site runoff.

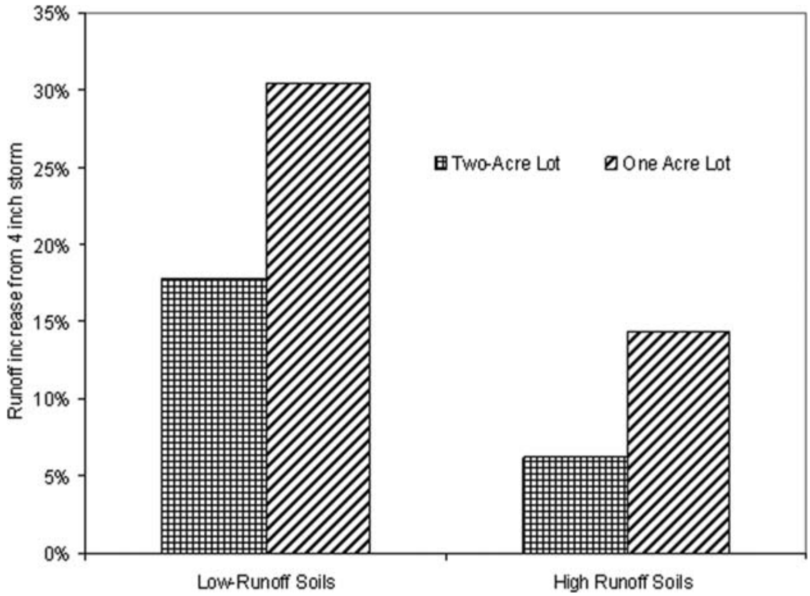

Fig. 11.2 For a large event, increasing lot density moderately increases runoff potential. Impacts are more pronounced for more pervious low-runoff-producing soils (comparison using method in USDA-NRCS (1986), values in Table 2, with B and D soils in open space in fair condition subjected to a 4-inch rainfall). Source: Evan Canfield and Richard Hawkins

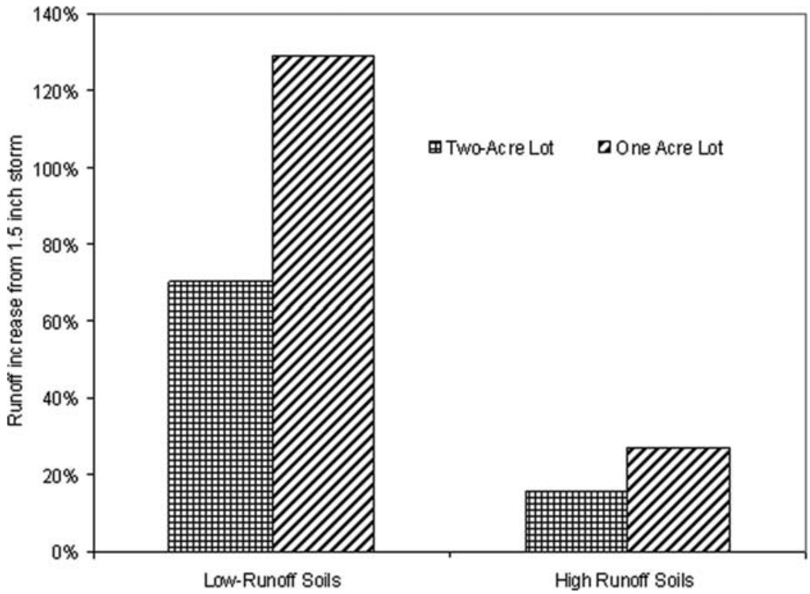

Fig. 11.3 For small and frequent events, increasing lot density dramatically increases runoff potential. Impacts are more pronounced for more pervious low-runoff-producing soils (comparison using methods in USDA-NRCS (1986), values in Table 2, with B and D soils in open space in fair condition subjected to a 1.5-inch rainfall). Source: Evan Canfield and Richard Hawkins

Siting of Homes and Other Structures

Rivers and drainages tend to have trees and attract wildlife and appear to be pleasant places to live. By their nature and function, however, these areas tend to be flood-prone, a reality often unappreciated in exurbia, especially in places where development is ad hoc. Furthermore, smaller exurban drainages may not be formally zoned to 100-year flood event (or other regulatory) limits. This lack of awareness (or concern) may lead to siting structures in flood plains. It is not uncommon for a trailer or a manufactured home to be lost in a flood. As well as the property loss, this is a hazard to downstream interests. For example, mobile homes, cars, and other exurban debris can clog culverts and create additional flooding hazards.

As discussed below, mapping floodplains is the single most important action a planner can take to limit impacts of flooding in exurbia. Even though regulations in exurbia are few, a mortgagee is required to purchase flood insurance if a structure is located within a mapped floodplain. Furthermore, building-code restrictions are greater in floodplains than outside them, even though they are difficult to enforce far from the urban fringe. In avoiding floodplains, it should be noted that maintaining a buffer between the stream and structures provides significant benefits to the stream as well as the aquatic system (Theobald, Miller and Thompson-Hobbs 1997).

Roads and Infrastructure Placement

The building of roads and the placement of infrastructure can create problems in exurbia. Roads are urban features superimposed on rural lands. As near-impervious and compacted surfaces, they are efficient runoff sources: road surfaces usually produce much more runoff per unit area than do native landscapes. At times, this leads to rilling, erosion, and downstream flows disproportional to the road surface (Montgomery 1994). A problem common in the western United States is that land is surveyed in a rectangular grid system, and boundary access roads are superimposed to follow straight section (property) lines. While this roadway configuration eases the subdivision and sales of land, it is not sympathetic to topography and landscape features. Finally, even though rural roads represent only a fraction of watershed areas, their impact on the landscape is profound. One estimate, for example, indicates that the hydrological effects of roads extend 50–200 m beyond the road surface (Forman and Alexander 1998).

Runoff and drainage from roads may be a notable problem in some forested areas. In such typically low-runoff situations, the near-impervious roads function as high-yielding tributary extensions to the natural network and contribute disproportionately to channel flows and channel disruption. In addition, a substantial portion of the sediment load can come from roads (Elliot 2000). Thus, special attention should be devoted to the design and construction of forest roads (http://forest.moscowfsl.wsu.edu/engr/).

Roads have the potential to capture natural flow paths on uplands and disrupt natural channel processes at stream crossings. Road ruts in riparian zones sometimes form starter channels that carry mainstream flows during high waters and – via erosion – capture the original channel. In one study of arroyo (gully) formation in the southwestern United States, Cooke and Reeves (1976) noted a variety of causes, but one was the role settler's roads played in capturing runoff. In the spectacular example shown in Fig. 11.4, the road ran parallel to the river, so it is not surprising that as road ruts formed, water flowing toward the river was captured in road ruts. This eventually caused the road to capture the river itself.

Fig. 11.4 This canyon formed when the old Tucson-Nogales wagon road was captured by the Santa Cruz River about 1940. Vehicle included for scale. Photograph by R. M. Turner. Courtesy of the Desert Laboratory Photography Archive

Because of the propensity of roads to collect water, their location should minimize disruption of the drainage network. Many exurban private roads are unpaved, and traffic, compaction, and ponded water can make them muddy and impassible. These problems can be addressed by grading and gravelling roads in order to minimize the ponding of water and compaction. Concentrated flows on the roadway itself can cause severe degradation of the roadway and the potential capture of runoff.

Considering the immense potential impact of rural roads, their proper placement can diminish potential problems (Jaarsma 1997). In general, placing the access road high on the landscape and parallel to drainage networks minimizes hydrological disruption (Zeedyk 2006). Even roads high on the landscape must accommodate drainage by insloping and outsloping roads periodically to minimize the potential to concentrate water. However, when roads cross drainages, Zeedyk (2006) recommends crossing at right angle to the flow, and crossing at a straight reach instead of at a bend or meander. Likewise, he suggests maintaining channel grade with at-grade crossings or culverts that pass the flow without upstream ponding.

Exurban jurisdictions, however, are not inclined to invest in improved roadways or roadway drainage because of large lot sizes and low tax bases. Furthermore, many exurban homes require private access roads, which are often built ad hoc and without adequate engineering. These private roads are typically unpaved, and ponded water makes them muddy and impassible. Concentrated flows often cause severe degradation of the roadway and the potential capture of runoff. This contributes to downstream water-quality problems.

Impacts of crossing on larger channels will result in short-term and long-term impacts (Richardson, Simons and Julien 1990). Because the cost of stream crossings is high, smaller and less-expensive crossings, which may constrict the flow on many rural roads, are common. These undersized stream crossings can destabilize upstream and downstream of the crossing as well as cause additional ponding during a flood. Long-term impacts can further destabilize the stream grade, which impacts fish and aquatic life. This problem is confounded by the fact that exurban development usually affords few formal stream-crossing structures: bridges are expensive, and thus rare. As a result, culverts and low water crossings are used frequently.

Living in areas with marginal transportation networks introduces additional concerns. Exurban residents might not have access to (or from) their properties when water levels are high. For example, if a rural road captures a drainage network, it will likely be impassable in a major rainfall event. Likewise, the road may require special equipment like snowplows to gain access. In a life-threatening health emergency, heroic measures such as a helicopter rescue may be required. On publicly maintained roads, the same problems associated with drainage might also occur. However, these roads are more likely to be designed, constructed, and maintained by a highway authority to minimize the impacts of drainage. Nonetheless, road crossings in particular remain a problem, and larger roads are more likely to cross larger channels.

Associated Land Uses

There are other siting impacts to consider in addition to structures. The increased moisture that accompanies drainage-ways leads to increased plant cover. This suggests that floodplains are good places to pasture animals such as cattle, horses, and sheep, which are raised often on a hobby basis. While lush in relative terms, multi-acre lots with some floodplain typically do not have the capability to support many animals. Thus, animals may overgraze vegetation in the floodplain and associated uplands, which reduces infiltration capacities, increases erosion, degrades channel function, and produces water-quality problems downstream (Kauffman, Krueger and Vara 1983).

The runoff and seepage from occupied sites adjacent to streams often contain water-quality-degrading pathogens, pesticides, and metals (Hudak and Banks 2006). In addition, this degradation can impact biodiversity of invertebrates and the quality of receiving waters – in effect, degrading the habitat that attracted people to exurbia in the first place (Roesner, Bledsoe and Brashear 2001).

Water Development

Storm water can be used beneficially. The same dynamic that results in more frequent nuisance flooding from urbanization also provides more reliable sources of storm water flows. The small amounts of increase in impervious surfaces can produce water even in smaller events (Fig. 11.3). Constructed ponds are one of the most common ways of capturing this storm water. Guidance on how to plan, construct, and use ponds is widely available (e.g. U.S. Department of Agriculture Natural Resource Conservation Service 1997). Ponds are very popular in the humid East, Midwest, and South with several hundred thousand in place. These are multipurpose features of the rural and exurban landscape that provide water for stock and wildlife, recreation, aquaculture, and scenic amenities. They affect some limited local flood control by mitigating the downstream impact of upstream impervious development.

Local conditions affect how the hydrologic cycle impacts ponds. Ponds have the potential of increasing groundwater recharge, although they are typically built to limit losses. Some measures reduce the potential for evaporation or seepage (Duesterhaus et al. 2008). As such, ponds are a potent planning tool for water resources and offer a method of using storm water resources effectively. It is noteworthy that in many water-limited environments, water rights issues may also emerge. In worst-case scenarios, there are also potential public health issues with some standing waters.

With safety issues in mind, and from tragic historical experience, many states regulate dam construction. These regulations include specific statutes on dam height and water storage capacity, stability of the structure, and the adequacy of spillways. However, the scale of most exurban developments usually falls below thresholds that require the construction of dams.

Attitudes Toward Flood Control

Residents of exurbia recognize that they live beyond the reach of public-supported infrastructure and typically accept that they bear some responsibility for maintaining private infrastructure such as rural roads. However, people generally believe that government has a role in protecting citizens from natural disasters. Storm water utilities, often called “flood control” utilities, are often viewed as having some responsibility in preventing flooding. Obviously, if structures are built beyond the range of effective regulation, these utilities cannot, in fact, control flooding. Even so, people living outside the range of effective regulation still complain that government should offer assistance. Furthermore, the cumulative impact of more development in exurbia increases both the likelihood of nuisance flooding and the potential for greater political clout to remedy nuisance flooding problems. This occurs as neighbors and affected parties coalesce and form lobbying constituencies. Their ability to effect change improves as development brings more people to exurbia.

Regulatory Framework

Storm water management typically involves an array of federal and local permitting issues. Protections are provided for the channel itself under Section 404 of the Clean Water Act. Water-quality protections are provided through the National Pollution

Discharge Elimination System (NPDES) and habitat and species preservation concerns may invoke the Endangered Species Act. However, this discussion will focus primarily on the role of development in flood control management.

The Federal Emergency Management Agency (FEMA) regulates floodplains through local jurisdictions. Jurisdictions themselves can designate, map, and regulate floodplains locally. In either case (federal or local), restrictions on construction will be in effect. Properties in FEMA floodplains often have additional restrictions. As a condition of issuing a mortgage, for example, mortgage companies must require that property owners purchase flood insurance if they are in a FEMA-designated 100-year floodplain. It is noteworthy that floodplain maps may (or may not) be available for exurban areas. If the land was previously owned by the state or the federal government, floodplain maps may not exist because there was no expectation that land would be developed.

Prior to 1968, there was no national program for managing the risk of flooding. The National Flood Insurance Program (NFIP) established a means to identify areas at risk for the 100-year flood (Federal Emergency Management Agency 2005). Because the program recognized the contiguous nature of floodplains, it is understood that development upstream can impact downstream users. Federal law requires that subdivisions (greater than 5 acres or 50 lots) and larger developments are regulated for flood risk. Even if a community chooses to regulate using local rather than federal floodplain designations, flood hazard risks must be considered in permitting construction in order to comply with federal law.

The NFIP is a self-insuring program. No additional federal taxes are used to fund the NFIP. Typically, flood insurance costs substantially more than homeowners insurance and can cost a property owner several thousand dollars per year. By choosing to map FEMA floodplains where they do not currently exist, a local jurisdiction takes on the benefits (and risks) of working within the federal system. Individual properties, such as homes on large parcels, will be treated differently than subdivisions. Existing homes will be treated differently in FEMA's eyes if they were constructed prior to the implementation of the NFIP in 1968 or prior to the Federal Insurance Rate Maps (FIRMs), first issued in 1986. The regulatory framework, therefore, may allow jurisdictions to exert more control over drainage networks in subdivisions than in individual lots. This means that many of the lots in exurban development cannot be well-regulated by FEMA or local flood control districts.

Structural, Nonstructural, and No-Action Floodplain Management

Jurisdictions employ three general strategies when managing drainage systems:

- nonstructural flood control (zoning and insurance);
- structural flood control (structures and flood proofing);
- no-action.

The most common nonstructural floodplain management tool is floodplain mapping. It is usually accompanied by restrictions on development in the floodplain. Even though single lots may not be subject to the same regulations as platted subdivisions, simply knowing the floodplain limits provides planners with an important tool. When a home is flooded, being able to document that the home in question is in the floodplain absolves the jurisdiction of some responsibility. Furthermore, if the home is serviced by a mortgage, the mortgage company will require flood insurance if the home is in a mapped FEMA floodplain. Typically the cost of flood insurance is many times greater than the cost of homeowners insurance and is a real deterrent to building a home in the floodplain.

While floodplain mapping requires technical analysis, defining an erosion hazard setback on the placement of all structures is often a first step. This method establishes a reasonable means of ensuring that structures are not placed in the most hazardous locations. Making buyers of manufactured homes aware of the risk, and educating manufactured home installers about erosion hazard setbacks, is one way to enforce the erosion hazard setback requirements.

Purchasing flood-prone land is another nonstructural option. The purchase of flood-prone lands excludes them from development and allows floodplains to return to natural function. This decreases downstream flood potential on other properties. Similarly, planning and zoning regulations that prohibit development on uplands can impact the potential for flooding by reducing the volume and rate at which water reaches the channel.

In general, low population densities in exurbia do not have the tax base to support structural floodplain management, except very small structures such as stock ponds. Structural floodplain management includes the classic structures associated with flooding and drainage. These include lining and realigning channels, installing bridges and culverts, installing grade control structures, building levees, or building detention basins. In addition, many construction activities, such as building vegetated buffers between the development and the floodplain, are considered "soft structural" activities.

Finally, jurisdictions may pursue a "no-action" strategy. This strategy is often a necessity rather than a choice because funding is unavailable or the impact of flooding is minimal and does not warrant costly structural improvements. This holds true especially for dispersed exurban development where there is little need for structural flood control and the tax base to pay for structures may not be viable. However, ponds can be placed so as to provide flood retention and detention. Ponds serve other purposes, such as recreation and water for livestock and wildlife. Often they can be constructed with cost-share agreements from land management organizations, such as the USDA-Natural Resources Conservation Service. Road crossings can also be designed to serve the secondary purpose of water detention. To some extent this will require recognizing that property upstream of the crossing might be at higher risk of flooding. Finally, the no-action alternative should be used only when a jurisdiction has little or no authority to implement planning and zoning ordinances.

In choosing between structural, nonstructural, and no-action alternatives, jurisdictions should consider the commitment to long-term maintenance. Nonstructural alternatives such as floodplain mapping and prohibiting development in floodplains should allow drainages to maintain channel function better than structural alternatives. However, structural alternatives might allow the use of more land near the channel.

Developments on individual parcels are usually subject to fewer restrictions than lots developed in a platted subdivision where floodplain infrastructure can be considered on the plat grading plan. As mentioned previously, from a storm water perspective, retirement villages and starter-home subdivisions are essentially urban developments.

Conclusion

Storm water management in exurbia is challenging because much of the development occurs in areas where regulation is difficult. There is often little information on where flood risks are likely to occur. Furthermore, there is limited capability to prevent people from placing their manufactured or site-built homes in unsafe locations or on parcels that may degrade riparian habitats and wildlife that attracted exurban residents in the first place.

Channel networks are complex and impacts that are relatively small spatially, such as roadways and rooftops, may impact the channel network by increasing local sediment loads or causeing perturbations in the channel network at crossings. While the increase in 100-year flood risk from exurban development may be fairly small, the incremental increase in impervious surfaces can cause more frequent small flows that create a nuisance. Since few flood control structures are in place in exurbia, incremental increases in flooding from impervious surfaces at upstream properties are apparent to downstream residents.

While residents inhabiting dispersed exurban housing may realize that they are not entitled to the same type of infrastructure found in planned subdivisions, they often feel entitled to protection from flooding – even though their houses were not constructed with flood control in mind. As such, planners and regulators often are expected to take some action to mitigate the flooding that impacts exurban residents. The first task a planner or a regulator can take is to understand the risk of flooding through floodplain mapping or, more simply, identifying an erosion hazard setback. These setbacks are measured from the stream banks and minimize the risk of undercutting structures during floods by setting structures back from hazardous areas. Likewise, planners should consider drainage in planning roadway layouts for public roads and provide guidance to exurban residents on placing private roads that limit the impact on stream networks. To the extent possible, multiuse facilities such as ponds or road crossings should be placed to limit flood potential.

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Part IV
Science-Based Planning in Exurban Areas

Chapter 12
A Science-Based Approach to Regional Conservation Planning

Robert J. Steidl, William W. Shaw, and Paul Fromer

Abstract Although single-species approaches have played an important role in conservation in the United States, the Endangered Species Act provides a mechanism for conservation at larger scales through Habitat Conservation Plans (HCPs). HCPs not only offer the potential for comprehensive conservation planning for a wide range of species across broader geographic scales but also provide assurances that eliminate risks related to endangered species concerns for nonfederal landowners, developers, and planners. Given their benefits, dozens of municipalities have adopted HCPs to address planning issues related to rare and vulnerable species. The challenge, however, is to develop conservation plans that reliably meet broader-scale conservation and planning objectives while not increasing risks posed to vulnerable species. Consequently, we designed a science-based framework from which to develop regional conservation plans, including HCPs. We designed a rigorous process that classifies areas based on their relative conservation value as part of a conservation strategy for more than 20,000 km^2 of Sonoran desert in Pima County, Arizona. This chapter describes our approach including the fundamental planning elements selected, the process used to quantify the relative biological importance of each landscape unit, and how we assembled landscape elements into units that form the framework of the Sonoran Desert Conservation Plan.

Introduction

Conservation issues in the desert southwest generally reflect those in other parts of the United States, although several issues are unique to this arid region. First, large portions of the landscape remain undeveloped and in relatively natural condition with high levels of biological diversity. Second, during the last several decades, the human population has increased more in the southwest than in any other area of the

R.J. Steidl (✉)
School of Natural Resources, University of Arizona, Tucson, AZ 85721, USA
e-mail: steidl@ag.arizona.edu

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country, a pattern that is predicted to continue in the future (Benedict et al. 2005). Increases in the human population intensify development pressure that inevitably compromises the structure and function of natural landscapes. To minimize losses of biological diversity, strategies to constrain and direct the development footprint need to be enacted quickly as remaining opportunities for conserving large, contiguous natural areas will only decrease. Consequently, efficient strategies that identify areas of high conservation value enable regional planners to maximize the conservation benefits of planning while accommodating growth. Although site- and species-specific conservations surely have value, conservation will be most effective when implemented at larger geographic and ecological scales. The history and benefits of large-scale ecological conservation are discussed in Chapter 7.

Many regional-scale plans have been initiated in response to practical concerns related to species listed as threatened or endangered under the Endangered Species Act (ESA) of 1973. The effects of land-use change on listed species typically have been addressed on a single-species and single-parcel basis. This has led to considerable regulatory complexity and, more importantly, ineffective and fragmented conservation. The Habitat Conservation Planning (HCP) process was created to ensure that the impacts of development or other activities on listed species ("incidental take") are minimized and mitigated. In addition to providing relief from regulatory complexity, HCPs expand single-species protection provided by ESA to cover multiple species at broader geographic scales. For this process to be meaningful, however, HCPs must provide genuine conservation benefits that exceed the species-level protection provided by ESA (Kareiva et al. 1999).

Land-use planning at a broader geographic scale provides the opportunity to enact conservation measures that influence a wider range of organisms and landscapes and consolidate disparate planning guidelines under a common framework. Broad-scale land-use plans can promote long-term conservation strategies when they are designed carefully around contemporary scientific principles and implemented expeditiously. Although scientific principles central to the discipline of conservation biology should guide conservation planning, there are inevitable practical limitations that hamper application on lands that have already experienced some development. The degree to which these limitations impede effective conservation planning varies with the size of the development footprint and the compatibility of land uses with conservation goals. Given the pressures of an increasing human population on land and natural resources, there are few situations outside of national parks and reserves where lands can be managed primarily for conservation. Therefore, developing a conservation strategy as part of a comprehensive land-use plan requires balancing conservation ideals and practical realities.

This chapter describes a strategy that positions biological conservation at the center of future land-use decisions. The strategy ultimately defines a network of conservation lands across a large geographic area. We discuss a scientific framework that enhances the goals and objectives of regional-scale planning by identifying lands most suitable for conservation. These lands are found beyond the metropolitan fringe where there are significant opportunities for maintaining valuable biological diversity. Specifically, we describe the method or approach used to classify lands based on their potential conservation value. Based on our analyses, we then allocated lands to a conservation network around which other regional-planning elements were incorporated. Our overarching goal was to identify and establish an integrated system of conservation lands that support biodiversity while simultaneously providing a framework that guides future land use. This framework was the basis for a comprehensive regional-planning effort in Pima County, Arizona, called the Sonoran Desert Conservation Plan. In 2002, the SCDP received an "Outstanding Planning Award" by the American Planning Association, which recognized the long-term value of establishing the regional plan on a foundation designed to conserve biological diversity.

Sonoran Desert Conservation Plan

The conflict between land development and protection of listed species as mandated by federal law was the impetus for Pima County's land-use planning strategy. But over time, the Sonoran Desert Conservation Plan became a comprehensive framework designed to guide future land-use decisions by first ensuring conservation of natural and cultural resources important to the region. Development of the plan was a large, public process guided by a steering committee of about 80 citizens, 12 scientific advisory and other technical teams, dozens of working groups, and involvement of more than 150 scientists. One of these technical teams, the Science Technical Advisory Team, was responsible for establishing the network of conservation lands that are the foundation for all other elements in the plan. These additional elements, however, followed the identification of areas most important for conserving biological diversity. As such, conservation science guided the development of the entire land-use plan.

The SCDP (http://www.pima.gov/sdcp/) was guided by five goals: (1) define urban form to prevent urban sprawl and protect natural and cultural resources; (2) provide a natural resource-based framework for making regional land-use decisions; (3) protect habitat for and promote recovery of species listed under ESA; (4) obtain a Section 10 permit under ESA for a multispecies HCP; and (5) develop a system of conservation lands to ensure persistence of the full spectrum of indigenous plants and animals by maintaining or restoring the ecosystems on which they rely, thereby preventing the need for future listings. This set of interrelated goals was implemented through a series of specific objectives that promote recovery of listed and other vulnerable species, reduce threats caused by the introduction of nonnative species and other factors that compromise ecosystem structure and function, and foster long-term viability of species, physical environments, and biotic communities in the region.

This chapter describes the biological foundation of the plan. Discussion focuses on the metric developed to quantify the conservation value of each area in the region, the use of this metric as the primary means of identifying areas of high conservation value, and how we synthesized those areas and other conservation targets into a network of conservation lands that became the foundation for the comprehensive land-use plan. Lands within the network are managed principally for conservation of biological diversity. This has implications for all other types of land use as they will either be located outside the land conservation network or designed to be compatible with development guidelines within the network (described later in this chapter). We hope our case study provides a starting point for planners, local government officials, and land managers who seek to design plans using a scientific framework geared to conservation in exurban areas.

Planning Area

Pima County, Arizona, covers an area of approximately 23,786 km^2 (9,184 mi^2), slightly smaller than the state of New Hampshire. The entire county is characterized as basin and range topography with isolated mountain ranges surrounded by valleys, encompassing two somewhat distinct ecoregions (Omernik 1987) (Fig. 12.1). The central and western portions of the county are of lower elevation and characterized by Sonoran desert vegetation (Brown, Lowe and Pase 1980). The eastern portion of the county includes areas of much higher elevation, vegetated with coniferous forests and oak woodlands surrounded by either desert scrub or grasslands.

The region supports unusually high levels of biological diversity because of its geographic position between the subtropical and temperate climatic zones of North America that include two floristic realms, the Neotropic and Holarctic (Warshall 1995). Because the county is located at the edge of the tropics, many species occur

Fig. 12.1 Map of Pima County, Arizona. Source: Amanda Borens

at the northern limits of their geographic range. Further, the range of elevations (from about 300 to 2790 m) and strong regional gradients in precipitation across the region create a wide range of physiographic contrasts that provide conditions suitable for many species. Annual precipitation generally increases in amount from west to east and typically falls in a bimodal pattern with heavy "monsoonal" rains in summer and lighter rains in winter.

A Process for Large-Scale Conservation Planning

A plan's geographic scale dictates the suitability of alternative metrics appropriate for biologically based planning. At small spatial scales, planning is ideally based on comprehensive field inventories of biological resources. At the largest scales, planning is only realistically based on broad regularities that reflect large-scale patterns and processes. At intermediate regional scales ($\sim$10,000–100,000 km^2), comprehensive inventories for many natural resources are likely impractical. Therefore, biological planning at this scale is usually accomplished through a combination of site-specific information and broad-scale patterns, with expert opinion used to meld these two disparate information sources. But planning efforts based on expert opinion are challenging because conclusions often reflect the knowledge and interests of any particular group of experts. Thus, pinning assessments to objective and explicit criteria is difficult at times. We therefore sought to develop a process that, although based in part on knowledge of local experts, is quantitative, explicit, and replicable and provides a rigorous foundation for exploring a range of planning alternatives that can be revised as additional information becomes available. This process is summarized in Fig. 12.2. Given the size of the planning area, analyses relied heavily on a geographic information system (GIS). Data resolution varied by source, but the highest resolution data available were used. In nearly all cases, the fundamental unit of analysis [approximately 300 $\times$ 300 m (9 ha)] was based on the digital elevation model used for analyses.

Landscape-level approaches based on strategies to conserve species assemblages, vegetation communities, and ecosystems are all useful in developing conservation programs (Noss and Cooperrider 1994). Although each of these targets can guide evaluation of an area's potential conservation value, our approach began at the scale of individual species (see Fig. 12.2). Quantifying the conservation value of each landscape unit in the planning area required selecting a subset of species that represents well the range of structural and functional diversity in the region. In general, species are most valuable to this process when they use and inhabit the landscape (grain) across a range of spatial scales so that differences in the conservation value of alternative land allocations are maximized. Species provide less information if (1) they are either rare or very common because these traits provide the least discriminatory power at the landscape scale; (2) they occur only on lands that are already protected and will therefore be part of all alternative land allocations; and (3) there is limited biological information available about likely distributions and habitat requirements.

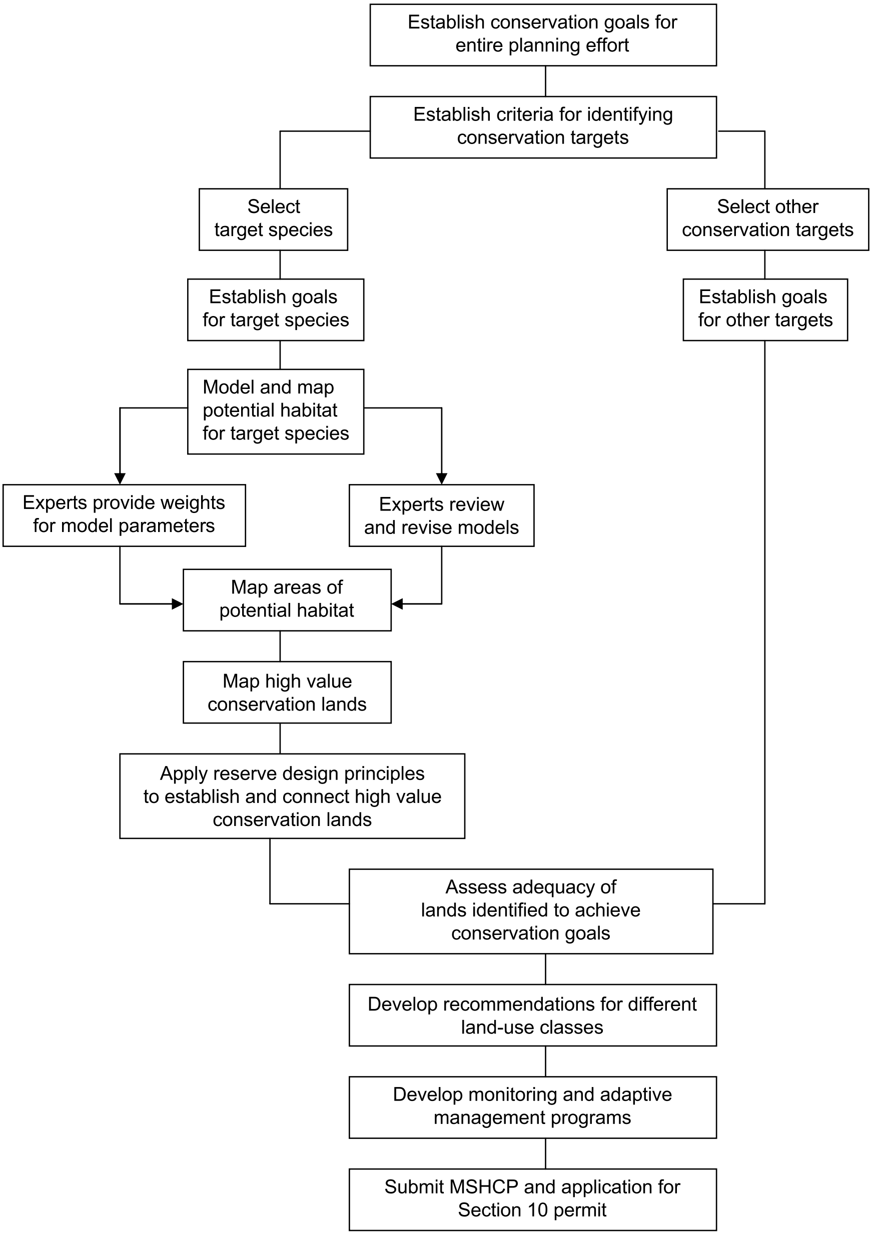

Fig. 12.2 A diagram of the process used to develop the SDCP. Source: Steidl, Shaw and Fromer

Provided that a large number of species inhabiting the full range of environments in a planning area are evaluated, the particular suite of species chosen should have little influence on the results of the analysis because a broad range of species should provide sufficient redundancy of environmental features needed to support biodiversity. In our process, a group of scientists with regional expertise in mammals, birds, fish, invertebrates, plants, reptiles, and amphibians identified species considered to be "vulnerable" in the region. Vulnerable species were defined as those thought to be declining throughout their range and where lands in the planning area were considered critical for their persistence. Scientists also considered species not thought to be at risk yet of considerable ecological or social importance to the region. Experts identified an initial group of 55 target species that was later reduced to 40 species as species with narrow distributions were eliminated. The final list included nine mammals, eight birds, seven reptiles, two frogs, six fish, and seven plants (see Table 12.1). More than 60% of target species were associated with riparian ecosystems, highlighting the importance of these environments to biodiversity in the desert southwest. A detailed account of each species was generated from the literature, including a description of its natural history, demography, taxonomy, geographic distribution, potential threats, and status as threatened or endangered. Most importantly, scientists identified each species' habitat requirements. This information was used for predicting landscape units that provide species habitat.

Table 12.1 Species used in development of the biological reserve. Species in bold face are federally listed as threatened or endangered

Group	Common name	Scientific name
Amphibians	**Chiricahua leopard frog**	*Rana chiricahuensis*
	Lowland leopard frog	*Rana yavapaiensis*
Birds	Abert's towhee	*Pipilo aberti*
	Bell's vireo	*Vireo bellii*
	Burrowing owl	*Athene cunicularia*
	Cactus ferruginous pygmy-owl	*Glaucidium brasilianum cactorum*
	Rufous-winged sparrow	*Aimophila carpalis*
	Southwestern willow flycatcher	*Empidonax traillii extimus*
	Swainson's Hawk	*Buteo swainsoni*
	Western yellow-billed cuckoo	*Coccyzus americanus*
Fish	Longfin dace	*Agosia chrysogaster*
	Desert sucker	*Pantosteus clarki*
	Sonora sucker	*Catostomus insignis*
	Desert pupfish	*Cyprinodon macularius*
	Gila chub	*Gila intermedia*
	Gila topminnow	*Poeciliopsis occidentalis occidentalis*
Mammals	Allen's big-eared bat	*Idionycteris phyllotis*
	Arizona shrew	*Sorex arizonae*
	California leaf-nosed bat	*Macrotus californicus*
	Lesser long-nosed bat	*Leptonycteris curasoae yerbabuena*
	Mexican long-tongued bat	*Choeronycteris mexicana*
	Merriam's mouse	*Peromyscus merriami*
	Pale Townsend's big-eared bat	*Plecotus townsendii pallescens*

Table 12.1 (continued)

Group	Common name	Scientific name
	Western yellow bat	*Lasiurus ega*
	Western red bat	*Lasiuris borealis*
Plants	Acuña cactus	*Neolloydia erectocentra. var. acuñensis*
	Gentry indigo bush	*Dalea tentaculoides*
	Huachuca water umbel	*Lilaeopsis schaffneriana recurva*
	Needle-spined pineapple cactus	*Echinomastus erectocentrus var. erectocentrus*
	Nichol's turk's head cactus	*Echinocactus horizonthalonius var. nicholii*
	Pima pineapple cactus	*Coryphantha scheeri var. robustispina*
	Tumamoc globeberry	*Tumamoca macdougalii*
Reptiles	Tucson shovel-nosed snake	*Chionactus occipitalis klauberi*
	Organ pipe shovel-nosed snake	*Chionactus palarostris*
	Giant spotted whiptail	*Cnemidophorus burti stictogrammus*
	Red-backed whiptail	*Cnemidophorus burti xanthonotus*
	Sonoran desert tortoise	*Gopherus agassizii*
	Ground snake	*Sonora semiannulata*
	Desert box turtle	*Terrapene ornata luteola*
	Mexican garter snake	*Thamnophis eques*

Goals and Guidelines

Conservation goals and objectives for regional planning should be established at levels needed to conserve identified targets, such as species or plant communities (Pressey, Cowling and Rouget 2003). This means that conservation objectives should be quantitative and based on the distribution and viability of targets, thereby providing an evidence-based approach to the planning process (Svancara et al. 2005). We sought to achieve our conservation goal at the landscape scale by identifying and establishing a network of conservation lands that provide the resources needed to maintain the collection of target species. The network incorporated additional areas known to support exceptional levels of plant and animal diversity, as well as protected areas that connect lands managed for their conservation value. To ensure achievement of these goals, we established several sets of specific objectives that provide a quantitative reference by which to compare alternative allocations of lands to the network of conservation lands.

The overarching goal of the planning process was to ensure persistence of the full spectrum of plants and animals in the region. Explicit conservation objectives were established for individual target species (fine-grain targets) and for conservation elements at larger ecological scales (coarse-grain targets) (see Fig. 12.2). Although these objectives were based on several different approaches, most were established in what has since been described as predefined analytical targets (Pressey, Cowling and Rouget 2003). Nearly all the objectives were set well above the targets established in other planning approaches that are policy driven (13%), conservation based (31%), or research based (42%) (Pressey, Cowling and Rouget 2003). For each target species, our goal was to make certain that adequate habitat is maintained in areas managed primarily for conservation to ensure long-term persistence of the species. Specifically, our objective was to ensure that between 75 and 100% of potential habitat for target species was classified as conservation land. The specific objective for each species varied with rarity and degree of endemism and by considering viability of individual potential populations and connectivity among areas thought to be inhabited by disparate populations. The objective for narrowly distributed endemics was established at 100% of potential habitat, and for more widely distributed species or those with significant populations outside the planning area, it was set at 75%. We also sought to ensure adequate representation of all plant communities and other important landscape features in the region in lands targeted for conservation (Table 12.2). This broader goal was established to complement the fine-filter approach of focusing on the conservation of individual target species (Haufler 1999).

Table 12.2 Plant communities, Brown, Lowe, and Pase (1980) classification, coverage in Pima County, and percentage of that area included within the Conservation Lands System (CLS). Other classification includes all plant communities that represent areas <5 km^2 combined

Plant community	Classification	Area in county (km^2)	Area included in CLS (%)
Pine forest	122.32	20.5	100.0
Pine	122.62	49.0	97.0
Oak–pine	123.3	24.9	100.0
Encinal	123.31	699.0	92.1
Oak–pine	123.32	111.6	81.0
Manzanita	133.32	61.4	36.0
Mixed sclerophyll	133.36	43.8	65.6
Scrub–grassland	143.1	545.5	96.9
Sacaton	143.14	11.1	100.0
Mixed grass–scrub	143.15	3950.5	93.4
Scrub disclimax	143.16	8.5	100.0
Creosote-tarbush	153.21	42.0	96.5
Chihuahuan mixed scrub	153.26	14.2	100.0
Sonoran desert scrub	154.1	513.6	78.1
Creosote bursage	154.11	3961.1	62.7
Paloverde-saguaro	154.12	12482.7	28.1
Saltbush	154.17	40.4	100.0
Interior riparian deciduous forest	223.2	23.6	100.0
Mesquite forest	224.52	107.2	92.5
Cottonwood-willow	224.53	13.7	99.1
Sonoran riparian scrub	234.7	28.5	93.8
Riparian scrub	234.71	25.4	36.0
Strand	254.7	21.2	88.3
Others		19.7	99.5

Modeling Potential Habitat

We explored several approaches to identify areas of high conservation value, all derived from geographic distributions of target species. We considered distributions based on the scientific literature, existing databases of documented locations (e.g., Natural Heritage Program databases), and expert opinion. Although aspects of each of these sources were incorporated in the design process, we relied primarily on models that predict the potential of each landscape unit to provide habitat for each target species. We chose to model potential habitat because it offered several distinct advantages over other alternatives. For example, published distributions are too general at and above the regional scale because they focus on the geographic limits of a species and typically include large areas that are uninhabitable by the species of interest. Documented locations are uneven in geographic coverage and are often biased toward areas commonly traveled and underrepresent remote areas. Expert opinion also has significant limitations because “on-the-ground” knowledge is rarely complete. Most species experts, however, know well the environmental features that provide habitat for a species. The last and perhaps most significant advantage of the approach is that habitat can be identified even if the species is currently absent from an area. This is especially likely for many jeopardized species. When populations are suppressed, there are almost certainly areas on the landscape that provide the full range of conditions necessary to function as habitat for a species, yet are currently unoccupied. Despite being unoccupied, these areas provide important targets for conservation because they identify areas in which threatened and endangered species might recover. Therefore, predicting the distribution of potential habitat for each species provided useful information and served as the foundation of the conservation plan.

We developed a spatially explicit model that predicts the distribution of potential habitat across the planning area for each target species, based on values established for four major categories of environmental features represented by 130 variables, each classified for every landscape unit. Environmental features included vegetation and land cover characteristics (60 variables, e.g., mixed broadleaf forest cover, agriculture), hydrology characteristics (11 variables, e.g., perennial stream width, groundwater depth), topographic and landform characteristics (45 variables, e.g., elevation, slope, aspect), and geologic characteristics (14 variables, e.g., soil type, presence of carbonates) (Fig. 12.3). Each feature was represented in a GIS layer.

Values used to represent the importance of each environmental feature to each species were based on expert opinion. We asked species experts to score the value of each environmental feature on the basis of its relative importance to habitat for each species, from unimportant (value = 0) to essential (value = 3). Experts were also asked to identify whether the absence of a specific feature kept an area from functioning as habitat for the species. For example, if elevation of a landscape unit was beyond the elevational limits of a species yet contained all other necessary habitat features, the unit was classified as having no potential as habitat. We then computed a simple sum of scores for the environmental features relevant to a species, thereby producing a suitability surface that represented the distribution of habitat

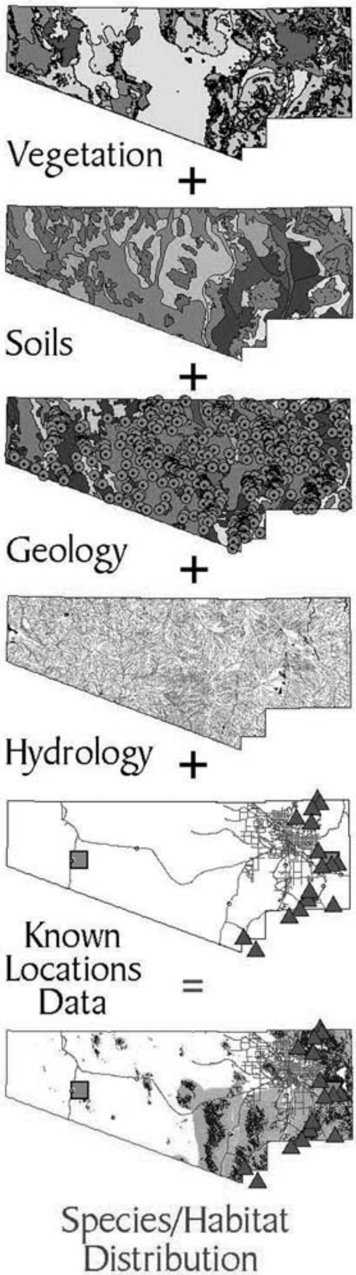

Fig. 12.3 Stylized illustration of several environmental features used for modeling the distribution of potential habitat for each species and the known locations and final model for one species. Source: Steidl, Shaw and Fromer

potential for each species on each landscape unit. The suitability surface was based on the presence of environmental features important to habitat for the species and classified as none, low, moderate, and high.

The modeling process was iterative (Fig. 12.2). Initial distributions of potential habitat were evaluated by experts and compared with a database of known locations; models were subsequently refined iteratively until experts thought the model provided a parsimonious representation of habitat potential for the species. This process resulted in a distribution of potential habitat for each target species across the planning area as predicted from biological and physical characteristics of each landscape unit (Fig. 12.3).

After exploring a series of alternatives, we reduced the range of scores for habitat potential for a species on each landscape unit into two classes: high potential and less than high potential. A GIS was then used to overlay areas of high potential habitat for all species to produce a map portraying species richness (i.e., number of species with high potential habitat value) for each geographic unit. This metric (species richness of target species) became the fundamental measure we used to classify the landscape into a collection of discrete polygons representing different levels of biological value on which we established the Conservation Lands System.

Conservation Lands System

After estimating the number of target species on each landscape unit—species richness—we evaluated the spatial arrangement, overall coverage, and success that different levels of species richness achieved toward meeting our conservation objectives (Fig. 12.4). Ultimately, areas with species richness of three or higher were

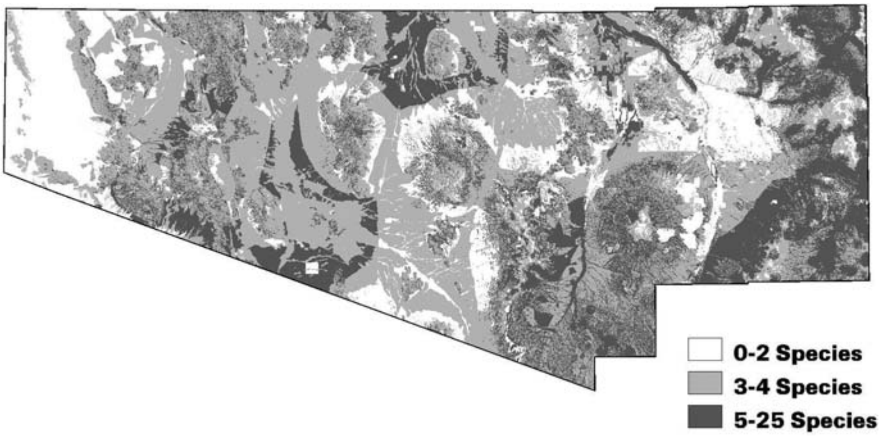

Fig. 12.4 Predicted richness of target species in Pima County. Areas with three or more species were considered to be of high conservation value and provided the starting point for the network of conservation lands. Source: Steidl, Shaw and Fromer

classified as lands with the highest conservation value. These lands were considered necessary components in all possible land allocation alternatives. Therefore, these areas became the starting point for the conservation plan, including the network of conservation lands called the Conservation Lands System (CLS). Lands with species richness of five or more were classified as areas of highest biological value. These lands were classified as the basis for establishing areas designated as "biological core" to represent their high conservation value. Lands with species richness of three or four were classified as areas of moderate to high biological value. These were identified as "multiple-use" lands, representing their importance for conservation, yet distinguishing them from lands classified as biological core.

The level of species richness used to distinguish lands of differing conservation value will be unique to each planning process and region. Ultimately, the decision will be the product of the number of target species used in a planning process, the range of environments in the target landscape, and the goals established for each plan. In our case, the levels of species richness identified a parsimonious network of lands that achieved the goals and objectives established for reserve design.

Each land classification within the CLS was associated with conservation targets that complement anticipated land-use change. The classifications ranged from 66.7 to 95%. Lands classified as "biological core" mandated a lower limit of 75% conservation (i.e., allow land-use change of 25% or less), "multiple-use" lands required a lower limit of 66.7% conservation, and "riparian areas" called for a lower limit of 95% conservation.

Setting boundaries for contiguous landscape units that share the same classification—called a "patch"—followed guidelines reported in the scientific literature on reserve design that maximizes conservation benefits in each patch and across the network of patches. For example, we sought to maximize the size of each patch, minimize distances between adjacent patches, maximize contiguity, and minimize fragmentation within and among patches. Additionally, we adjusted boundaries to better meet the conservation objectives established for target species and plant communities (see Table 12.3).

Ultimately, lands within the CLS covered 88% of the 13,723 km^2 planning area and are predicted to preserve an average of 75% of potential habitat (range = 28–100%) for the target species at build-out. Within the 12,073 km^2 CLS, 57% of the lands are federal, 24% state, 14% private, and 5% county/city. With a high percentage of land in public ownership, achieving the established conservation objectives for CLS lands seems tenable, although a portion of state-owned land remains open to development. Currently, about 4% of the CLS area is developed, with an additional 4% predicted to be developed in the future (ESI Corporation 2003). Although the quantity of development predicted at build-out will total <10% of the overall CLS, nearly all current and future developments are concentrated in the eastern portion of the county, which compromises the conservation value of these areas considerably (Fig. 12.5).

Table 12.3 Additional biological elements incorporated into the Conservation Lands System for the Sonoran Desert Conservation Plan

Group	Special element
Plant communities	Desert ironwood desert scrub (154.12 and 154.13)[a]
	Douglas fir-mixed conifer forests (122.61)
	Grasslands on unincised floodplains (143.1)
	Oak–scrub grassland ecotones (123.31 and 143.1)
	Sacton grasslands (143.14)
	Saltbush desert scrub (154.17)
	Upland grasslands, mixed grass–shrub (143.15)
Riparian areas	Cottonwood-willow forests (223.21 and 224.53)
	Mixed-broadleaf deciduous forests (223.22)
	Mesquite woodlands (224.52)
	Sonoran riparian scrub (234.71 and 154.1)
	Cattail (244.71)
Aquatic	Streams with perennial and intermittent flow
	Springs, cienegas, and other aquatic environments
Geologic and other	Caves, mine adits, and bridges occupied by bats
	Limestone outcrops
	Talus slopes

[a] Brown, Lowe, and Pase (1980) biotic community classification.

Riparian Areas as a Foundation for Connectivity

Riparian ecosystems typically support more and different species than adjacent upland systems in the southwest and are especially crucial to supporting biodiversity in desert biomes (Zaimes 2007). Riparian systems are also especially vulnerable to degradation imposed by development, as illustrated by the high loss of riparian plant communities compared to all other plant communities in the region (Baker et al. 2004). In addition to providing habitat for riparian species, riparian areas function as corridors for animal movements, especially across arid landscapes. These corridors form a natural network that links disconnected conservation lands (see Chapter 10 for a discussion of riparian conservation). Consequently, the conservation goals set for riparian areas are the highest among all lands (95%), in part because they foster connectivity across the landscape.

To enhance connectivity, landscape areas with current or anticipated barriers to animal movements were identified because they reduced the large-scale effectiveness of the CLS. We also recommended removal of, or modification to, existing barriers to facilitate movement and enhance connectivity among conservation lands, particularly those associated with major transportation corridors (see Chapter 5 for discussion of wildlife corridors and connectivity).

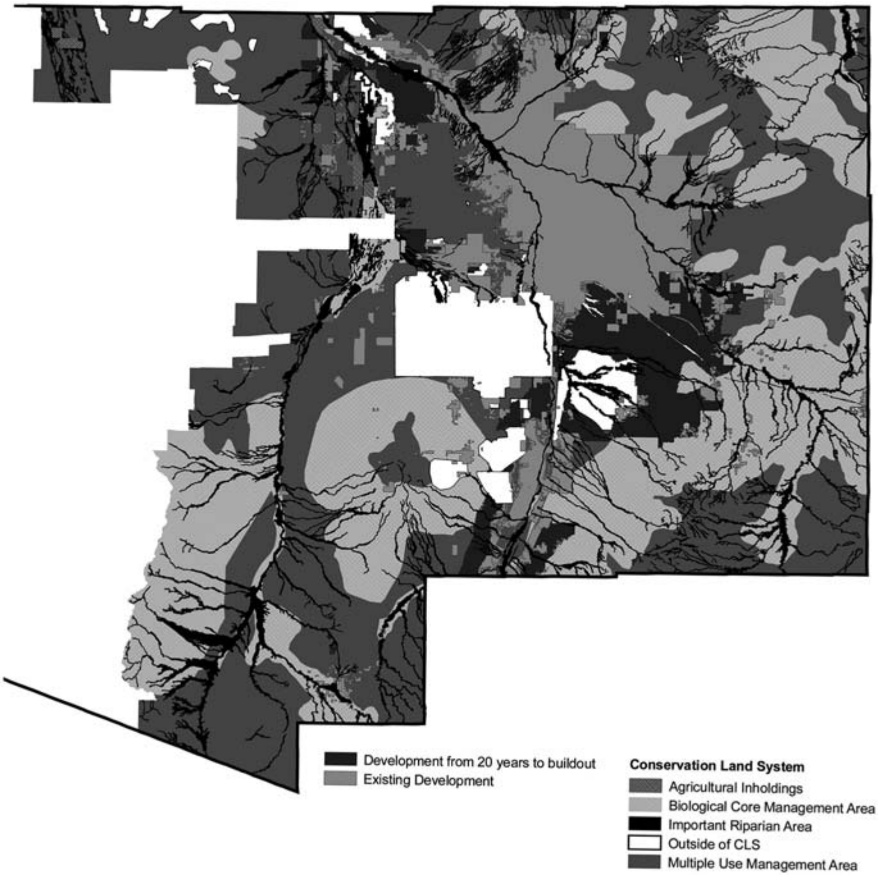

Fig. 12.5 Conservation Lands System and areas of existing and predicted future development in eastern Pima County. Source: Steidl, Shaw and Fromer

From Conservation Planning to Conservation Reality

No matter how carefully designed or how much biological potential they embody, conservation plans accomplish little unless land management reflects the plan. Without question, the majority of conservation plans have not realized their full potential because of the expense involved and/or the opportunity costs imposed by conservation rather than development. Nonetheless, many strategies foster the success of large-scale conservation plans, including conservation easements, transfer of development rights, incentives to private landowners, and the outright purchase of lands (see Chapter 13 for a discussion of land conservation devices). In Pima County, a range of alternatives have been employed, including ratification of a county-wide bond initiative in 2004 that provided \$174.3 million for acquisition of high conservation value lands. Perhaps the most far-reaching and effective strategy, however, has been a change in planning guidelines at the county level that reflect CLS boundaries and the conservation goals set forth in the SCDP. In Pima County, land-use change must follow a series of guidelines that ensure that development does not exceed conservation targets established for all lands within the CLS.

Conclusion

A region-wide approach to conservation planning enables a framework that conserves biodiversity while minimizing the disjointed array of conservation lands that result from small-scale conservation driven primarily by opportunism. A synthetic approach to regional planning is more effective for conservation and reduces the need for future listings under ESA, hence minimizing the regulatory challenges faced by developers.

Ultimately, conservation-minded regional planning consists of a set of consequential experiments that respond to the uncertainty of large-scale efforts such as the SDCP. The effectiveness of ambitious plans, such as the SDCP (or any MSHCP), can be reliably established only by measuring temporal changes in the natural resources that plans seek to conserve. Plans, therefore, must be accompanied by a rigorous monitoring program designed to quantify changes in natural resources over time and measure responses to land management actions. Although HCPs require a monitoring plan, the strategies that accompany many HCPs have been criticized (Kareiva et al. 1999). The monitoring and adaptive management programs developed for the SCDP respond to these criticisms by moving beyond requirements for MSHCPs. This revised approach ensures persistence of all biodiversity in the region by moving from monitoring single species to a broader and more ambitious goal of monitoring aspects of ecosystem structure and function, as well as threats across planning areas.

Land-use plans must incorporate change by being sufficiently flexible. As lands transition to their future uses, the planning footprint will inevitably change in response to unforeseen social pressures, novel conservation opportunities, and new scientific information. Incorporating these changes requires that planning frameworks incorporate new knowledge and respond accordingly; this is the purview of adaptive management. Land-use plans are only the first step in developing responsible regional management and conservation plans that are ultimately refined as uncertainty is reduced through rigorous monitoring and adaptive management (Wilhere 2002). Although much effort is devoted to initial planning, monitoring and adaptive management receive far less attention, including fewer financial and intellectual resources. Until the effectiveness of plans is evaluated rigorously and new information is collected to refine land-use decisions, regional HCPs pose a risk to the species they are designed to protect.

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Chapter 13
Mitigating Environmental Problems in Exurban Development: An Overview of Rural-Specific Planning Devices

David W. Marcouiller and David Tremble

Abstract The popularity of exurban living challenges regional planners as they seek to conserve natural resources, scenic amenities, and natural open space. This chapter highlights planning tools and techniques that have proven successful in preserving environmental integrity at regional- and site-specific scales. The chapter describes the unique context that colors rural land-use planning, describes a typology of tools and devices that promote rural land conservation, and provides a case study that highlights conservation efforts in rural South-Central Wisconsin.

Introduction

Rural regions experience land-use and environmental problems, which should be approached with awareness of their distinct sociopolitical and economic contexts. These unique problems and contexts are often at odds with how land-use planning takes place in urban and suburban areas. Rural land-use planning, for example, seeks to alleviate negative environmental outcomes that threaten natural amenities and open space, while urban land-use planning responds to different priorities (and problems) that arise from high population densities and crowded development patterns. These differences require creative and context-specific approaches to rural land-use planning, especially in view of the pace of exurban residential and commercial development in amenity-rich rural regions.

Special circumstances lead to the rural land-use planning dilemma. Given the power of central cities, it is not surprising that the forces affecting urban and suburban land use differ from those at play in exurban and rural areas. Beyond the suburban fringe, population densities decline, open space increases, land is less expensive, and land-use regulations are often less restrictive. Market forces in both commodity

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D.W. Marcouiller (✉)
Department of Urban and Regional Planning, University of Wisconsin-Madison,
Madison, WI 53706
e-mail: dwmarcou@wisc.edu

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and factor markets dominate rural land-use decision making, which means that the maintenance of land uses and environmental conditions deemed socially appropriate becomes more difficult, yet no less important. Further, devolution (the transfer of authority from centralized to more local units of government) adds complexity to the array of issues that must be addressed locally because rural policy making occurs often within the lowest scale of decision-making expertise (Westphal 2001). Clearly, regional placement along the urban-to-rural spectrum dictates both the appropriateness and the effectiveness of alternative open-space planning models (Maruani and Amit-Cohen 2007).

Rapid transitions in rural land use support the need for sound rural land-use planning. Indeed, turnaround migration to rural regions has persisted for the past quarter century (Johnson and Beale 1994; Frentz et al. 2004; Chi and Marcouiller 2008) causing dynamic pressures on rural land markets driven by a diverse set of frontier seekers. The "drivers" of exurban residential development are complex and include agricultural suitability, transportation and services, natural amenities, past development patterns, and economic and recreational characteristics of nearby towns (Gude et al. 2006).

The dilemma of land-use planning beyond the suburban fringe has received more attention in recent years, especially the development of planning approaches and devices that seek to manage rural land-use change within a rapidly developing context. To a large extent, the progression of tools has led to strategies that maintain land uses deemed socially desirable, but do so in a way that mimics market forces. These quasi-market tools provide incentives for people to manage land in prescribed ways.

As illustrated by Maruani and Amit-Cohen (2007), several elements of open-space planning models (or approaches) are sensitive to levels of urbanization. Fundamental needs, problems, and planning processes are elements that differ by regional placement along the urban-to-rural spectrum. This leads to the selection of appropriate tools used to affect land-use change that are tied to professional planning competence. Indeed, some have argued that inappropriate planning approaches by well-meaning planners can actually hasten the pace of exurban development, leading to outcomes that work against core open-space and land-use planning objectives (Esparza and Caruthers 2000; Allan 2003). Land-use planning in rural places requires an understanding of unique attributes of rural productive activities, economic structure, and the inclusion of diverse stakeholder interests, motivations, and levels of participation.

This chapter focuses attention on the unique context within which rural land-use planning takes place. Several questions provide the basis for how this chapter is organized. First, how does *rurality* provide context for land-use planning? What specific elements of the rural and exurban landscape provide key needs for open-space planning? How can public and private initiatives come together to affect market and quasi-market initiatives that act as incentives to exurban development? Finally, how can we characterize devices to affect open-space development activities that are specific to rural or exurban areas?

The chapter is organized into three subsequent sections. First, we outline key elements that characterize rural and exurban land-based issues. Second, a typology of devices used to affect exurban development is outlined. Finally, we present a case study that demonstrates how land-use devices can be used effectively to conserve valuable rural lands. The study examines land-use planning in a fast-growing rural community of South-Central Wisconsin, where a range of growth management and natural resource protection strategies have been applied.

The Rural Land-Use Planning Context

Rural land use and the planning devices used to affect environmental attributes and open space can be understood as unique along several specific themes. For purposes of this review, key land-use attributes include land, natural resources, amenities, infrastructure, and sociopolitical elements. Each of these elements has specific rural distinctions, which lead to concerns that affect land-use planning. These aspects are outlined in Table 13.1and include descriptions of their distinction and the specific aspect that leads to relevancy within a land-use planning context.

Note from Table 13.1 that particularly distinct rural elements involve commodity production as the dominant land use, the joint nature of natural resource production, nonlocal demands for nonmarketed outputs, generally lower levels of public infrastructure, and remoteness. These distinctly rural elements play an important role in defining the land-use planning context. As noted in Table 13.1, these planning contexts can be summarized as lax regulatory environments, high incidence of negative externalities resulting from traditional commodity production, nonlocal subversion of local ownership as a stakeholder issue, lack of in-place infrastructure, and general resistance to change.

The rural context, as outlined in Table 13.1 combined with rapid transitions toward amenity-based development currently underway, involves key sociodemographic and land-use concerns. Lower population densities in rural regions lead to differing demands for land and the natural resource base. Rural households tend to be more reliant than urban households on land and natural resources as sources of income. They exist in a dispersed fashion surrounded by open spaces used for commodity production. Further, rural residential, commercial, and industrial uses are not as confined by other like uses (relative to urban and suburban settings). Generally lower demands for land matched with abundant supply translate into less-expensive rural property (on a per-acre basis). Lower land prices alone provide less incentive from the market for development that is compact.

Urban and suburban (or metropolitan) incomes have long been seen as growing disproportionately when compared to rural (or nonmetropolitan) incomes (Redman et al. 1992; Hansen 1995; Renkow 1996). Further, there have been historically lower levels of income inequality in rural areas (compared to metropolitan) due, in large part, to the generally lower incidence of high-income households (Amos 1988; Levernier, Rickman and Partridge 2000; Kim, Marcouiller and Deller 2005). As a result of the disparity in wealth and the growing interest in pursuit of outdoor

Table 13.1 Unique exurban characteristics and sociopolitical context

Characteristic	Distinction unique to rural/exurban	Land-use planning concern
Land	Commodity production (agriculture, forestry, mining, etc.) dominate land use. Residential density is low; often single family residence tied to large parcel sizes without clustering. Residential, commercial, and industrial uses less confined	Large parcels under individual private control within generally lax regulatory environment exist and are relatively easy to subdivide. Land affordability and relative lax regulatory structure encourage exurban development
Natural resources	Natural resources characterized by jointness of production. Prices and economies of scale drive intensity of commodity production; intensity of commodity production often incompatible with amenity uses	Commodity production can present negative externalities that affect noncommodity land uses. Trade-off and tension between commodity and amenity uses of natural resources
Amenities	Natural amenities dominate and exist as nonmarketed resources whose values are often proxied by land price. Demand for amenity uses largely driven by nonlocals	Long-term distributional implications related to income; often distinguished by nonlocals subverting local ownership
Infrastructure	Low-density rural secondary and tertiary roads with shoulders; often broad ditches extend to undeveloped private lands. Publicly provided sewer and water rarely extend beyond town boundaries.	Lack of prepositioned planning assets; distance between communities often subvert economies of scale and consolidation
Sociopolitical	Lower densities dictate fewer opportunities for personal interaction; conservative personal and property rights values dominate; nonlocal property owners exhibit disproportionate economic assets and wealth	Rural residents exhibit a general tendency to resist change; less diversity of public opinion. Nonlocals lack direct ability to vote in local elections but exert pressure on local decision making

leisure opportunities, nonlocal (primarily urban and suburban) demands for rural land used as an amenity have grown and these demands have usurped control of land resources. This is particularly evident in rural areas with significant natural amenity resources. Examples include regions with lakes, coasts, and mountainous terrain where second homes, hobby farms, and hunting lands dominate local residential patterns.

Additionally, historical elements and current transitions provide important contextual aspects to rural land-use planning. The residents of rural regions tend to have a strong affinity for traditional rural agrarian society and have general concerns about the rapid transformation underway due to technology, demographic shifts, increased infrastructure and facility development, increases in disposable income, and new-age rural frontier seekers. Indeed, newcomers, differing value structures, and the distribution of who benefits at whose expense appear to be central concerns for rural people.

The second related element is a general distrust for the hegemony imposed upon rural residents by urban constituents. In general, rural people and their rural policymakers are slow to embrace regulatory elements that control key aspects of their livelihood. Land use is an excellent example of a central component of rural livelihood that does not have a long regulatory history. Long pointed to as a key problem of land-use planning in rural regions, the penchant for home rule and local control of land and its uses precludes broader regional elements of concern (Geisler and Martinson 1976).

Strong rural agrarian sentiments and general distrust of urban hegemony combined with inexpensive land and a general lack of regulation set the stage for rural-specific planning approaches. These distinctive elements provide understanding and conceptual attributes specific to the rural exurbanization process. Further, the context of public policies often acts against their own stated policy objectives. Indeed, duplicitous rural outcomes confuse and fuel cynicism toward planners and planning in general.

Examples of misapplied land-use planning tools that generate unintended consequences and counter stated objectives are found throughout the rural landscape. They are most pronounced in rural lands located near metropolitan areas. For instance, farmland preservation tactics often focus on use-value taxation policies that provide lower rates for productive agricultural lands. Such policies benefit farmers who seek to keep agricultural lands in production. At the same time, however, these policies often stimulate land banking by speculators intent on converting farmland to residential purposes. But the underlying problem that fuels land conversion is low commodity prices, which lead to highly competitive profit margins. Rural zoning can create zones where agricultural use takes place. While dictating specific rural land use, zoning does nothing to stimulate commodity prices that make farming more profitable. Furthermore, zoning variances, which are frequently used to sidestep designated land-use restrictions (in this case, for agriculturally zoned land), are highly political, particularly where pressures for land conversion are great. A final example of counterfactual land-use planning comes from the common situation in which we simultaneously implement farmland preservation policies *and* right-to-farm legislation designed to protect farmers from nuisance complaints launched by neighbors. The combination of these policies can work against farmland preservation as neighbors advocate for land-use conversion in order to lessen nuisances. Tax-valuation policies that keep agricultural land prices low hasten the land conversion process.

Indeed, rural regions have distinct elements that require creative devices to address key land use and natural resource needs. Commodity production as a dominant land use combined with resource-dependent households and nonlocal demands for nonmarketed outputs obfuscate land-use planning objectives. This said, there is a need for sound land-use planning and the application of appropriate planning tools that are sensitive to the rural context.

Devices Used to Affect Open Space

Land-use tools are policies or programs that regulate land use or create incentives to encourage or assist individuals in exchanging rights in land, consistent with a set of broader land-use policy objectives. Economic incentive policies provide financial rewards (or penalties) for undertaking specified actions that support (or undermine) societal land-use goals. The following outline categorizes land-use planning devices and provides a useful perspective into current rural-specific initiatives.

For purposes of this review, devices used to affect rural land use can be grouped into four distinct categories. The first and most obvious category includes collectivization or the public ownership of land and its management. The second category includes regulatory mechanisms, followed by voluntary and educational or outreach-oriented devices. In discussing each type of device, readers are referred to a summary of the typology presented in Table 13.2.

Collectivization Devices

It is important to acknowledge an obvious and highly successful mechanism that society uses to control rural land use: direct control of land by collective ownership. Governmental units own and control significant amounts of land and manage these lands based on constituency needs and desires. Federally owned land is significant in both the United States and Canada. For example, across the Western United States (and to a lesser extent throughout the Midwest, South, and East), the federal government (through the USDA Forest Service and the USDI – Bureau of Land Management, Park Service, Fish and Wildlife Service, Bureau of Reclamation, and Bureau of Indian Affairs) controls vast tracts of land. In Canada, federal lands (referred to as “crown lands”) dominate the vast expanse of sparsely populated Northern wilderness. States also own land, typically managed as state parks, forests, or recreation areas. Additionally, county governments own and manage significant parcels of land as county forests (particularly evident in the Lake States of Minnesota, Wisconsin, and Michigan). Finally, local and regional units including sovereign lands controlled by First Nations provide examples of government-controlled lands managed for a multitude of uses.

Publicly owned and managed lands have a historical evolution with roots of acquisition falling into one of four basic mechanisms. Much of the public land base originated as residual parcels after settlement (leftover lands following settlement patterns). This is particularly true for federal lands in the Western United States, crown lands across Canada, and the vast wilderness of Northern Europe (Scandinavia). Second, default of private owners on property tax payments led to tax

Table 13.2 Typology of devices used to affect rural land use

Type	Definition	Context and responsibility	Examples
Collectivization	The acquisition of land and associated natural resources by local, state, and/or federal government	Government and/nonprofit institutions including federal, state, or local units of government often in collaboration with land trusts	Park reserves Recreational corridors (trails and watercourses) Forest reserves Rangeland reserves Marine reserves (and water bodies)
Regulatory	Rules and regulations instituted by government agents to affect the ownership, management, and/or activities of land and associated natural resources	When enforced, acts to provide framework for land use, instituted by federal, state, or local units of government	Zoning and related ordinances Environmental legislation (e.g., NEPA, endangered species, etc.)
Voluntary	Private actions to ameliorate environmental problems; often stimulated by government agent encouragement and/or incentives	Requires incentive structures often in concert with public entities. Responsibility for implementation lies with private landowners, developers, and individuals often driven by incentives regulated by state or local governments	Conservation reserve program Purchase of development rights Transfer of development rights Impact fees
Educational	Programs intending to affect the implementation of tools or devices developed to improve the understanding of environmental problems, solutions, and/or approaches	Outreach and marketing information. Responsibility of Land Grant Universities, federal, state, and local governments, and special interest groups	Extension programs Applied research programs Information and Education Interpretation programs Documentaries Marketing efforts

reversion of land to government authorities. These payment-defaulted lands created publicly owned land bases. This has been a significant factor in regions characterized by marginal agriculture (based on fertility or the need for irrigation) where past public policy provided incentives for agricultural conversion but owners eventually could not profitably produce agricultural commodities (Stier, Kim and Marcouiller 1999). Third, land can come into public ownership through the exercise of eminent domain. This is a typical mechanism for acquiring land for infrastructure (roads, utility rights of way, among others). Finally, units of government are increasingly involved in land markets using outright purchase as a mechanism to gain control of land. This is significant where stewardship programs have been set up to acquire lands with sensitive ecological resources.

Collective ownership of rural lands has been an increasingly important focus of nonprofit institutions, including land trusts and foundations. For instance, The Nature Conservancy has increasingly used the practice of serving first as a recipient of philanthropic donations of land then turning over control to public agencies (most often state agencies that manage park land).

Regulatory Devices

Zoning is a typical tool used by urban planners to define appropriate land uses. Simply stated, zoning delineates areas, or zones, in which certain activities are allowed to take place. In addition, zoning regulations and their related ordinances often specify details about the physical design of residential, commercial, and industrial parcels that must be followed by the owner for development to take place. Although important in directing urban form, zoning has limited value in addressing exurban development.

Zoning has not been widely applied throughout rural North America. This is probably due, in large part, to political resistance to overt regulations that dictate how land can be used in rural areas. Zoning of land assumes that planners delineate fixed boundaries around zones and that land use and development within these zones follow regulations set forth in the zoning ordinance. Another regulatory element often associated with zoning is the application of ordinances that specify how land is subdivided from large parcels. Where rural zoning exists, one specific element that can have a dramatic affect on how exurban development plays out deals with subdivision delineation ordinances, sometimes referred to as rural land division ordinances (Olson 2006).

The urban growth boundary (UGB) is a zoning mechanism used to contain the physical expansion of urban areas (with an array of benefits and costs). While beyond the scope of this chapter due to its urban focus, the UGB requires a brief discussion (interested readers are referred to Van Kooten 1993; Evans 2004; Abbott and Margheim 2008). Urban growth boundaries are a very tight form of urban growth control that has seen limited implementation. Urban growth boundaries are most often associated with Portland, Oregon, but are used across the state. As part of Oregon's Statewide Planning Program, UGBs were defined for 241 cities with populations of 2,500 and greater. Since the 1970s, other metropolitan regions, such as San Francisco, CA, Charleston, SC, Denver, CO, and Knoxville, TN (to name a few), have adopted UGBs.

Urban growth boundaries literally entail drawing a line around a city – a boundary – within which future growth is expected to occur over a specified planning horizon. Development within and outside the growth boundary adheres to publicly determined land-use objectives. Urban growth boundaries were developed with multiple objectives in mind. Most advocates of urban growth boundaries point to their success in limiting the spatial extension of costly public services and facilities, the preservation of land for agricultural purposes, greater certainty for people who own, use, and invest in land at the edge of cities, and better coordination between city and county land-use planning. The use of UGBs to control sprawl continues to be a topic of contemporary policy discussion. The efficacy of UGBs to attain policy objectives remains a matter of contemporary political debate and provides an important applied research topic. Recent empirical work suggests mixed results, indicating it is too early to draw conclusions about the efficacy of urban growth boundaries as a viable land-use tool (Lang and Hornburg 1997; Phillips and Goodstein 2000; Anas and Pines 2008; Cho, Poudyal and Lambert 2008).

Voluntary Devices

The public will is often administered through government incentive programs that direct the course of land use. These take the form of positive and negative incentives. A wide variety of programs have been established to address land management and land-use practice across the United States. In addition to the federal government, state and local governments have a variety of incentive programs that target land use, broadly defined. Broad categories of publicly provided incentive programs include rental payment programs (e.g., the Conservation Reserve Program), subsidies (e.g., Stewardship Incentives Program and state-administered, cost-share programs), and land purchase programs (e.g., federally administered Land and Water Conservation programs).

Positive incentives programs, whether they provide up-front rental payments or cost-share payments, perform two essential tasks. First, they provide an incentive by lowering the landowners' relative costs of production. For instance, if in return for meeting program objectives, government provides financial assistance to landowners in the form of tree seedlings, technical expertise, or annual rental payments, landowners will more likely maintain land as a managed forest. From the landowner's financial perspective, this lowered cost of production may allow timber-producing lands to better compete with alternative land uses. The second essential task of any incentive program is to translate societal wants and needs into land management actions. For example, before receiving governmental financial assistance, program involvement often requires that the landowner agrees to legally binding contracts or other enforcement mechanisms that specify how land will be used and managed. In this way, socially determined goals are injected into land-use decisions.

The use of development impact fees is a good example of negative incentives that intend to affect spatial patterns of land use. Listed here as an incentive to more rational development, impact fees seek to remove inefficiencies and inequities associated with private decisions (sometimes referred to as market failures or failures to efficiently and equitably translate true market costs and returns to market clearing levels) by more closely linking benefits with actual costs to local governments. Impact fees are fees assessed to developers in order to more fully capture the true costs of development (Evans-Cowley, Forgey and Rutherford 2005; Burge and Ihlanfeldt

2006). As background, it is important to note that new residential developments at the urban fringe (and elsewhere) often create significant additional costs for service provision and facility development that are publicly offered by towns, municipalities, and other smaller units of government. Examples include sewer and water provision, roads, and sidewalks.

While development impact fees are now a fairly standard item in most urban centers that attempt to assess developers the average costs of providing these services and facilities, their application within exurban America remains limited due to high costs. This is particularly important with sewer and water as any use of excess capacity within a system represents an incremental step toward very high fixed-cost facility upgrades. Simply stated, if developers use all the excess capacity, the sanitary authority is forced to build a new sewage treatment plan or water treatment facility. Development impact fees result in a developer internalizing the negative fiscal externalities of urban expansion. Fees and regulations imposed on developers at the urban fringe can have important affects on the rate of development (Skidmore and Peddle 1998; Mayer and Somerville 2000). They can often result in a "dampening" of development pressure along the urban fringe and create more equitable relationships between cities and developers.

Several new initiatives attempt to split the various rights and responsibilities of land ownership. These are often initiated collaboratively between landowners, private special interest groups, and local units of government – thus they are included here as "quasi-public" partnerships. There are two categories of land-use tools that assign various land-use rights for the purpose of attaining open space or conservation demands. These include purchase of development rights (or PDRs) and transferable development rights (or TDRs). Both PDRs and TDRs are tools that rely on development rights independent of land ownership. The two approaches involve severing the right to develop land from the rights to exclusive ownership (Taintor 2001).

Albeit expensive, the outright purchase of development rights provides a rather straightforward rural land-use planning device. PDRs can affect development by providing financial incentives to landowners for their rights to develop land. Again, the essence of this approach relies on separating out the rights to own land from the rights to develop that land. The manner in which development rights are communicated often takes the form of permanent deed restrictions that are clearly specified and legally binding. These deed restrictions permanently separate the rights of owning land from the rights associated with the development of that land. Often, these development restrictions are specified in the deed as *conservation easements* (Rissman and Merenlender 2008).

With PDR programs, these payments for development rights can be made in the form of outright payments to landowners or in the form of long-term tax breaks in return for restrictive deed language. Landowners agree, for a "fee," to irrevocably restrict the deed to their land so as to prohibit certain uses.

The PDR approach has been successfully applied in a variety of rural situations throughout the United States during the past 20 or so years. Experience, however, has shown that wide-scale application of PDRs is an extremely costly endeavor for local, regional, or state units of government. With increasingly tight fiscal conditions and the devolution of an array of social programs, very few units of government can afford to make payments or forego the tax revenue to implement PDR programs.

The ability to trade development rights requires proximity to rapidly growing urban areas and adds complexity and institutional structure to the application of land-use planning devices. Instead of purchasing the rights to develop, landowners trade parcels of significant environmental quality with lands located within a development zone, hence the term "tradable development rights" or TDRs. TDR programs can be useful land-use tools for attaining previously identified goals to both maintain open space and foster more highly competitive and dense urban development. TDR agreements provide a market within which development rights can be traded. For instance, if land-use planning has targeted one area as logical for development and another for maintenance of more natural landscapes and open space, a TDR structure can allow landowners in the more restricted zone to sell development rights to landowners in a development zone. The development-zone landowner might be required to buy some extra development rights to develop the property or to increase the density of development. Thus, TDRs allow development to take place in one area while providing incentives for landowners to make decisions that are more in concert with socially determined wants and desires in another.

A key element of the TDR approach is that it relies on stable and well-recognized long-term plans of a community. The identification of sending areas (restricted) and receiving areas (areas for development) needs to be clearly and unequivocally identified through an overall planning initiative (e.g., comprehensive planning) that is accepted, implemented, and under close control. Like PDRs, TDRs rely on the ability to legally sever development rights from the rights to own land. Finally, TDRs rest on an institutional framework within which the rights can be traded between landowners.

Operationally, TDRs are set up by a regional governing body by establishing a TDR "Bank" that is responsible for holding the assets of land ownership and the rights to develop land. Landowners in the sending area "sell" rights to develop their land to the bank, which then turns around and uses these development assets to allow developers within the receiving area to develop. The incentive for both governments and developers to enter into these artificial markets is the ability to develop in the growth zone at higher densities than previously allowed.

The success of TDRs depends on three critical components. First, the TDR program must be simple and easy for landowners, the public, and developers to understand. Second, the TDR program must be a clearly identified growth management component of an overall comprehensive planning program for the region as a whole. Without a broader regional planning effort, the security required for a market for development rights vanishes. The regional decision to support a TDR clearly must provide predictability to those landowners permanently restricting their land development potential and those who purchase the rights to develop within receiving zones. This predictability represents the third aspect critical to the success of TDRs.

Clearly, developing markets for transferring development options presents a voluntary market-driven approach to rural land-use planning. This is particularly true in rural regions closely proximate to rapidly growing metropolitan regions. It has had the effect of making development restrictions more palatable to developers while permanently maintaining land as open space in exurban regions (Thorsnes and Simons 1999; Nickerson and Lynch 2001; Plantinga and Miller 2001).

Educational Devices

The final category of land-use planning devices represents the underlying efforts of land-use planners and outreach specialists who help constituents better understand the various concepts associated with land-use planning (in all forms). Educational devices reflect programs intended to affect the implementation of tools or devices that are developed to improve the understanding of environmental problems, solutions, and/or approaches.

While central to the land-use planning effort, educational programs focused on rural land-use planning are often central marketing tools used by nonprofit organizations and special interest groups involved in conservation, environmental education, and rural development. Successful educational programs can have dramatic effects on successful implementation of comprehensive planning within rural communities. A good example of educational programs targeting exurban developments within sensitive ecosystems can be found within lakeshore owners associations and organizations. These groups are bound to objectives that squarely face exurban residential development around lakes with the land-use planning needed to alleviate negative environmental consequences. Education with reference to land-use devices is often central to their missions.

Rural Land-Use Planning and Conservation in South-Central Wisconsin

We examine a rural region of South-Central Wisconsin to illustrate the specific context and application of rural land-use planning. We focus on Sauk County, which lies just to the northwest of Madison, the state capital. The case study provides a snapshot of rural land-use practices and is an excellent example of a rapidly growing region rich in land-based amenities struggling with effective implementation of land-use tools.

The Baraboo Hills, Sauk County's most significant natural feature, stand out as a unique geological formation at the northeastern edge of the driftless, or unglaciated, region of Southwestern Wisconsin. As such, the Baraboo Bluffs contain important forest and river systems that are a principal focus of conservation and open-space planning in Sauk County. Sauk County has seen strong growth in residential development during the past 25 years, but efforts by Sauk County planners to introduce alternative growth management policies such as "density-based" zoning (as opposed to more conventional large-lot approaches) are often misunderstood and have been met with local skepticism and even hostility as being too complicated and restrictive.

The tradition of local control remains strong in Sauk County, as it is throughout Wisconsin, where land use is primarily a local issue. But as rural communities change, so too will their approaches to growth. For years local leaders have been reluctant to create “winners and losers” by drawing separate land-use districts that restrict economic uses in one area but not in another. It is common, therefore, to witness an entire rural township restricted to agricultural or resource conservation uses, as opposed to a more thoughtfully considered mix of districts that reflect the urban-to-rural spectrum. In Sauk County, recent local comprehensive planning processes reveal a split between long-term rural residents who resist more restrictive land-use policies and newer residents who often accept regulation as a means of protecting their ownership investment in the area’s natural amenities. Ironically, by welcoming new residential development through lax regulation, the lifelong residents unwittingly yield control of their local government decision-making authority to new landowners who, having the numbers to support them, seek local office only to advocate for a more rigorous growth management program. With increasing consistency, expressions of rural agrarian values find their way into local comprehensive plans in the form of community vision statements, goals, and sometimes even specific policy recommendations. A desire to maintain productive farmland, natural resources, and the traditional rural character of the land are among the most commonly voiced goals of local comprehensive plans.

Sauk County has enforced its zoning regulations since 1963 and a land division ordinance since 1969. In its original “General Agricultural” district, the permitted uses reflect a somewhat casual regard for potential rural land-use conflicts. These uses include power plants and dams, power transmission towers and related facilities, commercial signage, mining, aircraft landing fields, hangers and bases, contractor storage yards, drive-in theaters, and landfills. Special exceptions can be granted by the Board of Adjustment that enable even more permissive uses.

The advent of Wisconsin’s Farmland Preservation Program in the 1970s led Sauk County to adopt the Exclusive Agricultural zoning district that required a minimum of 35 acres for a residential lot. Farmers in participating towns obtained income tax credits. The new district limited residential development in the eight rural Sauk County towns that adopted it, but new houses in these districts are often surrounded by 35-acre lawns. This inefficient land-use pattern led to a backlash against the Exclusive Agricultural zoning district, and the erosion of support now threatens to wash away conservation protections embedded in the state’s farmland preservation statutes. Pressures to provide property tax relief for farmers led to the passage of differential taxation legislation, significantly reducing the property tax burden on land used for agriculture. Agricultural value assessment currently carries no requirement for the landowner to engage in conservation practices, as was required with the Farmland Preservation Program. The conservation leverage once obtained through Farmland Preservation has now been negotiated away, along with incentives to maintain a low-density rural development pattern.

Nonregulatory strategies for growth management have gained acceptance but, as one alternative to land-use regulation, the acquisition of land for public purposes such as conservation and recreation remains controversial. Sauk County has a relatively meager amount of land in public ownership dedicated to conservation and recreation. According to the most current Wisconsin Statewide Comprehensive Outdoor Recreation Plan (Wisconsin 2006), only 29,900 acres are split among federal, state, county, and municipal entities. By comparison, 467,700 acres in Bayfield County (located in Northern Wisconsin) are publically owned. Of Sauk County's 537,600 acres, 22,511 are state owned; 4,954 are federally owned, and 1,498 are owned by Sauk County itself.

While acquisition of land offers the greatest degree of public oversight and management of important resources, it is expensive. Keeping private land on the tax rolls is an important consideration for local and county government. Private landowners can be induced to practice conservation through the use of financial and tax incentives. Sauk County's rural landowners have long benefited from a full array of incentive programs, ranging from the previously mentioned state Farmland Preservation Program and the Wisconsin Department of Natural Resources Managed Forest Law to the US Department of Agriculture's Conservation Reserve Program (CRP) and the Conservation Reserve Enhancement Program (CREP), which have retired thousands of marginal acres from agricultural production.

The Sauk County PDR Program

The local preference for private ownership of land appeared to offer Sauk County planners reasonable encouragement to propose a conservation easement program as an alternative to public land acquisition. Sauk County's initial consideration of the purchase of development rights appeared as a policy recommendation in the County's 1979 Agricultural Preservation Plan. Then, in 1999 after a lengthy planning process involving significant public participation, the *Sauk County 2020 Comprehensive Development Plan* recommended the adoption of a county purchase of development rights program. In 1999, the Sauk County Board allocated $200,000 in general funding to support a county PDR program. In March 1999, a *Memorandum of Agreement (MOA) Concerning U.S. Highway 12* was negotiated between the US Federal Highway Administration, the Wisconsin Department of Transportation, the US Environmental Protection Agency and the National Park Service and other parties, including Dane and Sauk Counties. The U.S. Highway 12 MOA authorized construction of a new four-lane expressway through Dane and Sauk County, including the Baraboo Hills. The MOA also allocated millions of dollars to local government, the Wisconsin Department of Natural Resources, and local nonprofit conservation organizations for the acquisition of lands and conservation easements in Dane and Sauk County and for preparation of local land-use plans. Sauk County used a $5 million allocation to create a land protection program and a full-time position to manage it. The Sauk County Baraboo Range Protection Program was established in June of 2000. Since then, Sauk County has purchased 41 conservation easements, protecting over 3,150 acres in the Baraboo Range National Natural Landmark (BRNNL) at a cost of $4,445,415. The Wisconsin Department of Natural Resources, The Nature Conservancy, and the Baraboo Range Preservation

Association (a local private land trust) have also protected Baraboo Range forest lands using funding authorized by the US Highway 12 MOA.

The Sauk County government cannot use eminent domain to acquire conservation easements. Instead, landowners interested in the easement program contact County staff on their own after learning about the program by word of mouth or through periodic media coverage. The process is relatively simple, although it sometimes takes a year or more to complete. Following an initial information-gathering/site assessment phase, landowners agree to have an appraisal conducted to determine the value of a conservation easement on their land. Appraisers generally rely on an assessment of comparable market real-estate values to determine an estimate of Fair Market Value (FMV), which in the Baraboo Hills have ranged from \$1,100/acre for a conservation easement in 2000 to upwards of \$2,200/acre in 2008. Conservation easement values typically represent between 35% and 50% of the full, unrestricted market value of the property. Sauk County retains responsibility for monitoring and enforcing the terms of these conservation easements in perpetuity. However, if Sauk County abdicates its responsibility in the future, other parties to the US Highway 12 MOA are authorized to step in and enforce terms of the easements.

Acceptance of the Baraboo Range Protection Program among Sauk County citizens has been relatively broad, if not deep. Most residents at least acknowledge the importance of the Baraboo Hills for their aesthetic appeal, the wildlife habitat, and for the local tourism economy. This support had been cultivated for decades by the combined efforts of The Nature Conservancy, the Baraboo Range Preservation Association, and other conservation organizations. When the National Park Service declared the Baraboo Hills a National Natural Landmark in the 1970s (creating the Baraboo Range National Natural Landmark), the designation afforded the region a measure of public recognition, if not actual protection. In 1997, Sauk County conducted a random telephone survey of residents as part of the *2020 Comprehensive Development Plan* process. Over 80% of respondents indicated favorable support for protecting the Baraboo Hills. Support indicated by such public opinion surveys and local land-use planning helped convince parties to the US Highway 12 MOA that Sauk County was ready to implement an effective land protection program.

Land protection planning relative to the Baraboo Range Protection Program relies on this general consensus. The Baraboo Range Commission, a nine-member body appointed by the Sauk County Board to oversee the Baraboo Range Protection Program, has relied on the program's authorizing documents for guidance in establishing protection priorities. Both the US Highway 12 MOA and the *Baraboo Range Protection Plan* identify forest habitat, scenic quality, and ecosystem diversity in a list of regional "livability" features that are important to maintain. The *Baraboo Range Protection Plan* emphasizes the importance of a landowner's interest, the relative conservation value of a property, and the participation of the local town government in identifying preservation areas. These steps were intended to build local confidence and trust for the Commission and its decision making.

The protection of the Baraboo Hills has not been without controversy. Sauk County's foray into the arena of public land acquisition was met with significant and constant criticism by those claiming to represent taxpayers' private property rights. Critics also object to public meddling in private land markets. Claiming that private landowners are in all cases the best, and only legitimate protectors of their own land, members of local property rights advocacy organizations like "PLOW" (Private Landowners of Wisconsin) and the "Glacial Area Conservancy Federation" have argued their case at public meetings, issued press statements and literature, and generally attempted to insert themselves into public deliberations over the use of the US Highway 12 MOA funding. Their arguments include quotations of obscure English common law and vaguely worded cautionary notes that compare the sale or donation of private land rights to "feudal servitude." Publications exposing the supposed horrors of life as dictated by the United Nation's "Agenda 21" began to surface in Sauk County media, public events, and during meetings of local planning committees. "Smart Growth" comprehensive planning, county land-use regulations, and the purchase of development rights all became conflated within the heated rhetoric of local property rights activists, sometimes with the help of nationally recognized movement figures such as Chuck Cushman of Montana.

In recent years the uproar over the Baraboo Range Protection Program has subsided somewhat. Property rights advocates have been successful in convincing a slight majority of the County Board membership that proposed program expansions represent a step too far and would somehow be detrimental to landowners, negatively impacting local government revenue flows by "devaluing" land, stripping off its development potential, thus reducing its maximum potential assessed value.

These developments demonstrate that, in Wisconsin at least, public policy over land protection remains a highly divisive local political issue. Despite evidence of success across the country in local conservation funding ballot measures, as frequently reported by The Trust for Public Land, continued support for conservation easement programs at the local level, even when augmented by state and federal funding, will be difficult to maintain in an environment of widespread public contempt for government and general acceptance of the tax-cutting-at-all-costs mentality so prevalent in the nation's rural areas.

The experience of Sauk County illustrates how collaborative efforts among public agencies and nonprofit conservation and advocacy organizations can leverage the capacity of each to achieve mutual education and policy goals. Sauk County, The Nature Conservancy, the Wisconsin Department of Natural Resources, the Aldo Leopold Foundation, and others have combined their resources to reach a broad segment of the local population with a message of support for natural resource conservation and public land protection. As local conservation priorities such as the reuse of the Badger Army Ammunition Plant became recognized for their regional importance, organized outreach brought political and funding support from interested parties far beyond Sauk County's boundaries. These efforts would not have been fully realized, however, without the underlying support provided by Sauk County's commitment to open and participatory public planning. Collaborative education and outreach yield best results when paired with effective community planning for growth management and natural resource protection.

Conclusion

In this review, several key attributes build the context for exurban land-use planning and the application of devices used to affect the course of development. Further, these attributes are then used to provide a typology of devices used to affect land-use change in rural regions and are categorized into four specific types. These can be summarized as collectivization, regulatory, voluntary, and educational devices. Each has its own set of distinct contexts, responsible institutions, and intended outcomes.

It is clear that the time for change is now. As confirmed by Carruthers and Vias (2005), the long-term prosperity of rural exurban regions depends on an ability to maintain and improve the amenity base upon which growth is positioned. This hinges on successful land use, infrastructure, and environmental planning accomplished through multicommunity collaboration, coordination, and attention to the character of economic, sociodemographic, and environmental structures unique to exurban regions.

This said, simply applying devices used in urban land-use planning would appear to lack needed rural context; such misapplication can, and often does, exacerbate problems associated with land use, natural resource conservation, and amenity provision in exurban regions. In this chapter, four specific device types were presented that offer rural-sensitive approaches appropriate to the rural context.

Further research is needed to more fully understand exurban land development. The extent and the character of residential development in exurban places have key impacts on landscape fragmentation, wildlife habitat, and related conservation metrics. The obvious potential for intense negative environmental effects of continued exurban sprawl (uncontrolled rural development) requires a firm empirical footing. To be sure, landscape ecology and its scientific basis can aid in strategies to affect conservation benefits. Thus far, however, low-density exurban land development remains poorly defined and understudied by landscape ecologists (Theobald 2004). Existing studies (cf. Odell, Theobald and Knight 2003; Lenth, Knight and Gilbert 2006; Compas 2007), while somewhat conflictive, tend to confirm the need for clustering residential developments in rural areas. Clustering is the key argument associated with Randall Arendt's "rural by design" (Arendt 1994, 2004) and contemporary land-use planning devices often attempt to stimulate clustered exurban development. Indeed, the need for further research into the effects of alternative exurban development patterns on landscape-level change is clear.

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