Ecological Applications, 17(4), 2007, pp. 1031–1038

LAND USE CHANGE AROUND PROTECTED AREAS: MANAGEMENT TO BALANCE HUMAN NEEDS AND ECOLOGICAL FUNCTION

Ruth DeFries,[1,2,7] Andrew Hansen,[3] B. L. Turner,[4] Robin Reid,[5] and Jianguo Liu[6]

[1]*University of Maryland, Department of Geography, College Park, Maryland 20742 USA*
[2]*University of Maryland, Earth System Science Interdisciplinary Center, College Park, Maryland 20742 USA*
[3]*Montana State University, Ecology Department, Bozeman, Montana 59717 USA*
[4]*Graduate School of Geography, and George Perkins Marsh Institute, Clark University, Worcester, Massachusetts 01610 USA*
[5]*International Livestock Research Institute, Nairobi, Kenya*
[6]*Center for Systems Integration and Sustainability, Department of Fisheries and Wildlife, Michigan State University, East Lansing, Michigan 48824 USA*

Abstract. Protected areas throughout the world are key for conserving biodiversity, and land use is key for providing food, fiber, and other ecosystem services essential for human sustenance. As land use change isolates protected areas from their surrounding landscapes, the challenge is to identify management opportunities that maintain ecological function while minimizing restrictions on human land use. Building on the case studies in this Invited Feature and on ecological principles, we identify opportunities for regional land management that maintain both ecological function in protected areas and human land use options, including preserving crucial habitats and migration corridors, and reducing dependence of local human populations on protected area resources. Identification of appropriate and effective management opportunities depends on clear definitions of: (1) the biodiversity attributes of concern; (2) landscape connections to delineate particular locations with strong ecological interactions between the protected area and its surrounding landscape; and (3) socioeconomic dynamics that determine current and future use of land resources in and around the protected area.

Key words: *connectivity; greater ecosystem; land use change; protected areas; regional management; small loss–big gain opportunities; socioeconomic dynamics.*

The Challenge to Balance Human Needs and Ecological Function

Land use for agriculture, forestry, and settlements provides food, fiber, and other ecosystem services that satisfy immediate human needs (Millennium Ecosystem Assessment 2003). Protected areas provide a host of other services, including biodiversity, watershed protection, and carbon storage, as well as more difficult to quantify cultural services such as recreation and spiritual fulfillment. We follow the World Conservation Union (IUCN) definition of protected area as "an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means." Protected areas include strict nature reserves, wilderness areas, national parks, and management areas. The appropriate balance between land use to improve human well-being and protected areas to conserve other ecosystem services is ultimately a societal decision at the crux of the debate between conservation and development (Adams et al. 2004, DeFries et al. 2004).

As land use change occurs outside the administrative boundaries of existing protected areas, with potential negative consequences for the ecological functioning of the protected areas themselves (Hansen and DeFries 2007), the trade-offs between human uses and longer term conservation of ecosystem services become complex. In this paper, we explore possibilities for management alternatives that recognize both human needs for using unprotected lands and conservation needs to maintain ecological function in protected areas. The challenge is to apply ecological principles to identify opportunities that do not unrealistically constrict human land use, while minimizing negative consequences for protected areas.

Ideally, land use management can achieve "win–win" solutions that satisfy human needs while maintaining ecological function (Daily and Ellison 2002, Rosenzweig 2003), for example, where conservation results in direct economic benefits. Natural amenities in the American West have spurred economic growth (Rasker and Hansen 2000). Tourism revenue from wildlife is a major component of national economies in East Africa. In the case of the Wolong Nature Reserve in Sichuan, China (Viña et al. 2007), a "win–win" alternative was achieved

Manuscript received 2 August 2005; revised 15 March 2006; accepted 11 April 2006. Corresponding Editor: M. Friedl. For reprints of this Invited Feature, see footnote 1, p. 972.
[7] E-mail: rdefries@mail.umd.edu

by providing nonagricultural employment opportunities for local populations around the reserve, simultaneously reducing pressure on giant panda (*Ailuropoda melanoleuca*) habitat from fuelwood collection and agriculture while improving local livelihoods. In Kitengela, Kenya, payments to families to prevent the building of fences on land in the wildebeest migration corridor double the income of the poorest families during droughts, when they need cash the most (calculated from data in Kristjanson and Nkedianye [2001]). The effectiveness of these management strategies is dependent on sound ecological understanding of the habitat loss from human pressures and its implication for wildlife populations.

Although ideal, "win–win" opportunities are not possible in all situations. Nonlinear relationships between ecological responses and land area under protection make it possible to identify "small loss–big gain" opportunities, in which ecological functioning of the protected area might be maintained ("big gain") with minimum negative consequences for human land use ("small loss") (DeFries et al. 2004). In the Greater Yellowstone Ecosystem (GYE), for example, Gude et al. (2007) illustrate that restrictions in rural home development in key, but small, crucial habitats covering only a small percentage of land area outside the park disproportionately benefit biodiversity in the park. In this case, restrictions over a small land area ("small loss") can achieve a "big gain" for biodiversity.

In the coming decades, many protected areas around the world are likely to undergo increasing pressures, depending on the land use and socioeconomic dynamics of the regions in which they are located. The case studies in this Invited Feature illustrate some of these varying conditions. Protected areas located in affluent countries, such as the case study in the Greater Yellowstone Ecosystem (Gude et al. 2007), probably will continue to be magnets for homes and tourism. Other protected areas are located in densely populated areas where poverty and insufficient employment opportunities dictate that local human populations rely on local resources for food and energy needs. Such situations are common throughout the developing world, as illustrated by the case study on the Wolong Nature Reserve in Sichuan, China (Viña et al. 2007). Other protected areas are likely to undergo changes in types and extents of land use in their surroundings as regions undergo land use transitions from subsistence to commercial agriculture (Mustard et al. 2004), such as the conversion from swidden ("cut-and-burn") agriculture to commercial chili production around the Calakmul Nature Reserve in the southern Yucatán Peninsula (Vester et al. 2007).

The challenge to develop scientifically based, regional land use management approaches pertains to both the development community to incorporate ecological principles in land management (Dale and Haeuber 2001) and the ecological community to consider growing human needs for ecosystem services in management recommendations.

This paper draws on the case studies in this Invited Feature to provide a framework for identifying management alternatives, developed on the concept that protected areas are embedded within larger ecosystems. The complexities of ecosystems and their multiple interactions among biotic, abiotic, and human components on multiple temporal and spatial scales (Mayer and Rietkerk 2004) foreclose simple prescriptions that are applicable across many situations. Effective management requires detailed and specific understanding developed by scientists and managers with long-term field knowledge of particular regions. Instead, in this paper, we identify a framework applicable across varying situations as a basis for identifying specific management options in particular situations.

Ecological Knowledge for Regional Management of Land Use around Protected Areas

Ecosystem management provides a framework for identifying land use options around protected areas (Grumbine 1994). An important component of ecosystem management is cross-boundary management, e.g., managing ecological functions across ecosystem boundaries (Liu and Taylor 2002, Schneider et al. 2002). Craighead (1979) focused attention on ecosystem management by showing that the needs of grizzly bears could not be met solely within the borders of Yellowstone National Park. Newmark (1985) demonstrated that the park boundaries do not encompass the necessary area for any of the large fauna. These works help to establish the notion of greater ecosystems in which protected areas are embedded, although the attributes that should be used to define a greater ecosystem remain controversial (Andelman and Fagan 2000).

A greater ecosystem, whether defined by ranges of particular species, hydrologic boundaries, or other ecological attributes, characterizes very large areas well outside the boundaries of existing protected areas. It is unlikely that such large areas can be wholly conserved without unrealistic compromises with human needs, except in the few remaining remote areas of the world (Sanderson et al. 2002). In much of the world, these large ranges are no longer suitable for carnivores due to human land use. The question then becomes: Are there key locations within the greater ecosystem that, if managed appropriately, would maintain ecological function while minimizing restrictions on human use? As described in Hansen and DeFries (2007), the ecological mechanisms through which land use change alters ecological functioning of protected areas suggest approaches for identifying these key locations. These mechanisms include (1) changes in effective size of a protected area, with implications for minimum dynamic area, species richness, and trophic structure; (2) altered flows of materials and disturbances into and out of

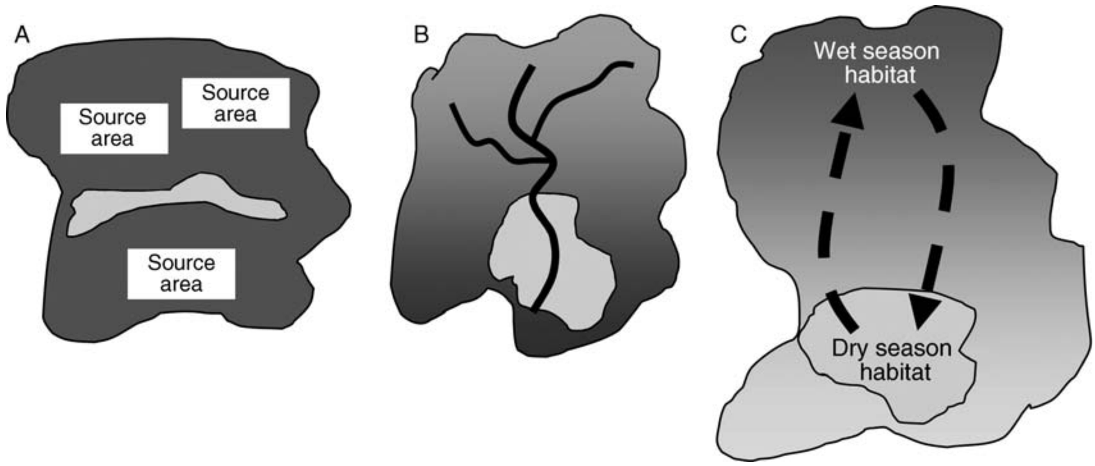

FIG. 1. Schematic representation of biophysical settings of protected areas (light gray) within greater ecosystems (dark gray) for different biophysical settings: (A) high elevation in protected area and low elevation in population sources areas; (B) protected area in lower reaches of watershed; and (C) protected area situated in gradient from low to high precipitation and productivity.

reserves; (3) loss of crucial habitats for seasonal migrations and population source areas; and (4) exposure to human activity through hunting, poaching, exotic species, and disease.

The relative importance of these ecological mechanisms in any particular protected area varies with the ecological characteristics and socioeconomic setting. If a protected area is located in the lower reaches of a watershed, for example, water quality is likely to be altered by land use occurring in the upper watershed. Human effects are more likely to be important if populations rely on natural resources obtained within a protected area. Critical habitats, population source areas, and migration routes for wild populations are likely to be located outside protected area boundaries when protected areas do not encompass gradients in climate and productivity present in the greater ecosystem.

The relative size and placement of a protected area within the greater ecosystem may be more relevant than absolute size for the ability of a protected area to maintain ecological function. Most protected area boundaries do not encompass biophysical gradients in precipitation, elevation, and temperature present within the greater ecosystem, not even the large Serengeti National Park in Tanzania with boundaries designed to encompass the migratory extent of wildebeest (Sinclair 1995). Here, the dry-season grazing reserve for the million-strong wildebeest migration lies across an international boundary in Mara Reserve and surrounding pastoral lands of Kenya (Broten and Said 1995). Protected areas are generally situated in locations with low productivity, high elevation, poor soils, and other areas less desirable for human use (Scott et al. 2001). Plant communities and other resources critical to wild populations are consequently not proportionally represented in the protected areas, and animal species rely on areas outside the boundaries of protected areas for food and water sources and breeding.

Delineating the placement of the protected area within the biophysical gradients of the greater ecosystem is key for identifying movements of species, critical habitats, and other ecological interactions (Fig. 1). The biophysical setting helps to identify the "zone of interaction" and possible management opportunities. For example, panda habitat within the Wolong Reserve is connected to similar habitat outside the reserve, with the "zone of interaction" being defined by the distance a panda can travel (Viña et al. 2007).

The degree to which a protected area maintains ecological function also is not static through time. Disturbances, such as drought, fire, and hurricanes, may alter the representation of different habitats. If the protected area does not contain the minimum area for a "shifting steady state" of habitat types (Gillson and Willis 2004), the "zone of interaction" with outside areas will also shift over time as ecological flows vary. In the Calakmul Biosphere Reserve, for example, hurricanes shift the proportional representation of secondary and mature forest patches (Vester et al. 2007).

Placement of the protected area within the greater ecosystem guides management opportunities to balance human land use needs with ecological function of protected areas (Fig. 1). Where the biophysical setting leads to population source areas located distant from the protected area, as in Yellowstone National Park, conservation easements or incentives to maintain those relatively small areas can maintain ecological function. Where the protected area is located downstream in a watershed, upstream watershed protection might be more important to maintain ecological function. Maintaining corridors for migrations will be most important where protected areas are located within large, gradual biophysical gradients, such as in East Africa.

TABLE 1. Examples of management opportunities appropriate for different socioeconomic and land use settings.

	Land use in and around protected areas		
Socioeconomic setting	Forest ecosystems	Savanna ecosystems	Management opportunities
Remote, low human population density	low-intensity use of forest products	low-intensity pastoral	not needed
Extractive frontier landscape	logging, mining, agricultural expansion	conversion of pastoral to sedentary agriculture	identify and protect critical habitats and corridors
High density of human populations dependent on local resources	fuelwood and NTFP† collection, forest grazing, hunting or poaching	nomadic livestock grazing, farming, settlements, hunting or poaching	promote alternative livelihoods to reduce resource dependence
High density of affluent human populations	second homes, recreation, tourism	second homes, recreation, tourism	concentrate development away from crucial habitats with incentives such as conservation easements

† Non-timber forest products.

Knowledge of Socioeconomic Conditions for Regional Management of Land Use around Protected Areas

People reside within the boundaries of 70% of protected areas in the tropics (Terborgh and Peres 2002) and almost 90% in China (China's National Committee on Man and the Biosphere 2000). Some form of human land use occurs around all but the most remote protected areas. Poaching and hunting affect more than three-fourths of the parks in the tropics (van Schaik et al. 1997, Dugelby and Libby 1998). Even the most ardent conservationist will concede that management of protected areas must consider people's needs and aspirations for use of land and other resources, particularly where the livelihoods of indigenous, tribal, and traditional peoples depend on these resources.

Polarized debates continue about whether conservation in developing countries should follow the "Yellowstone" model, excluding local and indigenous people from parks, or the "people and parks" model, accommodating development and livelihoods needs (Stevens 1997*b*). On one hand, local peoples are essential components for long-term conservation (Schwartzman et al. 2000), particularly in tropical hot spots of biodiversity where human population densities are high (Cincotta et al. 2000). On the other hand, conservation projects that have attempted to link with social and economic development in surrounding communities have a mixed record of success due to insufficient clarity in goals and institutional constraints (Barret and Arcese 1995, Agrawal and Gibson 1999, Schelhas 2001). Regardless of one's stand on the moral and ethical dimensions of strict conservation vs. local rights to use natural resources, the historical view of protected areas as islands isolated from surrounding areas and neighboring communities is superseded by the reality that effective management in and around protected areas must account for human use of natural resources.

Many questions remain to apply scientifically based management to these issues. What are the relative contributions of people living inside protected areas vs. human pressures in the surrounding area to declining ecological function? Do employment opportunities through tourism for local peoples reduce or increase pressure on protected areas? Answers probably vary from place to place, and require attention from the research community.

Management opportunities for balancing human needs and ecological function of protected areas vary with socioeconomic setting and stage in the land use transition (DeFries et al. 2004, Mustard et al. 2004) (Table 1). Protected areas in remote locations may have fewer conflicts with human use of local resources. In frontier landscapes undergoing rapid transitions from wild lands to stable human land uses, extraction of resources takes the form of logging, mining, rapid agricultural expansion, and hunting. Challenges to conservation are significant in these frontier landscapes due to general lack of institutional infrastructure and few possibilities for enforcement (Brandon 2002). The opportunity is to identify and protect critical habitats and corridors before they are converted.

In more stable, non-frontier landscapes, management opportunities and challenges vary depending on the socioeconomic setting. In locations with human populations that are heavily reliant on local resources, as in much of the biodiversity-rich developing world, the foremost management challenge is to promote livelihood alternatives that improve human well-being and reduce overexploitation of forest products and other land resources. This is perhaps the greatest conservation challenge for the coming decades (Terborgh and van Schaik 2002). In more affluent settings, management that deflects development away from critical habitats might be achieved through existing institutions for zoning and economic incentives.

Regardless of the specific case, ecological theory is better developed than human–environment theory on which to base management principles. Development of a sound basis for management depends on a better understanding of interactions between nonhuman and human species, interactions within human communities, institutions, resource use, and many other socioeconomic factors. Because the vast majority of protected areas are public, the challenges for effective governance of the commons are particularly pertinent (Dietz et al. 2003).

Lessons from Case Studies

Although it is not possible to capture the full range of ecological and socioeconomic conditions around protected areas throughout the world, the case studies in this Invited Feature provide insight into how these varying factors suggest management approaches that might be effective in different situations. The case studies represent variations in several factors: biodiversity attribute considered in the analysis; ecological setting of the protected area within the greater ecosystem; and conflicts with use of land and other resources in and around the protected area. These factors determine which ecological mechanisms and attributes might be most altered by land use surrounding the protected area and ultimately guide the identification of "win–win" or "small loss–big gain" management opportunities.

Each case study considered different attributes of biodiversity appropriate for the location. The Wolong Nature Reserve analysis considered a single species, the giant panda (Viña et al. 2007). Others considered a range of species depending on data availability, such as butterflies and tree species in the southern Yucatán (Vester et al. 2007), and bird hotspots, migration corridors for grizzly bear (*Ursus arctos*), elk (*Cervus elaphus*), pronghorn antelope (*Antilocapra americana*), and moose (*Alces alces*), and an index of habitat irreplaceability (Pressey and Cowling 2001) in Yellowstone (Gude et al. 2007). The management opportunities depend on the biodiversity attribute of interest. For instance, a focus on large migratory mammals suggests a management focus on corridors, dispersal areas, and connectivity between protected areas. A focus on bird populations might shift focus to critical population source areas outside the protected area.

Second, the case studies vary in terms of the biophysical setting of the protected areas within their greater ecosystems. Boundaries of protected areas generally do not encompass the full gradients in precipitation, temperature, elevation, and other biophysical factors present in the larger ecosystem. Yellowstone National Park is located at higher elevation and has lower productivity than the greater ecosystem. Calakmul Biosphere Reserve in the southern Yucatán Peninsula spans the precipitation gradient present in the greater ecosystem, but does not include proportional representation of secondary and mature forest types, especially the more humid variety. Wolong Nature Reserve is not located across a gradient to the same extent. Instead, the connectivity is essential to maintain panda populations due to habitat loss inside the reserve during stochastic events such as fire and bamboo flowering.

Third, the case studies vary greatly in the socioeconomic conditions in which they are located and the resulting conflicts. Conflicts with surrounding land use in Yellowstone National Park arise from the attraction for second homes and tourism in proximity to the park. Conflicts around the Wolong Nature Reserve in Sichuan, China are rooted in the dependence of local people upon fuelwood and subsistence agriculture. In Calakmul Biosphere Reserve, land uses for local subsistence are changing to more market-based agriculture, so that the conflict is shifting from hunting pressure and clearing for swidden agriculture to sustained habitat loss from intensive chili production. Understanding the nature of these conflicts is key to identifying appropriate management strategies that minimize constraints on human needs. Locating sedentary agriculture away from migration corridors and dispersal areas, for example, provides a management opportunity.

Approach to Identify Management Opportunities

Various management approaches address ecological interactions between protected areas and their surrounding landscapes. One approach focuses on maintaining connectivity among protected areas within a region. Examples include the Yukon to Yellowstone (Y2Y) corridor, which aims to maintain intact landscapes for native wildlife in North America (Chester 2003), and the Mesoamerican Biological Corridor in Central America (Miller et al. 2001). Another management approach to resolve conflicts between local populations and protected areas became popular over the last few decades with mixed-used biosphere reserves, buffers, and Integrated Conservation and Development Projects (ICDP) (Stevens 1997*a*). Community involvement and participatory management, in theory, address the dual goals of conserving biodiversity and alleviating poverty for peoples living near protected areas. The degree to which these goals have been achieved and whether they are complementary or contradictory remain an open question (Adams et al. 2004).

Biological corridors and local community development address only two of the four ecological mechanisms governing interactions between protected areas and their surroundings, as identified in Hansen and DeFries (2007): critical habitats outside protected areas and effects from exposure to human activity, respectively. Although the need to manage protected areas within a regional context is increasingly recognized (Prendergast et al. 1999, Margules and Pressey 2000), comprehensive approaches to regional management that consider the range of ecological mechanisms and socioeconomic interactions relevant in particular settings have not been systematically identified.

The case studies highlight that regional management approaches aimed at balancing human needs and ecological function in protected areas will be most effective if based on detailed knowledge of particular ecological and socioeconomic conditions. However, a general approach to arrive at management options may be applicable across different conditions. We identify three factors that can help to identify management opportunities for regional land use: clear definition of the biodiversity attributes of greatest concern to management; delineation of the "zone of interaction" between protected areas and their surrounding landscapes based on the biophysical setting; and consideration of the socioeconomic conditions that lead to current or future conflicts between land use and biodiversity. These factors can together help managers to identify opportunities to maintain ecological function of protected areas while minimizing constraints on human land use.

The management objectives: which attributes of biodiversity are of greatest concern?

Management of some protected areas focuses on particular keystone or flagship species, such as giant panda in Wolong Nature Reserve in Sichuan, China (Viña et al. 2007). The premise is that maintaining habitat for these species also conserves other species. Not all protected areas have such clearly stated goals, focusing rather on maintaining native, intact, or pristine habitats; mosaics of habitats; aesthetic, scenic, or recreational uses; or overall species richness.

Clear definitions of the biodiversity and ecological attributes of greatest concern are crucial to delineate "zones of interaction." Focus on giant panda will include bamboo forests, birds on riparian habitats, large migratory mammals on seasonal corridors, and dispersal areas, depending on life history traits. In reality, management goals relate to a variety of species and habitats, but clear articulation of the biodiversity responses of interest will allow most straightforward assessment of key locations within the greater ecosystem and identification of management opportunities. Gude et al. (2007) analyze multiple biodiversity attributes (bird hotspots, mammal migrations, and habitat irreplaceability) to identify overlapping areas of particular management concern. Such approaches that use multiple indicators may be particularly useful in increasing the conservation value of landscapes protected for single species.

The biophysical setting: What is the spatial extent of interactions between protected areas and their surroundings?

Although ecological flows of materials, energy, and organisms are rarely contained within the administrative boundaries of protected areas, the spatial scales of the interactions are difficult to define, and depend on the species and communities of interest, ecological setting, and land use characteristic. Large mammals might migrate far outside protected area boundaries where biophysical gradients span large areas and locations of food and water resources vary seasonally. Steep topographic gradients might restrict populations to small areas. Very distant economic and political processes also influence protected areas in cases where global markets or national policies influence land use and livelihoods of people living in and around protected areas (Liu and Diamond 2005).

Protected areas do not generally have systematically determined boundaries for the larger ecosystems in which they are contained. The Greater Yellowstone Ecosystem is the exception, with the boundaries defined by grizzly bear range combined with administrative jurisdictions (Gude et al. 2007). Although it is difficult to define precise boundaries of the spatial extent of ecological interactions with protected areas, identification of the general area of interest is necessary to determine opportunities for regional management. Perhaps more importantly, specifically located "zones of interactions" within the greater ecosystem where ecological interactions with the protected area are particularly strong are key to identifying "small loss–big gain" management opportunities. Detailed analyses and ground-based understanding of the region can identify these locations, as indicated through the case studies in this Invited Feature.

The socioeconomic setting: what are the conflicts between biodiversity and land use in and around the protected area?

Finally, the extent and magnitude of human resource use in and around a protected area will determine which management approaches might be most effective to balance human needs with ecological function of protected areas. Existing and future uses of land and other resources in the greater ecosystem set the stage for identifying possible regional-scale management approaches. Where the land use leads to conversion of habitat, such as in frontier landscapes with agricultural expansion or logging, efforts to identify the most crucial habitats and locations to maintain ecological flows before they are converted is an appropriate management focus. Where effects from poaching, hunting, and other human pressures are intense but do not result in habitat conversion per se, alternative livelihoods for local populations might be most effective. The latter is a major challenge as conservation efforts focus on biodiversity-rich tropics. Successful approaches to deal with these conflicts have not been widely demonstrated.

The socioeconomic setting also determines types of land use, which vary in terms of their ability to support biodiversity. Agroforestry and low-intensity agriculture, for example, provide more suitable habitat than intensive, mechanized farmland. However, some results suggest that, on balance, the latter may maintain higher levels of biodiversity over a landscape (Green et al. 2005). In reality, studies addressing the trade-offs of different land uses for both biodiversity and human well-being are few and the lessons sparse. The subject requires attention to identify opportunities for alternative land uses within critical "zones of interaction."

Conclusions

Land use surrounding protected areas probably will continue to expand and intensify. A key management challenge is to identify "small loss–big gain" opportunities, in which ecological functioning of the protected area might be maintained ("big gain") with minimum negative consequences for human land use well-being ("small loss"). Case studies in this Invited Feature offer examples. Concentration of development away from small but critical bird habitats in the Greater Yellowstone Ecosystem would result in a "big gain" for ecological function with no reduction in the overall development of rural homes. Provision of nonagricultural livelihoods reduced dependence of local peoples on forest resources and improved habitat connectivity for giant pandas in Wolong Nature Reserve in Sichuan, China. This connectivity is particularly important for maintaining panda populations in times of stochastic events such as fire and bamboo flowering.

Identification of these "small loss–big gain" opportunities depends on detailed understanding of the ecological and socioeconomic settings in and around the particular protected areas. Regional land use management to balance human well-being and ecological function in protected areas will be most effective if based on detailed knowledge of these conditions in particular situations. A general approach for identifying the management opportunities, however, emerges from the case studies. Components are:

1) Clear definition of the management objective and biodiversity attributes of concern. These attributes might be maintaining populations of particular flagship species, representative habitats, or recreational and tourism objectives.

2) Delineation of the spatial extent of ecological interactions between protected areas and their surrounding landscapes, based on the biophysical setting. Ecological flows of materials, energy, and organisms across the landscape depend on the biophysical gradients and migration patterns. Within these greater ecosystems around protected areas, particularly important "zones of interaction" for migrations, critical habitats, and disturbances can guide management to focus on key locations that cover a small area but have particular ecological significance.

3) Understanding the socioeconomic setting and conflicts between use of land and other resources in and around protected areas. In frontier landscapes where land clearing and agricultural intensification is underway, such as in the southern Yucatán case study in this Invited Feature, the management challenge is to identify and conserve key portions of the landscape before they are converted. In more stable landscapes, a major challenge occurs in many areas throughout the developing world where local populations rely on resources in and around protected areas for livelihoods.

Focus on key locations around protected areas that are most important for the biodiversity attributes of management concern can help bound this difficult management challenge. Ultimately, human needs and desires for land and other resources determine both the pressures on protected areas and the management options to reduce them. Management approaches based on detailed, scientific analysis of the interactions on the regional scale, aimed toward maintaining ecological function with minimum constraints on human uses, offer possibilities for maintaining function of protected areas in a world where biodiversity is rapidly declining.

Acknowledgments

This work was supported by NASA Grant NAG511161. J. Liu was supported by Michigan Agricultural Experiment Station, National Science Foundation, and National Institutes of Health.

Literature Cited

Adams, W. M., R. Aveling, D. Brockington, B. Dickson, J. Elliot, J. Hutton, D. Roe, B. Vira, and W. Wolmer. 2004. Biodiversity conservation and the eradication of poverty. Science 306:1146–1149.

Agrawal, A., and C. Gibson. 1999. Enchantment and disenchantment: the role of community in natural resource conservation. World Development 27:629–649.

Andelman, S. J., and W. F. Fagan. 2000. Umbrella and flagships: efficient conservation surrogates or expensive mistakes? Proceedings of the National Academy of Sciences (USA) 97:5954–5959.

Barret, C., and P. Arcese. 1995. Are integrated conservation–development projects (ICDPs) sustainable? On the conservation of large mammals in Sub-Saharan Africa. World Development 23:1073–1084.

Brandon, K. 2002. Putting the right parks in the right places. Pages 443–467 *in* M. Rao, editor. Making parks work: strategies for preserving tropical nature. Island Press, Washington, D.C., USA.

Broten, M. D., and M. Said. 1995. Population trends of ungulates in and around Kenya's Masai Mara Reserve. Pages 169–193 *in* A. Arcenas, editor. Serengeti II: dynamics, management, and conservation of an ecosystem. University of Chicago Press, Chicago, Illinois, USA.

Chester, C. 2003. Responding to the idea of transboundary conservation: an overview of public reaction to the Yellowstone to Yukon (Y2Y) conservation initiative. Journal of Sustainable Forestry 17:103–125.

China's National Committee on Man and the Biosphere. 2000. Study of sustainable management policies for China's nature reserves. [In Chinese.] Scientific and Technical Documents Publishing House Beijing, China.

Cincotta, R., J. Wisnewski, and R. Engelman. 2000. Human population in the biodiversity hotspots. Nature 404:990–992.

Craighead, F. 1979. Track of the grizzly. Sierra Club Books, San Francisco, California, USA.

Daily, G., and K. Ellison. 2002. The new economy of nature: the quest to make conservation profitable. Island Press, Washington, D.C., USA.

Dale, V., and R. Haeuber. 2001. Applying ecological principles to land management. Springer-Verlag, New York, New York, USA.

DeFries, R., J. Foley, and G. P. Asner. 2004. Land use choices: balancing human needs and ecosystem function. Frontiers in Ecology and the Environment 2:249–257.

Dietz, T., E. Ostrom, and P. Stern. 2003. The struggle to govern the commons. Science 302:1907–1912.

Dugelby, B., and M. Libby. 1998. Analyzing the social context at parks in peril sites. Pages 63–75 *in* S. E. Anderson, editor.

Parks in peril: people, politics, and protected areas. Island Press, Washington, D.C., USA.

Gillson, L., and K. Willis. 2004. "As Earth's testimonies tell": Wilderness conservation in a changing world. Ecology Letters 7:990–998.

Green, R., S. Cornell, J. Scharlemann, and A. Balmford. 2005. Farming and the fate of wild nature. Science 307:550–555.

Grumbine, R. E. 1994. What is ecosystem management? Conservation Biology 8:27–38.

Gude, P. H., A. J. Hansen, and D. A. Jones. 2007. Biodiversity consequences of alternative future land use scenarios in Greater Yellowstone. Ecological Applications 17:1004–1018.

Hansen, A. J., and R. DeFries. 2007. Ecological mechanisms linking protected areas to surrounding lands. Ecological Applications 17:974–988.

Kristjanson, P. M., and D. Nkedianye. 2001. Valuing land use options. International Livestock Research Institute, Nairobi, Kenya.

Liu, J., and J. Diamond. 2005. China's environment in a globalizing world: How China and the rest of the world affect each other. Nature 435:1179–1186.

Liu, J., and W. Taylor, editors. 2002. Integrating landscape ecology into natural resource management. Cambridge University Press, Cambridge, UK.

Margules, C. R., and R. L. Pressey. 2000. Systematic conservation planning. Nature 405:243–253.

Mayer, A. L., and M. Rietkerk. 2004. The dynamic regime concept for ecosystem management and restoration. BioScience 54:1013–1020.

Millennium Ecosystem Assessment. 2003. Ecosystems and human well-being: a framework for assessment. Island Press, Washington, D.C., USA.

Miller, K., E. Change, and N. Johnson. 2001. Defining common ground for the Mesoamerican Biological Corridor. World Resources Institute, Washington, D.C., USA.

Mustard, J., R. DeFries, T. Fisher, and E. F. Moran. 2004. Land use and land cover change pathways and impacts. *In* M. A. Cochrane, editor. Land change science: observing, monitoring, and understanding trajectories of change on the Earth's surface. Springer-Verlag, Dordrecht, The Netherlands.

Newmark, W. D. 1985. Legal and biotic boundaries of western North American national parks: a problem of congruence. Biological Conservation 33:197–208.

Prendergast, J. R., R. M. Quinn, and J. H. Lawton. 1999. The gaps between theory and practice in selecting nature reserves. Conservation Biology 13:484–492.

Pressey, R. L., and R. M. Cowling. 2001. Reserve selection algorithms and the real world. Conservation Biology 15: 275–277.

Rasker, R., and A. J. Hansen. 2000. Natural amenities and population growth in the Greater Yellowstone region. Human Ecology Review 7:30–41.

Rosenzweig, M. 2003. Win–win ecology: How the Earth's species can survive in the midst of human enterprise. Oxford University Press, Oxford, UK.

Sanderson, E. W., M. Jaiteh, M. Levy, K. Redford, A. Wannebo, and G. Woolmer. 2002. The human footprint and the last of the wild. BioScience 52:891–904.

Schelhas, J. 2001. The USA national parks in international perspective: Have we learned the wrong lesson? Environmental Conservation 28:300–304.

Schneider, R., E. Mills, and D. Josephson. 2002. Aquatic–terrestrial linkages and implications for landscape management. Pages 241–262 *in* W. Taylor, editor. Integrating landscape ecology into natural resource management. Cambridge University Press, Cambridge, UK.

Schwartzman, S., A. Moreira, and D. S. Nepstad. 2000. Rethinking tropical forest conservation: peril in parks. Conservation Biology 14:1351–1357.

Scott, J. M., F. W. Davis, R. G. McGhie, R. G. Wright, C. Groves, and J. Estes. 2001. Nature reserves: do they capture the full range of America's biological diversity? Ecological Applications 11:999–1007.

Sinclair, A. R. E. 1995. Serengeti past and present. Pages 3–30 *in* P. Arcese, editor. Serengeti II. Dynamics, management and conservation of an ecosystem. University of Chicago Press, Chicago, Illinois, USA.

Stevens, S. 1997*a*. Conservation through cultural survival: indigenous peoples and protected areas. Island Press, Washington, D.C., USA.

Stevens, S. 1997*b*. The legacy of Yellowstone. Pages 13–32 *in* S. Stevens, editor. Conservation through cultural survival: indigenous peoples and protected areas. Island Press, Washington, D.C., USA.

Terborgh, J., and C. Peres. 2002. The problem of people in parks. Pages 307–319 *in* M. Rao, editor. Making parks work: Strategies for preserving tropical nature. Island Press, Washington, D.C., USA.

Terborgh, J., and C. van Schaik. 2002. Why the world needs parks. Pages 3–14 *in* M. Rao, editor. Making parks work: Strategies for preserving tropical nature. Island Press, Washington, D.C., USA.

van Schaik, C. P., J. Terborgh, and B. Dugelby. 1997. The silent crisis: the state of rain forest nature preserves. Pages 64–89 *in* J. Johnson, editor. Last stand: protected areas and the defense of tropical biodiversity. Oxford University Press, Oxford, UK.

Vester, H. F. M., D. Lawrence, J. R. Eastman, B. L. Turner II, S. Calmé, R. Dickson, C. Pozo, and F. Sangermano. 2007. Land change in the southern Yucatán and Calakmul Biosphere Reserve: effects on habitat and biodiversity. Ecological Applications 17:989–1003.

Viña, A., S. Bearer, X. Chen, G. He, M. Linderman, L. An, H. Zhang, Z. Ouyang, and J. Liu. 2007. Temporal changes in giant panda habitat connectivity across boundaries of Wolong Nature Reserve, China. Ecological Applications 17: 1019–1030.