Evaluating Potential Wildlife Impacts of Future Land Development Adjacent to Protected Areas

Tony Prato, Anthony S. Clark, and Yan Barnett

Introduction

GLOBAL CHANGE IS INCREASING BIODIVERSITY LOSS, changing climate and land use, modifying hydrological systems, and altering global biogeochemical cycles, all of which are significantly impacting human and natural systems, including protected areas and their gateway communities (Walker and Steffen 1997; McCarthy et al. 2001). Human-induced landscape change influences the ecological integrity of natural systems by altering the availability of energy, water, and nutrients, increasing the spread of exotic species, accelerating the natural processes of ecosystem change, and adversely affecting the structure and functioning of ecosystems (Adger and Brown 1994; Ojima et al. 1994; Vitousek 1994; Vitousek et al. 1997; IIASA 1998).

Global change is the result of the interactions among social, economic, and environmental processes that occur at numerous spatial scales. Of particular interest in this paper are the interactions that occur between protected areas and their gateway communities in Northwest Montana. Swanson et al. (2003:33) define a gateway community as "[a] town or group of towns that provides access to public lands such as national parks, as well as services for visitors to these natural areas" Howe et al. (1997:1) state that "gateway communities have become a magnet for millions of Americans [so-called equity exiles or amenity migrants] looking to escape the congestion, banality, and faster tempo of life in the suburbs and cities."

There are several interactions between gateway communities and protected areas. First, gateway communities provide food, lodging, and other visitor services. Second, protected areas enhance the social and environmental amenities (e.g., quality of life, scenery, clean air, and clean water) available to gateway communities. Third, protected areas are often the economic engines for gateway communities. Fourth, economic and population growth and associated land development in gateway communities has the potential to decrease the quality of life in those communities and degrade the natural and cultural resources—including wildlife—of protected areas (Rasker and Hansen 2000; Swanson et al. 2003; Rasker et al. 2004; Prato and Fagre 2005). Gateway communities need to plan their development in a manner that achieves the socioeconomic benefits of economic growth and land development without threatening the quality of life and amenity values provided by nearby protected areas and other public land (Howe et al. 1997). Such planning requires a better understanding of the potential natural resource impacts of future economic growth and land development in gateway communities for protected areas.

The objectives of this paper are to assess the potential impacts of future land development on wildlife habitat adjacent to five protected areas in Flathead County, Montana, and to determine whether such impacts can be alleviated by implementing more restrictive land use policies. To the authors' knowledge, this is one of the first studies to examine the potential impacts of future land development on wildlife habitat adjacent to protected areas.

Wildlife impacts of land development

In describing the impacts of urban sprawl, Burchell et al. (2005) pointed out that "[e]ach year, development disrupts wildlife habitat by claiming millions of acres of wetlands and forests. This loss often results in habitat fragmentation, in which animals are forced to live in smaller areas isolated from other members of their own species and sometimes unable to forage or migrate effectively. Habitat destruction is the main factor threatening 80 percent or more of the species listed under the Endangered Species Act." The survival of many wildlife species depends on the quantity and quality of habitats surrounding protected areas (e.g., grizzly bear in Glacier National Park and bison in Yellowstone National Park). American Wildlands (2006) determined that: (1) habitat is lost when important areas for the feeding, shelter, or breeding of certain species are converted to residential development; (2) habitat is fragmented when roads, houses, and buildings disconnect parcels that are too small for the survival of many animals; (3) roads built through habitat areas contribute to wildlife mortality; and (4) wildlife migration corridors are degraded or destroyed by the subdivision of large private tracts of land. This study assesses the potential future wildlife impacts of such effects.

Wildlife impacts in areas adjacent to protected areas are numerous. Consider these examples. As a consequence of the 400% increase in rural residential development that occurred in the Montana and Wyoming portions of the Greater Yellowstone Ecosystem between 1970 and 2000 (Williams 2001), current and potential grizzly bear habitat on private lands has been degraded and fragmented. If this trend continues, then grizzly bear recovery in the region will be more difficult (Johnson 2001). Double-digit growth in residential subdivisions adjacent to the National Elk Refuge in Jackson, Wyoming has diminished winter range for the 10,000 elk that use the refuge and displaced corridors that elk use to reach summer range in Yellowstone and Grand Teton national parks (Howe et al. 1997). Over twenty years ago, Keiter (1985) determined that the cumulative impacts of residential, timber, and energy development on lands surrounding Glacier threaten the park's natural resources. In an updated assessment, Sax and Keiter (2007: 36) concluded that "[w]hile the park is still at risk, things are not as bleak as we anticipated from the perspective of the mid-1980s," especially on the west and east sides of the park. However, Sax and Keiter found that residential development south of the park in the Flathead Valley and energy development northwest of the park in the Canadian Flathead threaten the park.

In a similar vein, the National Parks Conservation Association (2002) determined that residential, commercial, and resort developments on ranch, farm, and forest lands outside the western and southern boundaries of Glacier have encroached on important seasonal habitat for bear, elk, mountain lion, mule deer, and other wildlife species, and that rapid population growth and poorly planned development in gateway communities can adversely impact wildlife.

In addition to residential development, wildlife habitat can be lost or degraded by logging and energy development on private and public lands adjacent to protected areas. Most logging operations require the construction of roads and roads fragment and reduce the wildlife habitat security (e.g., American Wildlands 2006). Furthermore, existing or proposed energy developments near protected areas can degrade water quality, wildlife, and other natural resources (e.g., Humphries 1996; Thompson and Thomas 2007).

American Farmland Trust (no date) concluded that 11% of all prime ranchland in a region covering seven Rocky Mountain states is at risk of being converted to residential development between 2000 and 2020. In particular, 3.6 million ha in the top 25 at-risk counties in the region contain ranchland with a high likelihood of being developed. Most of the at-risk acreage is located in Montana and Idaho (over 2 million ha in each state), and considerable strategic and prime ranchland located west and southwest of Glacier in Flathead County is at risk of development.

The Yellowstone to Yukon (Y2Y) Conservation Initiative identified 17 critical areas that are essential for the survival of key wildlife species in the Y2Y region (Y2YCI 2006). One of the critical areas is the Northern Continental Divide Ecosystem (NCDE), which encompasses the Castle–Crown wilderness and Waterton Lakes National Park in Canada and Glacier and the Bob Marshall–Great Bear wilderness complex in the United States. The NCDE provides core habitat for a variety of species and contains the healthiest populations of bull trout, grizzly bears, non-reintroduced wolves, and westslope cutthroat trout in the lower 48 states. In addition, the American Wildlands' Corridors of Life program (American Wildlands 2007a) has developed a map of wildlife corridors in the U.S. Northern Rockies that is being used to promote, protect, and restore public and private lands within identified wildlife corridors.

Previous research

Land use change in rural and urban communities and its wildlife impacts have been assessed in many community and environmental settings. Bockstael (1996) and Geoghegan et al. (1997) modeled the conversion of forest and agricultural land to different densities of residential use in a seven-county area of the Patuxent Basin in Maryland. Schumaker et al. (1997) simulated the potential impacts of future landscape change in the agriculturally dominated Willamette Basin in Oregon. White et al. (1997) examined impacts of landscape change on biodiversity in a recreational area. Maxwell et al. (2000) quantified changes in land use in Three Forks and surrounding areas in Gallatin County, Montana. Apps et al. (2002) and the Miistakis Institute for the Rockies (2002) identified habitat suitable for grizzly bear in the U.S. Northern Rockies. Hansen and Rotella (2002) examined whether intense land use outside of Yellowstone National Park degrades the viability of bird habitat inside and outside of the park. Irwin et al. (2003) modeled urban growth in eastern Maryland. Finally, Berube et al. (2006) evaluated the growth of exurban residential development around metropolitan areas of the United States. We could not identify any studies that evaluated the potential impacts of future economic growth and land development on wildlife habitat in areas adjacent to protected areas.

Study area

The study area is Flathead County in Northwest Montana (see Figure 1). The county encompasses 1.32 million ha or 13,204 sq km; an area that is approximately the size of Connecticut (Flathead County Planning and Zoning Office 2006). Flathead County is selected as the study area for four reasons.

First, the county has experienced rapid growth, which is expected to continue into the future. From 1990 to 2000, the total population of the county, most of which resides in the Flathead Valley, increased 25.8% compared with a 12.9% increase for the state of Montana as a whole and 13.1% for the nation (U.S. Census Bureau 2001). From 1990 to 2005, the total population of Flathead County increased 60%, making it the second-fastest growing county in Montana.

Population and economic growth and associated land development in Flathead County have caused widespread conversion of agricultural and forest lands to residential and commercial uses and increased landscape fragmentation. An on-going landscape change study (CARES 2007) used Landsat TM satellite imagery to estimate land cover in the county. Results indicate that from 1985 to 2002 the urban/built-up area more than doubled from 46 sq km to 94 sq km, the number of patches increased 40% from about 25,000 to 35,000, and average patch size decreased, particularly for deciduous forest (36% smaller) and cropland (78% smaller) in developable areas of the county (personal communication with R. Sugumaran). A "patch" is defined as "[a] continuous area of space with all necessary resources for the persistence of a local population [of a species] and separated by unsuitable habitat from other patches" (Turner et al. 2001:210). Increases in the number of patches implies greater landscape fragmentation, which has adverse effects on some wildlife species.

Figure 1. Location of Flathead County, Montana.

Second, Flathead County was chosen as the study area because it contains a highly diverse flora and fauna that are vulnerable to habitat loss and fragmentation from economic growth and land development. In particular, the Flathead region contains 300 species of aquatic insects, 22 native and introduced species of fish, and nearly all of the large mammals of North America (Norse et al. 1986; OTA 1987; Flathead Basin Commission 2000). The county is home to bald eagle, bighorn sheep, bull trout, Canada lynx, elk, gray wolf, grizzly bear, lynx, moose, mountain lion, mule deer, peregrine falcon, and wolverine. The bald eagle, bull trout, Canada lynx, Chinook salmon, gray wolf, grizzly bear, sockeye salmon, trumpeter swan, white sturgeon, and woodland caribou are on the federal list of threatened and endangered species (Mahr 2007).

Third, several of the wildlife species in Flathead County utilize habitat within and adjacent to protected areas in the county. This study evaluates potential impacts of future land development on wildlife habitat in buffer zones for five protected areas: (1)

Glacier National Park; (2) the Great Bear wilderness and the northern portion of the Bob Marshall wilderness; (3) a northern unit of roadless areas west of Glacier; (4) a southern unit of roadless areas west of the Great Bear wilderness; and (5) the Lost Trail National Wildlife Refuge in the western area of the county. This delineation is based on three criteria: (1) the federal agency managing the protected area; (2) the objectives governing the management of the protected area; and (3) the location of the protected area relative to the human population. In particular, Glacier is part of the U.S. national park system and is managed by the National Park Service. Additionally, Glacier is a biosphere reserve, a World Heritage site, and part of the Waterton–Glacier International Peace Park. The Great Bear and Bob Marshall wilderness areas are units of the national wilderness preservation system and are managed by the U.S. Department of Agriculture–Forest Service (USFS). The two roadless areas are part of the national forest system and are managed by USFS. Lost Trail is a unit of the national wildlife refuge system and is managed by the U.S. Fish and Wildlife Service. Although the two roadless areas are managed by the same federal agency, they were treated separately because they are not contiguous (i.e., they are divided by the northern portion of the Flathead Valley).

Fourth, Flathead County was chosen as the study area because future land use change in the county has already been simulated in the on-going landscape change study (CARES 2007).

Methods

Alternative futures. The potential wildlife impacts of future economic growth and land development in areas adjacent to the five protected areas are evaluated for nine alternative futures. These scenarios consist of combinations of low, moderate, or high annual growth rates for 2000 to 2024 (24 years) in demand for eleven major industries in the county, and current, moderately restrictive, or highly restrictive land use policies. The current land use policy approximates current land development and subdivision regulations in the county and is the least restrictive of the three policies.

Potential wildlife impacts of future land development are simulated using the Ecosystem Landscape Modeling System (ELMS), which was developed in an on-going landscape change study (Prato 2005; CARES 2007). ELMS uses geospatial technologies (i.e., geographic information systems and remote sensing) to simulate future conversion of developable parcels to residential and commercial–institutional and industrial (CI&I) uses in Flathead County. It simulates the total acreage required for different housing units by combining the increase in housing units required by the additional workers estimated for each of the three growth rate scenarios, the distribution of houses among housing types, and the densities of housing types.

Average growth rates for the eleven major industries are 3.91%, 6.26%, and 8.78% (between 2000 and 2014) and 1.95%, 3.13%, and 4.39% (between 2014 and 2024) for the low-, moderate-, and high-growth rate scenarios, respectively. The percentage of housing units in the six housing types for the three land use policies are given in Table 1. Relative to the current policy, the moderately restrictive policy has a higher percentage of housing units in the high-density and urban categories and a lower percentage in the suburban category.

Housing type	*Current*	*Moderately restrictive*	*Highly restrictive*
High-density[a]	3	10	20
Urban[b]	18	20	25
Suburban[c]	42	34	30
Rural[d]	6	6	5
Exurban[e]	18	18	10
Agricultural[f]	12	12	10

[a] 2.8 units per ha
[b] 2.2 units per ha
[c] 0.8 units per ha
[d] 1 unit per 0.4 ha
[e] 1 unit per 3 ha
[f] 1 unit per 19 ha

Table 1. Assumed percentages of housing units in six housing types for three land use policies.

Relative to the moderately restrictive policy, the highly restrictive policy has a higher percentage of housing units in the high-density and urban housing types, and a lower percentage in the other housing types.

The three land use policies assume a setback of housing and CI&I units from water bodies of 6.1 m for the current policy, 10.7 m for the moderately restrictive policy, and 15.2 m for the highly restrictive policy. The current policy does not restrict the types of housing units constructed near environmentally sensitive areas (i.e., national parks, wildlife refuges, state parks, and county parks). The moderately restrictive policy allows only urban, suburban, rural, exurban and agricultural housing units, and the highly restrictive policy allows only suburban, rural, exurban, and agricultural housing units, in a 1.61-km wide buffer area around environmentally sensitive areas. None of the land use policies allow new CI&I units to be constructed in the buffer area for environmentally sensitive areas. Conversion of developable parcels to housing units and CI&I units is restricted based on whether or not parcels have access to sewer service. Construction of high-density, urban, and suburban housing units and CI&I units are allowed only on sewer-accessible parcels. Construction of rural, exurban, and agricultural housing types is allowed on parcels both within and outside of sewer-accessible areas.

For each growth rate scenario, the number of additional housing units is determined by multiplying the increase in employment between 2000 and 2024 for that scenario (estimated using the IMPLAN regional economic model for Flathead County; Lindall and Olson 1993) and the estimated housing requirements per worker. The procedure for estimating future housing requirements takes into account vacant housing units and housing units occupied by non-permanent residents of the county. Acreage requirements for the six housing types are determined based on the total number of housing units required to achieve a particular growth rate scenario, the percentage of housing units in each of six housing types with each land use policy, and the area required by each housing type. For each growth rate scenario, the total acreage requirements for additional CI&I units are determined by multiplying the estimated increase in employment between 2000 and 2024 for that scenario and the CI&I acreage requirements per worker.

The order in which developable parcels are converted to housing and CI&I units is determined based on development attractiveness scores for parcels and other factors. The development attractiveness scores for parcels are calculated using a multiple attribute evaluation procedure (Herath and Prato 2006). Development attractiveness scores for housing units are calculated based on four parcel attributes: (1) the maximum acceptable distance from a major highway; (2) the maximum acceptable distance from the edge of town; (3) the maximum acceptable distances from seven amenities (i.e., lakes, rivers, preserve/parks, golf courses, ski resorts, forests, and the elevation from the valley floor); and (4) the minimum acceptable distances from five disamenities (i.e., industrial facilities, trailer parks, commercial centers, railroad tracks, and airports). Development attractiveness scores for CI&I units are calculated based on two parcel attributes: (1) the maximum acceptable distance from a major highway; and (2) the maximum acceptable distance from the edge of town. Parcel attributes are determined using a geographic information system.

Table 2 summarizes the simulated land requirements, land developed into housing units and CI&I units, and land surpluses or shortages for the nine alternative futures. For purposes of this study, the simulated land developed into the six housing types and CI&I units were aggregated into three land use classes: (1) low-density uses consisting of acreage developed into exurban and agricultural housing units; (2) moderate-density uses consisting of acreage developed into suburban and rural-density housing units; and (3) high-density uses consisting of acreage developed into high-density and urban-density housing units and CI&I units.

Delineating buffer zones. Buffer zones for protected areas are delineated based on the conceptual design for biosphere reserves. This design consists of a *core area*, a *buffer zone* for the core area (see Figure 2), and a *transition area* (Creswell and Thomas 1977). A core area is a legally protected area, such as a national park or wilderness area, in which human disturbances to land and water are kept to a minimum. Primary management objectives for core areas are long-term conservation of biological diversity, and low-impact research, educational, and recreational activities. The buffer zone is an area surrounding or adjoining the core area in which human activities compatible with the management objectives for the core area are allowed, such as environmental education and recreation. Outside of the buffer zone is a transition area (not shown in Figure 2) that contains human settlements, farms, and other human activities that are compatible with sustainable development. Only five of the 47 biosphere reserves in the United States have designated buffer zones and transition areas (UNESCO 2007b).

Lockwood (2006:93) points out that the zonation concept for biosphere reserves is "applied in many different ways, in order to accommodate geographical conditions, socioeconomic settings, available legal protection measures and local constraints." Li et al. (1999) indicate that specifying a uniform buffer width around nature reserves is not justified and that buffer width should be varied depending on the activities that occur in different areas of the buffer. Shafer (1999) contends that a protected area may require different buffer sizes. Since there no

Land use category	*Low-growth*	*Moderate-growth*	*High-growth*
		Current policy	
Required			
CI&I units	645	1,174	2,032
Total housing units	141,070	256,933	444,582
CI&I + housing units	141,715	258,107	446,614
Developed[a]			
CI&I units	647	1,174	2,033
Total housing units	141,157	215,756	214,897
CI&I + housing units	141,804	216,930	216,930
Surplus or shortage[bc]	75,217	-41,176	-229,683
		Moderately restrictive policy	
Required			
CI&I units	645	1,174	2,032
Total housing units	103,630	194,859	326,589
CI&I + housing units	104,275	196,033	328,620
Developed[a]			
CI&I units	645	1,232	2,093
Total housing units	103,709	194,894	214,837
CI&I + housing units	104,354	196,126	216,930
Surplus or shortage[bc]	112,656	20,898	-111,690
		Highly restrictive policy	
Required			
CI&I units	645	1,174	2,032
Total housing units	62,152	113,199	195,873
CI&I + housing units	62,797	114,373	197,904
Developed[a]			
CI&I units	645	1,188	2,047
Total housing units	53,301	97,039	167,699
CI&I + housing units	53,946	98,226	169,746
Surplus[b]	154,134	102,558	19,026

[a] In some cases, the area developed exceeds the area required for development due to the discreteness of the parcels.
[b] A surplus (positive acreage) indicates that the area available for development (216,931 ha) *exceeds* the area required for development. The surplus equals the area available for development minus the area developed.
[c] A shortage (negative acreage) indicates that the area available for development (216,931 ha) is *less than* the area required for development. The shortage equals the area developed minus the area required for development.

Table 2. Simulated land requirements and land developed into housing and commercial–institutional and industrial (CI&I) units, and land surpluses and shortages, for nine alternative futures, Flathead County, 2000–2024 (in ha).

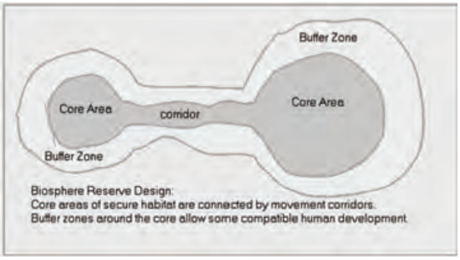


Figure 2. Biosphere reserve design. Source: American Wildlands 2007b.

uniform guidelines for buffer widths, the choice of buffer widths is somewhat arbitrary. Two widths were evaluated in this study: 8 km and 16 km. A geographic information system was used to determine the areas covered by the two buffer zones for the five protected areas (see Figures 3 and 4). Since ELMS only simulates future land use changes in Flathead County, it is not possible to evaluate the potential wildlife impacts of future land development in areas of the buffer zones that fall outside of Flathead County.

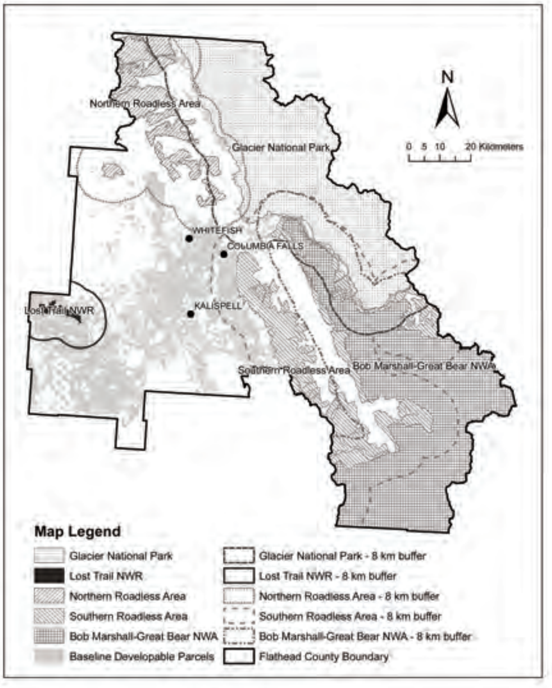
Surrogate indicators of wildlife impacts of land use change. Potential wildlife impacts of future land development vary depending on: (1) the nature and extent of the built-up area (e.g., whether the development is low-density or high-density, and the total acreage converted to developed uses); (2) where development occurs relative to important wildlife habitat (e.g., whether development occurs in wildlife migration corridors); and (3) the habitat requirements for wildlife species (e.g., whether development fragments large roadless areas favored by grizzly bears).

Three approaches were considered for evaluating the potential wildlife impacts of future land development. First, there is the conventional approach, which determines land cover from satellite imagery, uses the land cover data to calculate landscape metrics (e.g., number of patches, area-weighted mean patch size, the relative size of a patch containing a particular cover type, etc.), and interprets the implications of the resulting landscape metrics for wildlife habitat based on existing knowledge of how different landscape patterns influence habitat suitability for species (e.g., Griffiths et al. 1993; Hansen et al. 1995; Hansen et al. 2001; Turner et al. 2001). It was not possible to use this approach in the current study because ELMS simulates future land use changes, not future land cover changes. Although it is possible to infer future land cover changes from land use changes, the procedures for doing so are problematic (Lambin et al. 1997; Brown et al. 2000).

Second, potential wildlife impacts of future land development can be assessed using landscape metrics calculated using simulated future land use changes in the buffer zones. Unfortunately, it is not straightforward to interpret what such metrics mean for wildlife habitat quality.

Third, potential wildlife impacts of future land development can be evaluated in terms of surrogate indicators calculated using simulated land use changes in buffer zones. This approach is used here. Three surrogate indicators are used: (1) the *overall vulnerability of wildlife* (V); (2) the *extent of wildlife disturbance* (E); and (3) the *security of wildlife habitat* (S). Increases in land development, more restrictive land use policies, and changes in buffer width can alter V, E, and S, and hence the potential future quantity and quality of wildlife habitat. Since the three surrogate indicators are generic, they cannot be used to draw inferences about the potential impacts of future land development on specific wildlife species.

Indicator V is measured by the per-



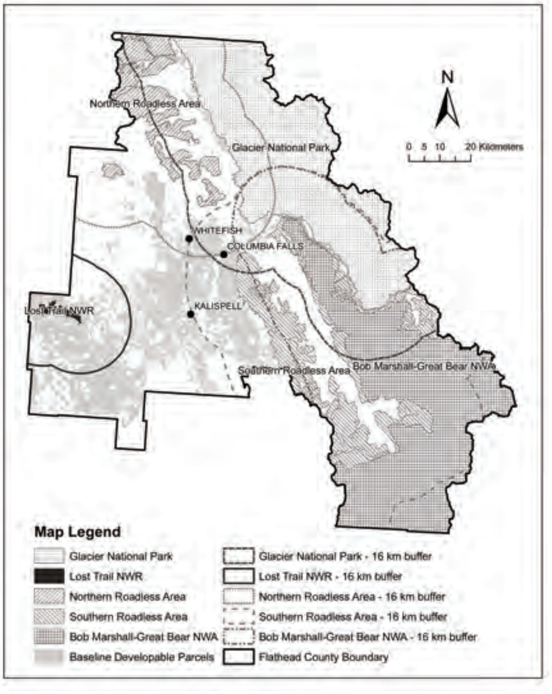


Figure 3 (top). Eight-km buffer zones for five protected areas in Flathead County, Montana.
Figure 4 (bottom). Sixteen-km buffer zones for five protected areas in Flathead County, Montana.

centage of the total area of a buffer that is developable. High (low) values of V imply high (low) overall vulnerability of wildlife to future development. Total developable area of a buffer equals the total area of a buffer, minus the area of public land (i.e., national, state, and local parks, wilderness areas, national forests, and national wildlife refuges) in the buffer, minus the area of private land in the buffer that is excluded from development by a particular land use policy. Total area of a buffer and the area of public land in a buffer do not vary across the nine alternative futures. Hence, variation in V results from variation in the area of private land in a buffer that is excluded from development by a land use policy. Parcels are excluded from development if: (1) less than half of the area of the parcel is in the portions of the buffers for the five protected areas that fall in Flathead County; (2) more than half of the area of the parcel is in slopes that exceed 30%; (3) more than half of the area of the parcel is in the designated 100-year floodplain; and (4) the size of the parcel is too small for development after imposing a 6.1-m setback of structures from water bodies, In addition, parcels are excluded from development due to the restrictions imposed by the land use policies. Parcel boundaries and attributes are determined from the Montana Department of Revenue's (2006) CAMA (Computer Assisted Mass Appraisal System) database as of November 2005.

Indicator E is measured by the percentage of the total developable area in a buffer that is developed under an alternative future. High values of E imply that a large percentage of the total developable area in a buffer is developed, which implies less effective habitat for species that are intolerant to human disturbance. Effective habitat is the area of potential habitat for a species multiplied by the proportion of potential habitat that is useable by that species; it takes into account the impacts of human disturbances, such as roads, structures, logging, and recreation, on the occurrence and persistence of a species in a potential habitat area (Apps and Hamilton 2002). Potential habitat is the habitat area potentially available to a particular species; it does not consider impacts of human disturbances on habitat quality (Miistakis Institute for the Rockies 2002). In summary, high values of E portend detrimental effects on wildlife habitat.

High values of V and E imply that few patches of land are potentially or actually suitable for wildlife, respectively, and a greater likelihood that patches of human-disturbed land are interspersed with patches of public land or undeveloped private land. In other words, high values of V and E suggest smaller and less heterogeneous patches of suitable wildlife habitat, which has the potential to decrease the number of species and the number of individuals relative to what they would be with larger patches of the same habitat (Turner et al. 2001). In summary, high values of V and E imply less effective wildlife habitat.

Indicator S is measured by [(LD)/(LD + MD + HD)][100], where LD, MD, and HD are the acreages in low-density, moderate-density, and high-density housing units, respectively. Other things equal, high values of S imply that a high percentage of the total area developed is in less compact (i.e., low-density) housing units. Consequently, high values of S imply greater landscape fragmentation and less secure wildlife corridors. Lower corridor security increases the risk of injury or death to species that depend on migration corridors to travel between protected areas, such as grizzly bear and elk.

Results and discussion

The values of V, E, and S for the nine alternative futures and two buffer widths are summarized in Table 3. There is a substantial difference in the average V (calculated over the three land use policies and two buffer widths) between Lost Trail National Wildlife Refuge and the other protected areas. Average V over all three land use policies and two buffer widths is 61% for Lost Trail compared with 8% for the remaining

Table 3. Values of V, E, and S for nine alternative futures and 8- and 16-km buffers (percent).

Buffer width and protected area	V[a]	E[b]			S[c]		
		Growth Rates					
		Low	Moderate	High	Low	Moderate	High
				Current policy			
8-km							
Glacier National Park	9	67	100	100	96	97	93
Lost Trail NWR	72	68	100	100	99	96	94
Northern Roadless Area	11	68	100	100	97	93	92
Southern Roadless Area	9	63	100	100	95	95	90
Bob Marshall-Great Bear NWA	2	64	100	100	95	99	92
16-km							
Glacier National Park	9	65	100	100	93	92	86
Lost Trail NWR	53	69	100	100	99	96	95
Northern Roadless Area	13	67	100	100	94	91	87
Southern Roadless Area	11	64	100	100	94	93	89
Bob Marshall-Great Bear NWA	2	61	100	100	93	96	90
				Moderately restrictive policy			
8-km							
Glacier National Park	9	44	89	100	96	98	95
Lost Trail NWR	67	53	84	100	96	98	97
Northern Roadless Area	9	41	88	100	96	96	92
Southern Roadless Area	9	46	91	100	92	94	90
Bob Marshall-Great Bear NWA	2	53	93	100	97	98	98
16-km							
Glacier National Park	9	47	92	100	91	90	86
Lost Trail NWR	53	51	87	100	97	99	97
Northern Roadless Area	13	45	9	100	91	91	86
Southern Roadless Area	11	48	92	100	90	91	87
Bob Marshall-Great Bear NWA	2	49	91	100	94	95	89
				Highly restrictive policy			
8-km							
Glacier National Park	9	28	51	91	97	96	95
Lost Trail NWR	67	26	59	92	100	98	100
Northern Roadless Area	9	21	53	91	91	90	93
Southern Roadless Area	9	33	54	90	91	91	90
Bob Marshall-Great Bear NWA	2	33	48	92	96	94	98
16-km							
Glacier National Park	9	32	57	92	85	85	83
Lost Trail NWR	53	26	56	93	100	98	98
Northern Roadless Area	13	29	55	92	86	83	85
Southern Roadless Area	11	34	54	91	86	86	86
Bob Marshall-Great Bear NWA	2	32	51	91	91	90	90

[a] Higher values of V imply higher vulnerability of wildlife to development.
[b] Higher values of E imply less effective habitat for human-intolerant species.
[c] Higher values of S imply greater landscape fragmentation and less secure wildlife habitat.

four protected areas. Buffers for the latter have values of V that range from 2% to 13%. Potential buffer vulnerability to future land development is substantially lower for the Bob Marshall–Great Bear wilderness complex than for Lost Trail (average V values of 2% for the former versus 61% for the latter), and moderately lower for Bob Marshall–Great Bear than for the Glacier–Northern Roadless Area–Southern Roadless Area complex (average V values of 2% for the former versus 10% for the latter). The average potential vulnerability of the five protected areas does not vary much with respect to land use policy and buffer width.

The five protected areas are ranked from highest to lowest overall potential vulnerability of wildlife to future land development (i.e., highest to lowest V) based on the sum of ranks for V (see Table 4). Rankings indicate that the buffer zone for the Lost Trail is the most vulnerable and that for Bob Marshall–Great Bear is the least vulnerable to future development.

Table 5 tabulates the average percentage point increases in E between the growth rates for each land use policy and buffer width. The average extent of potential wildlife disturbance due to future development in the buffer zones (1) increases substantially between the low and moderate growth rates and remains the same between the moderate and high growth rates for the current policy; (2) increases more between the low and moderate growth rates than between the moderate and high growth rates for the moderately restrictive policy; (3) increases more between the moderate and high growth rates than between the low and moderate growth rates for the highly restrictive policy; and (4) increases by similar amounts for the 8- and 16-km-wide buffers.

Table 4 (top). Ranking of the buffers for five protected areas according to the overall vulnerability of wildlife to development (V). The lower the ranking, the higher the wildlife vulnerability.
Table 5 (bottom). Average percentage point increases in E between growth rates for the three land use policies and two buffer widths.

Protected area	*Sum of Ranks*	*Ranking*
Glacier National Park	19	4
Lost Trail NWR	6	1
Northern Roadless Area	12	2
Southern Roadless Area	16	3
Bob Marshall–Great Bear NWA	25	5

Change in growth rates	*8-km buffer*	*16-km buffer*
	Current policy	
Low to moderate	34	35
Moderate to high	0	0
	Moderately restrictive policy	
Low to moderate	35	35
Moderate to high	26	25
	Highly restrictive	
Low to moderate	21	20
Moderate to high	32	31

For both buffer widths, the potential future increase in human disturbance to wildlife between the low and moderate growth rates is smaller with the highly restrictive policy than with either the current or moderately restrictive policies. In contrast, the potential future increase in human disturbance to wildlife between the moderate and high growth rates is greater with the highly restrictive policy than with the current or moderately restrictive policies.

Table 6 tabulates the average percentage point decrease in E between the current and moderately restrictive policies and between the moderately and highly restrictive policies for the low-, moderate-, and high-growth rate scenarios for each buffer width. The potential impact of future land development on the extent of wildlife disturbance decreases moderately as the land use policy becomes more restrictive. With an 8-km buffer, decreases in the extent of wildlife disturbance between the current and moderately restrictive policies become smaller as growth rates increase. This is not the case between the moderately restrictive and highly restrictive policies. The decreases in the extent of human disturbance to wildlife are similar for the two buffer widths at the low- and high-growth rates, but dissimilar at the moderate-growth rates.

Table 3 indicates relatively high values of S (≥ 85%) for the nine alternative futures and two buffer widths. This result suggests a high future potential for habitat fragmentation and low future potential for habitat security for human-intolerant species in the buffer areas. S is high because a high percentage of the additional land developed under all alternative futures goes for low-density housing units (i.e., MD + HD is small compared with LD). Averaged over all alternative futures and buffer widths, the buffers for Lost Trail have the highest future potential for fragmentation and lowest future potential for habitat security (average S of 98), and the buffers for Bob Marshall–Great Bear have the lowest future potential for fragmentation and the highest future potential for habitat security (average S of 94). The ranking of the five protected areas from lowest to highest future potential for landscape fragmentation and wildlife habitat security based on S was the same as the

Table 6. Average percentage point decreases in E from the current land use policy to the moderately restrictive land use policy, and from the moderately restrictive land use policy to the highly restrictive land use policy, for the low-, moderate-, and high-growth rate scenarios and 8- and 16-km buffers.

Buffer width	*Current to moderately restrictive*	*Moderately restrictive to highly restrictive*
	Low-growth-rate scenario	
8 km	18	20
16 km	17	17
	Moderate-growth-rate scenario	
8 km	11	36
16 km	26	19
	High-growth-rate scenario	
8 km	0	9
16 km	0	8

ranking of the five protected areas from highest to lowest future potential for vulnerability to development based on V. In general, S varies only moderately across alternative futures and buffer widths.

Summary and conclusions

This study is one of the first to systematically evaluate the potential adverse impacts of future economic growth and land development on wildlife habitat adjacent to protected areas. It was not possible to use the conventional approach to evaluate wildlife habitat suitability in the study area. Hence, three surrogate indicators were constructed and used to evaluate the potential impacts of future economic growth and land development on wildlife habitat in 8- and 16-km-wide buffer zones around five protected areas.

The overall vulnerability of wildlife to land development is the highest in the buffer zones for Lost Trail National Wildlife Refuge and lowest in the buffer zones for the Bob Marshall–Great Bear wilderness complex. Potential human disturbance to wildlife in the buffer zones is substantial for all three land use policies and two buffer widths. However, the magnitude of disturbance decreases as the future economic growth rates decrease and land use policy becomes more restrictive. The latter suggests that land use policy may be effective in alleviating the adverse wildlife impacts of future land development. For all nine alternative futures and two buffer widths, habitat fragmentation is high and the security of wildlife habitat is low in the buffer zones because a large percentage of the newly developed land is in low-density housing units. This result suggests that future land development in the county could have potentially negative impacts on wildlife unless the density of new housing units is substantially reduced. The buffer zone for Lost Trail, which is the smallest of the five protected area evaluated, has the highest potential habitat fragmentation and the lowest potential habitat security in the future. The buffer zone for the Bob Marshall–Great Bear wilderness complex, which is a relatively large protected area, has the lowest potential habitat fragmentation and the highest potential habitat security. An interesting follow-up study would be to determine how sensitive the results and conclusions stated above are to changes in these assumptions.

The results and conclusions of this study apply to the protected areas in Flathead County and the assumptions underlying the alternative futures and ELMS. However, the alternative futures approach, ELMS, and surrogate indicators used in this study can be used to evaluate the potential wildlife impacts of future land development in buffer zones for other protected areas.

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Tony Prato, Center for Agricultural, Resource, and Environmental Systems, University of Missouri–Columbia, 212 Mumford Hall, Columbia, Missouri 65211; pratoa@missouri.edu

Anthony S. Clark, Department of Agricultural Economics, University of Missouri–Columbia, 327 Mumford Hall, Columbia, Missouri 65211

Yan Barnett, Center for Agricultural, Resource, and Environmental Systems, University of Missouri–Columbia, 130A Mumford Hall, Columbia, Missouri 65211