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Evaluating Tradeoffs Between Economic Value and Wildlife Habitat Suitability in Buffer Zones for Protected Areas in the Northern Rocky Mountains, USA

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Future economic growth and land development have the potential to produce tradeoffs in which economic values increase at the expense of environmental values. Although such tradeoffs have not been empirically verified in mountain ecosystems, they are likely to exist for an ecosystem containing abundant natural resources and environmental amenities that is undergoing rapid economic and population growth. Quantifying future tradeoffs between economic and environmental values is important because it provides information for natural resource managers and community planners that is useful in alleviating the adverse impacts of future growth and development on wildlife. Such tradeoffs are quantified for Flathead County, Montana, located in the Northern Rocky Mountains of the United States, using the Ecosystem Landscape Modeling System (ELMS). In particular, the ELMS is used for the following: (1) to simulate the extent of the tradeoffs between economic values (ie total output of goods and services) and wildlife habitat suitability (ie extent of habitat disturbance and the degree of loss in habitat security) in buffer zones for 5 protected areas in Flathead County between 2005 and 2024; and (2) to determine whether implementing a more restrictive land use policy than existed in 2005 would reduce future adverse impacts of growth and development on wildlife habitat. Simulation results indicate that future growth in Flathead County increases total output of goods and services, and the resulting land development reduces the suitability of wildlife habitat in the buffer zones. Degradation in habitat suitability can be alleviated by implementing a more restrictive land use policy. The methods used in the study provide a coarse assessment of the tradeoffs between economic values and wildlife habitat suitability in buffer zones for mountain protected areas.

Keywords: *Economic growth; land development; economic value; wildlife habitat suitability; tradeoffs; Rocky Mountains; Montana; United States.*

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Introduction

Land development caused by economic growth often reduces the ecological integrity of mountain ecosystems through loss and fragmentation of wildlife habitat, increases wildlife mortality resulting from human–wildlife conflicts, boosts soil erosion and water pollution, increases the spread of exotic (nonnative) species, raises temperatures in streams, lakes, and ponds, and accelerates the natural processes of ecosystem change (Adger and Brown 1994; Ojima et al 1994; Turner and Meyer 1994; Vitousek 1994; Vitousek et al 1997; IIASA 1998; Baron et al 2000; Miller and Brown 2001; Solecki 2001). Environmental impacts of land development, including landscape fragmentation, have been widespread and extensive in the United States (eg Gonzalez-Abraham et al 2007). Over 90% of the land in the Lower 48 states has been logged, plowed, mined, overgrazed, paved, or otherwise modified from presettlement conditions (Terborgh and Soule 1999). Between 1982 and 1997, 121,000 km^2 of undeveloped nonfederal lands in the United States were transformed into urban areas (USDA 2000), which has contributed to species extinction (Stoltzenburg 1996). During the last 3 centuries, nearly 1.2 million km^2 of forest and woodland and 5.6 million km^2 of grassland and pasture have been converted to other uses on a global basis (Ramankutty and Foley 1999).

Economic growth in the Northern Rocky Mountains of the United States is being driven by lower crime rates, less traffic congestion, cleaner air and water, and more diverse outdoor recreational opportunities and environmental amenities than exist in other regions of the country (Prato 2004; Gude et al 2006; Gruver 2007). Although economic growth increases economic values, notably total output, jobs, and personal income, the resulting land development changes land cover and land use, which can diminish environmental amenities and the quality of life (Meyer 1993; Rasker and Hansen 2000; Swanson et al 2003; Rasker et al 2004; Prato and Fagre 2005).

In the Northern Rocky Mountains, metropolitan as well as gateway communities for protected areas, such as national parks, wilderness areas, and wildlife refuges, are experiencing substantial growth and development (Howe et al 1997; Rasker et al 2004). Between 1970 and 2000, rural residential development in the Montana and Wyoming portions of the Greater Yellowstone Ecosystem increased 400% (Williams 2001), causing degradation and fragmentation of current and potential grizzly bear habitat on private lands. Double-digit growth in residential subdivisions adjacent to the National Elk Refuge in Jackson, Wyoming, has reduced the 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). Cumulative impacts of residential and resource development (ie timber harvesting and energy development) near Glacier National Park in northwest Montana threaten the park's natural resources (Keiter 1985; Prato 2004; Sax and Keiter 2007). Burchell et al (2005) observe 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% or more of the species listed under the [U.S.] Endangered Species Act."

The objectives of this paper are the following: (1) to simulate the extent of the tradeoffs between economic value (ie total output of goods and services produced) and wildlife habitat suitability (ie extent of habitat disturbance and the degree of loss in habitat security) in buffer zones for 5 protected areas in Montana's Flathead County; and (2) to determine whether a more restrictive land use policy than existed in 2005, which is the base year for simulating changes in land use, would reduce adverse impacts of future growth and development on wildlife habitat through 2024. Quantifying prospective tradeoffs between economic and environmental values is important because it provides information to natural resource managers and community planners that is useful in supporting decisions to alleviate the adverse impacts of future growth and development on wildlife.

Study area

The study area is Flathead County, Montana (Figure 1), which is located in the Northern Rocky Mountains of the United States. The county has spectacular mountain landscapes that sustain diverse employment and outdoor recreational opportunities and afford a high quality of life. From 1990 to 2000 the total population of the county increased 25.8% to 74,471 (United States Census Bureau 2007), compared to 12.9% for the state of Montana and 13.1% for the nation. Between April 2000 and July 2005, the population of the county grew 11.7%, compared to 3.7% for Montana and 5.3% for the United States. The July 2005 population of Flathead County was 83,000 (United States Census Bureau 2007), and the population is projected to grow to 113,140 by 2025 (NPA Data Services 2003).

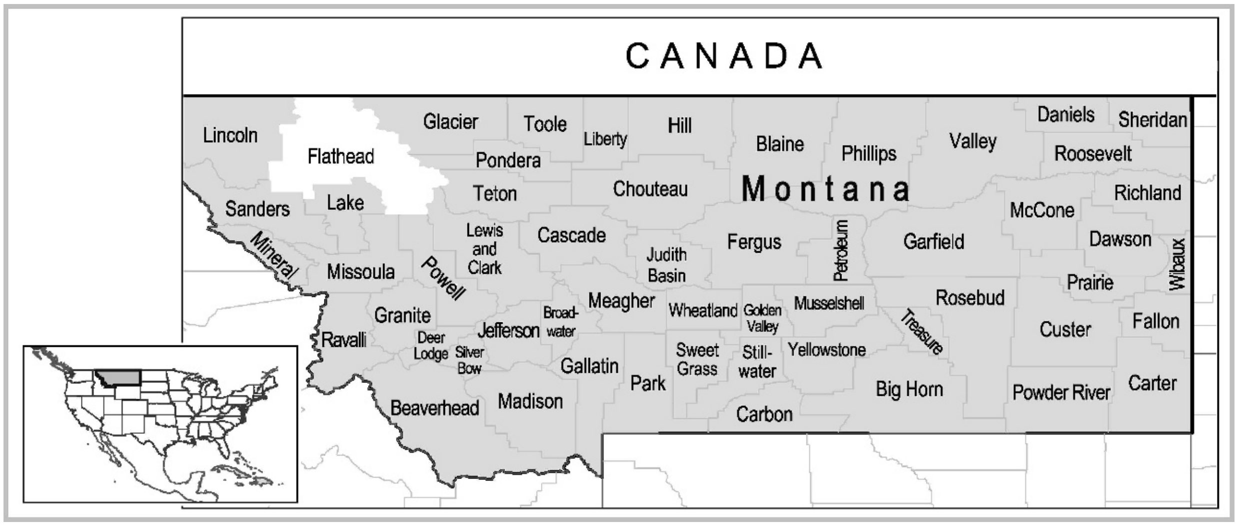
Much of the growth and development in Flathead County has occurred in the Flathead Valley, an area containing rich farmland, low rolling timbered hills, and residential and commercial areas. In the last 30 years, 42,998 ha of farmland in the Flathead Valley have been converted to developed uses (Anonymous 2003). Ranchland in the county is at risk of being converted to low-density residential development (Wenger 2004). As a result of growth and development, most old-growth forests that once existed outside protected areas in the county have been harvested, rivers have been altered by hydroelectric power development, significant acreage has been converted from farms and forests to residential and commercial developments, lakes and streams have become polluted by agricultural and urban runoff, fish and wildlife habitat has been lost or degraded, large areas have been invaded by nonnative species, and air pollution has increased.

Despite these changes, Flathead County has plentiful and relatively clean water and air, numerous world-class natural protected areas, and abundant wildlife. Six rivers flow through Flathead Valley: the North, Middle, and South Forks of the Flathead River; Stillwater River; Whitefish River; and Swan River. The Flathead River flows into Flathead Lake, one of the 300 largest lakes in the world and the largest body of fresh water west of the Mississippi River. The county contains several natural protected areas, including the Great Bear Wilderness, the northern portion of the Bob Marshall Wilderness, roadless areas in the Flathead National Forest, the west side of Glacier National Park, and the Lost Prairie National Wildlife Refuge (Figure 2). Glacier National Park is a UNESCO Biosphere Reserve, and Waterton-Glacier International Peace Park is the world's first international peace park and a World Heritage Site (FCVB 2008). Despite its temperate climate, Flathead County has a highly diverse flora and fauna with 300 species of aquatic insects, 22 native and introduced species of fish, and nearly all of the large mammals of North America. Five of these species are threatened, and 2 are endangered (Norse et al 1986; Prato and Fagre 2007).

The land area of the county is about 13,605 km^2 (approximately the size of the state of Connecticut in the United States), of which 78.6% is managed by the federal government, and 82.5% is controlled by federal, state, and tribal agencies (Flathead County Planning and Zoning 2007).

The climate of Flathead County falls in the transition zone between continental and Pacific maritime. Average annual temperature is 5.9°C (averaging 2.2°C in the winter and 25.6°C in the summer), average annual rainfall is 419 mm, and average annual snowfall is 1402 mm (GCS

FIGURE 1 Location of Flathead County, Montana, USA. (Map by Christian Hergarten)



Research 2005). Elevation in the county ranges from approximately 900 to 3000 m, resulting in a range of vegetation communities.

Methods

The primary method of analysis is the Ecosystem Landscape Modeling System (ELMS) (Prato et al 2007). The ELMS was used to simulate future land use changes in Flathead County for 9 economic growth–land use policy scenarios. A scenario-based approach is used in the ELMS because of uncertainty regarding future growth rates and land use policies. The ELMS consists of an economic growth model, a land use change model, and a wildlife habitat assessment model, which are described in the next three sections.

Economic growth model

Economic growth scenarios for Flathead County specify the annual percentage increase in the total output of goods and services produced in 11 economic sectors of the county between 2000 and 2024 (see Prato et al [2007]) for a complete specification of the growth scenarios). The 11 sectors are: (1) agricultural, forestry, and fishery; (2) construction; (3) farming and ranching; (4) government; (5) finance, insurance, and real estate; (6) manufacturing, including forest products; (7) mining; (8) services; (9) retail trade; (10) transportation; communications, and public utilities; and (11) wholesale trade. A diverse group of stakeholders from the county reached consensus on the annual growth rates for total output of goods and services produced in the 11 sectors during the periods 2000–2014 and 2014–2024 for low, moderate, and high growth scenarios. Annual average growth rates for the 11 sectors are 8.78%, 6.26%, and 3.91% for the low, moderate, and high growth scenarios, respectively, between 2000 and 2014, and 4.39%, 3.13%, and 1.95% for the low, moderate, and high growth scenarios, respectively, between 2014 and 2024.

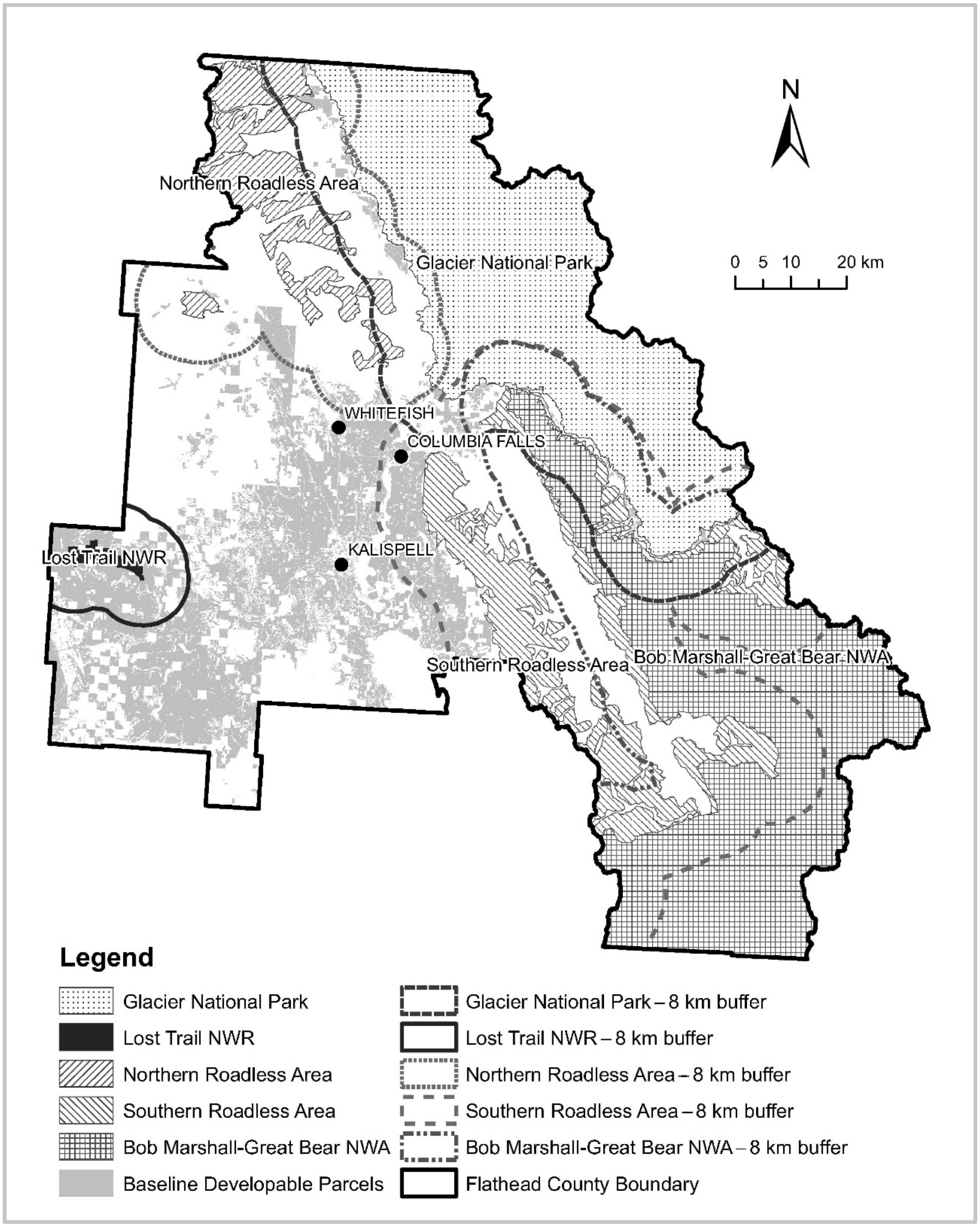
The economic growth model uses the IMPLAN program (Minnesota IMPLAN Group 2008) to estimate the increases in total output and total jobs in Flathead County between 2000 and 2024 for 3 economic growth scenarios (ie low, moderate, and high). IMPLAN is a menu-driven computer software program developed by the USDA Forest Service that permits nonsurvey regional input-output analysis of any county or combination of counties in the United States. A productivity adjustment estimated using forecasts of productivity increases over time (Berman 2004) was applied to the IMPLAN multipliers to account for increases in labor productivity over time (2000 to 2024) due to technological change. The starting year for the IMPLAN analysis is 2000. This was the most recent year for which IMPLAN data were available for Flathead County at the time the ELMS was developed.

Job increases by sector between 2000 and 2024 were estimated by applying the jobs-to-output ratios calculated using the IMPLAN model to the increases in sector outputs for each growth scenario. Increases in total housing units from 2005 to 2024 were estimated for each growth scenario as follows:

$$H = [(J \times PJ) \div PH] \times HL,$$

where H = estimated increase in total housing units, J = estimated increase in total jobs, PJ = population-to-jobs ratio (1.5), PH = average persons-per-household ratio (2.48), and HL = housing units-to-households ratio (1.18). The PJ, PH, and HL ratios were developed as part of the

FIGURE 2 Location of 8-km-wide buffer zones for 5 protected areas in Flathead County, Montana. (Map by the Center for Applied Research and Environmental Systems, University of Missouri)



2000 Census for the United States. The calculation of H accounts for housing units that are either vacant or occupied by nonpermanent county residents of the county.

Acreage required for new commercial, institutional, and industrial (CI&I) units under each growth scenario was determined by multiplying the estimated increase in total jobs and the estimated CI&I acreage per job in Flathead County in 2004. The latter is 114.36 m^2 per job, which is the product of the square meters per worker (Nelson 2004) and the number of workers per job in Montana (DOE 2002; Nelson 2004).

Land use change model

The land use change model simulates the conversion of developable parcels to new residential housing units and new CI&I units based on the following: (1) the number of additional CI&I units and housing units required between 2005 and 2024 with each growth scenario; (2) the proportion of additional housing units in each of 6 density classes; (3) the number and location of developable parcels in 2005; (4) the desirability of developable parcels for CI&I units and residential housing units; and (5) the order in which parcels are converted to CI&I units and residential housing units. The number of additional CI&I units and housing units required between 2005 and 2024 with each growth scenario are determined by the economic growth model. The land use policies specify the proportion of additional housing units in each of the following density classes: (1) high (2.8 units per hectare); (2) urban (2.2 units per hectare); (3) suburban (0.8 units per hectare); (4) rural (1 unit per 0.4 hectares); (5) exurban (1 unit per 3 hectares); and (6) agricultural (1 unit per 19 hectares).

The number and location of developable parcels in 2005 (ie baseline developable parcels) are determined by eliminating from the set of all parcels ones that: (1) cannot be developed because they are located on public land; (2) are already developed and are too small to accommodate additional development after imposing the setbacks of housing units and CI&I units from water bodies as specified by a land use policy; and (3) cannot be developed because of restrictions imposed by county ordinances and county subdivision regulations. A parcel is excluded from development based on item (3) if more than half of the area of the parcel has an average slope that exceeds 30% or more than half of the area of the parcel is in the designated 100-year floodplain. The size, location, and other features of developed and developable parcels obtained from the 2005 parcel database created by the Montana Cadastral Mapping Project (Montana Cadastral Mapping 2008) were incorporated into a geographic information system.

The desirability of developable parcels for development is determined using a multiple attribute evaluation procedure that calculates development attractiveness scores for all developable parcels and ranks the parcels based on their scores (Herath and Prato 2006). Parcel development attractiveness scores for residential development are based on 4 parcel attributes: (1) maximum acceptable distance from a major highway; (2) maximum acceptable distance from the edge of town; (3) maximum acceptable distances from 7 amenities (ie lake, river, preserve/park, golf course, ski resort, forest, and elevation difference between the parcel and valley floor); and (4) minimum acceptable distances from 5 disamenities (ie industrial facility or park, trailer park, commercial center, railroad tracks, and airport). Parcel development attractiveness scores for CI&I development are based on 2 parcel attributes: (1) the maximum acceptable distance from a major highway; and (2) the maximum acceptable distance from the edge of town. Maximum and minimum acceptable distances of developable parcels from landscape features are specified in Prato et al (2007), and actual distances are determined using a geographic information system. Since it was not possible to obtain sufficient feedback from community stakeholders about attribute weights, assumed values were used for the attribute weights (see Prato et al 2007 for actual weights).

The order of parcel development is the following: (1) CI&I units; (2) high-density housing units; (3) urban density housing units; (4) suburban density housing units; (5) rural density housing units; (6) exurban density housing units; and (7) agricultural density housing units. This order constrains the number and area of parcels developed when the amount of land available for development is less than the amount of land required for development, which occurs with the current land use policy at the moderate and high growth rates.

Three land use policies are simulated with the ELMS: current or baseline; moderately restrictive; and highly restrictive. These policies differ with respect to the following: (1) the percentage of new residential housing units allocated to the 6 density classes; (2) the setbacks of residential housing and CI&I units from water bodies; (3) the kinds of new residential housing units and CI&I units permitted in environmentally sensitive areas; and (4) the types of residential housing and CI&I units allowed on parcels that are not sewer accessible. As the land use policy becomes more restrictive (ie current to moderately restrictive to highly restrictive), the proportion of housing units in higher-density classes increases, and the proportion of housing units in lower-density classes decreases. Setbacks of housing units and CI&I units from water bodies are 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 land use policies impose restrictions on development in 1.61-km-wide buffer areas around environmentally sensitive areas (ie national parks, wilderness areas, wildlife refuges, county parks, and state parks). The current land use policy, which closely approximates the land use policy in effect in 2005, allows housing units in all 6 density classes to be constructed in 1.61-km-wide buffer areas for environmentally sensitive areas. The moderately restrictive land use policy allows housing units in the urban, suburban, rural, exurban, and agricultural density classes to be constructed in the 1.61-km-wide buffer areas. The highly restrictive land use policy allows housing units in the suburban, rural, exurban, and agricultural density classes to be constructed in the 1.61-km-wide buffer areas. None of the land use policies allow the construction of additional CI&I units in the 1.61-km-wide buffer areas for environmentally sensitive areas.

Finally, development of a parcel is restricted based on whether or not it is sewer accessible. A parcel is considered sewer accessible if it is located within the 2003 growth boundaries for the incorporated cities in Flathead County or within the boundaries of the unincorporated areas in Flathead County. Only CI&I units and housing units in the high, urban, and suburban density classes are allowed on sewer-accessible parcels. Rural, exurban, and agricultural housing units are allowed within and outside sewer-accessible areas.

Wildlife habitat assessment model

Since protected areas and lands adjacent to protected areas provide important habitat for many wildlife species in the study area, the wildlife habitat assessment model evaluates the impacts of land development on the suitability of wildlife habitats in 8-km- and 16-km-wide buffer zones around 5 protected areas in Flathead County: Glacier National Park; the Great Bear Wilderness plus the northern portion of the Bob Marshall Wilderness; a northern unit of roadless areas in the Flathead National Forest; a southern unit of roadless areas in the Flathead National Forest; and the Lost Trail National Wildlife Refuge. The buffer width (ie 8 km and 16 km) represents the straight-line distance between the boundary of the protected area or inner boundary of the buffer zone and the outer boundary of the buffer zone. Since the simulations of land use change for the 9 economic growth–land use policy scenarios were based on economic data for Flathead County, it was not possible to simulate land use change outside the boundaries of the county. For this reason, the buffer zones around the 5 protected areas do not extend beyond the boundaries of the county. A geographic information system is used to delineate the buffer zones. Figure 2 illustrates the 8-km buffer zones for the 5 protected areas.

Ideally, the potential impacts of future land development on the suitability of wildlife habitat in the buffer zones should be assessed using landscape metrics (Forman and Godron 1986; Turner 1989) calculated from land cover data using computer programs, such as FRAGSTATS (McGarigal and Marks 1995) and APACK (Mladenoff and Dezonia 1997). Although landscape metrics were calculated using APACK, it has been difficult to interpret the wildlife habitat implications of those metrics because they are based on simulated land use. APACK is typically applied to land cover.

Potential impacts of simulated future land use changes on wildlife habitat suitability in the buffer zones are evaluated using 2 indicators of wildlife habitat suitability: the *extent of habitat disturbance* (E) and the *degree of loss in habitat security* (S). Indicator E measures the percentage of the total area of a buffer zone that is developed in 2005 under the current land use policy and in 2024 under a particular economic growth–land use policy scenario. If the value of E is higher (or lower) in 2024 than in 2005, then habitat suitability decreases (or increases) from 2005 to 2024.

Indicator S equals $[(LD)/(LD + MD + HD)] \times [100]$, where LD, MD, and HD are the area of parcels developed into low, moderate, and high density land uses, respectively, in 2005 and 2024 under a particular economic growth–land use policy scenario. Low density land uses include residential housing units in the exurban and agricultural density classes. Moderate density land uses include residential housing units in the suburban and rural density classes. High density land uses include residential housing units in the high density and urban density classes plus CI&I units. S measures the percentage of the total developed area of a buffer zone in low density land uses in 2005 under the current land use policy and in 2024 with a particular economic growth–land use policy scenario. For a given growth scenario, higher (or lower) values of S indicate that a higher (or lower) percentage of the developed area of a buffer zone is in patches disturbed by human activity. In other words, a higher (or lower) value of S implies a greater (or lesser) degree of loss in habitat security for wildlife species in the buffer zone, especially species that are intolerant of human disturbance (Turner et al 2001). Less (or more) human disturbance in buffer zones decreases (or increases) the likelihood of injury or death to species with large home ranges, such as grizzly bear, wolverine, and mountain lion, all of which inhabit the study area.

Tradeoff analysis

Tradeoffs between wildlife habitat suitability in the buffer zones (E and S) for the 5 protected areas and total output of goods and services for the 11 sectors (T) are evaluated using 2 tradeoff elasticities: $\Delta E_{fij}/\Delta T_j$ and $\Delta S_{fij}/\Delta T_j$. ΔE_{fij} is the percentage change in the extent of wildlife disturbance in buffer size f between 2005 and 2024 with land use policy i and growth scenario j (f = 1 for the 8-km buffer zone and f = 2 for the 16-km buffer zone; i = 1 for the current land use policy, i = 2 for the moderately restrictive land use policy; and i = 3 for the highly restrictive land use policy; j = 1 for the low growth scenario, j = 2 for the moderate growth scenario, and j = 3 for the high growth scenario). ΔS_{fij} is the percentage change in the degree of loss in habitat security in buffer f between 2005 and 2024 with land use policy i and growth scenario j. ΔT_j is the percentage change in total output of goods and services produced in Flathead County between 2005 and 2024 with growth scenario j. For example, if $\Delta E_{811} / \Delta T_1 = 0.03$, then for each 1% increase in total output for the low growth scenario there is a 0.03% increase in the developed area of the 8-km buffer zone under the current land use policy and low growth scenario. Similarly, if $\Delta S_{811} / \Delta T_1 = 0.02$, then for each 1% increase in total output for the low growth scenario there is a 0.02% increase in the area in low density land uses in the 8-km buffer zone under the low economic growth–current land use policy scenario. Positive (or negative) values of $\Delta E_{fij} / \Delta T_j$ and $\Delta S_{fij} / \Delta T_j$ imply that future growth and development decrease (or increase) the suitability of wildlife habitat in the buffer zones. Additionally, a higher (or lower) absolute value of the tradeoff ratio implies a greater (or lesser) tradeoff between total output and wildlife habitat suitability.

Results and discussion

The size of the developed area in the 8-km- and 16-km-wide buffer zones under the baseline (2005) and 9 economic growth–land use policy scenarios in 2024 are summarized in Table 1. In all cases (ie combinations of buffer sizes and scenarios), the developed area of the buffer zone is largest for the southern roadless area and smallest for the wilderness areas. For the most part, the ranking of the other 3 protected areas according to the size of the developed area is Lost Trail National Wildlife Refuge, northern roadless area, and Glacier National Park. As expected, the 16-km buffer zones have a larger developed area than the 8-km buffer zones, and the developed area of the buffer zones for the 5 protected areas (last column in Table 1) increases as growth rates increase, except between the moderate and high growth rate scenarios under the current land use policy. This exception occurs because all of the land available for development in the buffer zones is developed under the moderate economic growth–current land use policy scenario. Except for the buffer zone for Glacier National Park between the current and moderately restrictive land use policy under the low growth scenario, the developed area of the buffer zones for each protected area decreases as the land use policy becomes more restrictive (ie current to moderately restrictive to highly restrictive) for each growth scenario. Therefore, a more restrictive land use policy than existed in 2005 moderates the increase in the developed area of the buffer zone between 2005 and 2024.

The percentages of developed area in a buffer zone (E) under the 9 economic growth–land use policy scenarios are summarized in Table 2. Recall that an increase (or decrease) in E implies a decrease (or increase) in the suitability of wildlife habitat in the buffer zones between 2005 and 2024. As expected, E increases between 2005 and 2024 for all buffer zones and economic growth–land use policy scenarios, increases as growth rates increase, and, for each growth scenario, generally decreases as the land use policy becomes more restrictive except between the current and moderately restrictive land use policy for the high growth scenario. Consequently, as growth rates increase, the extent of disturbance to wildlife habitat increases, and implementing a more restrictive land use policy than existed in 2005 moderates that disturbance. The ranking of buffer zones for protected areas from highest-to-lowest extent of habitat disturbance, or equivalently highest-to-lowest habitat vulnerability to development in buffer zones, is Lost Trail National Wildlife Refuge, northern roadless area, southern roadless area, Glacier National Park, and the wilderness areas.

The percentages of the developed portion of a buffer zone in low density uses (S) with the 9 economic growth–land use policy scenarios are summarized in Table 3. Recall that a higher (or lower) value of S implies less secure (or more secure) habitat in the buffer zones, especially for wildlife species that are highly intolerant to human disturbance (eg grizzly bear). For the most part, between 2005 and 2024 the security of wildlife habitat in the buffer zones decreases between the low and moderate growth scenarios and increases between the moderate and high growth scenarios. With one exception, the security of wildlife habitat for both buffer sizes increases as the land use policy becomes more restrictive for the northern and southern roadless areas and wilderness areas. For Glacier National Park and the Lost Trail National Wildlife Refuge, there are some cases for which the security of wildlife habitat decreases and other cases for which it increases as the land use policy becomes more restrictive. However, the decreases are rather small. The Lost Trail National Wildlife Refuge, northern roadless area, and Glacier National Park have the lowest, second lowest, and third lowest habitat security, respectively, for all economic growth–land use policy scenarios. The ranking of habitat security in buffer zones for the southern roadless area and wilderness areas varies with the buffer width. For 6 of the 9 scenarios, habitat security is less in the 8-km buffer zone for the southern roadless area than in the 8-km buffer zone for the wilderness areas. The converse is true for all 9 economic growth–land use policy scenarios in the 16-km buffer zone.

Tradeoff elasticities $\Delta E / \Delta T$ and $\Delta S / \Delta T$ for the 9 economic growth–land use policy scenarios and 2 buffer widths are given in Table 4. As a point of reference, estimated total output (T) is US$ 5,437 million in 2005 and US$ 12,825 million, US$ 15,329 million, and US$ 18,860 million in 2024 for the low, medium, and high economic growth scenarios, respectively. All tradeoff elasticities are positive, indicating that increases in total output between 2005 and 2024 are accompanied by

TABLE 1 Developed area in 8-km- and 16-km-wide buffer zones for Glacial National Park (GNP), Lost Trail National Wildlife Refuge (LTWR), Northern Roadless Area (NRA), Southern Roadless Area (SRA), and Great Bear Wilderness and northern portion of Bob Marshall Wilderness (Wilderness) in Flathead County for the baseline (2005) and 9 economic growth–land use policy scenarios (2024).

Economic growth–land use policy scenario	Protected area					
	GNP	LTWR	NRA	SRA	Wilderness	Total
Developed area in 8-km buffer zone (×1000 ha)						
Baseline	**2263**	**3845**	**2980**	**5483**	**594**	**15,165**
Low growth						
Current	9452	19,688	12,079	25,288	2408	68,915
Moderately restrictive	10,198	15,718	11,264	20,327	1812	59,319
Highly restrictive	5866	13,314	8165	13,847	1283	42,475
Moderate growth						
Current	17,682	29,778	34,057	37,882	3369	122,768
Moderately restrictive	15,984	26,031	19,601	31,921	2991	96,528
Highly restrictive	10,864	16,183	13,251	20,205	1682	62,185
High growth						
Current	17,682	29,778	34,057	37,882	3369	122,768
Moderately restrictive	17,658	29,776	33,979	37,864	3368	122,645
Highly restrictive	13,436	25,839	16,520	33,558	3068	92,421
Developed area in 16-km buffer zone (×1000 ha)						
Baseline	**4138**	**12,351**	**5959**	**13,540**	**1584**	**37,572**
Low growth						
Current	18,387	41,667	27,036	50,797	5213	143,100
Moderately restrictive	16,983	35,284	23,042	40,884	4400	120,593
Highly restrictive	11,212	27,394	16,755	29,626	3153	88,140
Moderate growth						
Current	30,871	61,774	62,819	73,842	7751	237,057
Moderately restrictive	27,832	54,447	40,234	63,839	6842	193,194
Highly restrictive	18,409	34,723	27,646	41,981	4290	127,049
High growth						
Current	30,871	61,774	62,819	73,842	7751	237,057
Moderately restrictive	30,847	61,761	62,704	73,816	7750	236,878
Highly restrictive	25,087	54,219	37,307	66,187	7071	189,871

increases in E and S and hence degradation in wildlife habitat suitability. For both buffer widths, $\Delta E/\Delta T$ increases or remains the same as growth rates increase, which indicates the tradeoffs between habitat disturbance and total output stay the same or increase as growth rates increase. The value of $\Delta E/\Delta T$ increases between the 8-km and 16-km buffer zones, indicating that tradeoffs between habitat disturbance and total output are greater in the 16-km buffer zone than in the 8-km buffer zone. Conversely, for all cases $\Delta S/\Delta T$ decreases with growth rates for both

TABLE 2 Percentage of developed area (E) in the 8-km- and 16-km-wide buffer zones for Glacial National Park (GNP), Lost Trail National Wildlife Refuge (LTWR), Northern Roadless Area (NRA), Southern Roadless Area (SRA), and Great Bear Wilderness and northern portion of Bob Marshall Wilderness (Wilderness) in Flathead County for the baseline (2005) and 9 economic growth–land use policy scenarios (2024).

Economic growth–land use policy scenario	Protected area				
	GNP	LTWR	NRA	SRA	Wilderness
Developed area in 8-km buffer zone (%)					
Baseline	**0.6**	**9.7**	**1.4**	**1.2**	**0.1**
Low growth					
Current	2.5	49.6	5.6	5.6	0.6
Moderately restrictive	2.7	39.6	5.2	4.5	0.4
Highly restrictive	1.5	33.5	3.8	3.1	0.3
Moderate growth					
Current	4.6	75.0	15.7	8.4	0.8
Moderately restrictive	4.2	65.6	9.1	7.1	0.7
Highly restrictive	2.8	40.8	6.1	4.5	0.4
High growth					
Current	4.6	75.0	15.7	8.4	0.8
Moderately restrictive	4.6	75.0	15.7	8.4	0.8
Highly restrictive	3.5	65.1	7.6	7.4	0.7
Developed area in 16-km buffer zone (%)					
Baseline	**0.8**	**13.7**	**1.8**	**2.1**	**0.3**
Low growth					
Current	3.5	46.3	8.3	8.0	0.9
Moderately restrictive	3.3	39.2	7.0	6.4	0.8
Highly restrictive	2.2	30.4	5.1	4.7	0.6
Moderate growth					
Current	5.9	68.6	19.2	11.6	1.4
Moderately restrictive	5.4	60.5	12.3	10.0	1.2
Highly restrictive	3.5	38.6	8.4	6.6	0.8
High growth					
Current	5.9	68.6	19.2	11.6	1.4
Moderately restrictive	5.9	68.6	19.2	11.6	1.4
Highly restrictive	4.8	60.2	11.4	10.4	1.3

buffer widths, indicating that tradeoffs between loss in habitat security and total output decrease as growth rates increase. $\Delta S / \Delta T$ decreases between the 8-km and 16-km buffer zones, indicating the tradeoffs between loss in habitat security and total output decrease as the buffer width increases. Except for $\Delta E / \Delta T$ for both buffer widths at the high growth scenario and $\Delta S / \Delta T$ for the 8-km buffer width at the high growth scenario, $\Delta E / \Delta T$ and $\Delta S / \Delta T$ decrease as the land use policy becomes more restrictive for all growth scenarios. Therefore, a more restrictive land use policy appears to be effective in reducing the magnitude of the tradeoffs between habitat

TABLE 3 Percentage of the developed area in low density land uses (S) in the 8-km- and 16-km-wide buffer zones for Glacial National Park (GNP), Lost Trail National Wildlife Refuge (LTWR), Northern Roadless Area (NRA), Southern Roadless Area (SRA), and Great Bear Wilderness and northern portion of Bob Marshall Wilderness (Wilderness) in Flathead County for the baseline (2005) and 9 economic growth–land use policy scenarios (2024).

Economic growth–land use policy scenario	Protected area				
	GNP	LTWR	NRA	SRA	Wilderness
Developed area in low density land uses in 8-km buffer zone (%)					
Baseline	**66.8**	**97.7**	**86.2**	**51.1**	**43.2**
Low growth					
Current	90.0	99.4	94.9	85.0	83.0
Moderately restrictive	90.7	99.3	93.4	81.3	77.2
Highly restrictive	85.0	99.3	90.6	73.7	70.8
Moderate growth					
Current	92.9	98.8	97.2	85.6	86.8
Moderately restrictive	93.0	97.7	94.3	86.8	86.4
Highly restrictive	90.4	99.3	93.3	80.1	77.2
High growth					
Current	92.9	96.9	94.5	84.8	87.3
Moderately restrictive	93.0	97.7	94.3	86.8	86.4
Highly restrictive	90.4	98.6	91.4	84.6	86.3
Developed area in low density land uses in 16-km buffer zone (%)					
Baseline	**66.2**	**97.6**	**69.1**	**51.4**	**60.7**
Low growth					
Current	87.8	98.5	88.7	81.7	84.2
Moderately restrictive	85.0	98.7	85.9	76.4	81.3
Highly restrictive	76.2	98.7	78.3	68.2	74.0
Moderate growth					
Current	90.0	98.8	93.1	83.8	87.3
Moderately restrictive	88.0	96.8	88.4	82.5	86.3
Highly restrictive	83.3	98.6	84.1	75.4	79.3
High growth					
Current	85.6	95.9	88.7	81.3	85.9
Moderately restrictive	86.7	96.6	89.6	81.2	84.2
Highly restrictive	80.8	98.6	82.9	79.0	83.5

disturbance and total output, and between habitat security and total output. Tradeoff elasticities indicate that implementing a more restrictive land use policy is generally most effective in reducing tradeoffs at low growth rates, moderately effective at moderate growth rates, and least effective at high growth rates.

Conclusions

Economic growth and land development between 2005 and 2024 in Flathead County, Montana, are expected to generate economic benefits in the form of increased production of goods and services and increased

TABLE 4 Estimated tradeoff elasticities for the percentage change in the developed area of buffer zones with respect to a 1% increase in total output (Δ E / ΔT) and the percentage change in low density uses in buffer zones with respect to a 1% increase in total output (ΔS / ΔT) in Flathead County between the baseline (2005) and 9 economic growth–land use policy scenarios (2024).

Land use policy scenario	Economic growth scenario		
	Low	Moderate	High
Tradeoff elasticities for ΔE / ΔT for 8-km buffer zone			
Current	0.05	0.07	0.05
Moderately restrictive	0.04	0.05	0.05
Highly restrictive	0.02	0.03	0.04
Tradeoff elasticities for ΔE / ΔT for 16-km buffer zone			
Current	0.07	0.13	0.13
Moderately restrictive	0.05	0.10	0.13
Highly restrictive	0.03	0.06	0.10
Tradeoff elasticities for ΔS / ΔT for 8-km buffer zone (%)			
Current	0.27	0.22	0.15
Moderately restrictive	0.24	0.21	0.15
Highly restrictive	0.20	0.18	0.14
Tradeoff elasticities for ΔS / ΔT for 16-km buffer zone (%)			
Current	0.24	0.20	0.12
Moderately restrictive	0.20	0.17	0.13
Highly restrictive	0.13	0.14	0.11

employment at the expense of reducing the suitability of wildlife habitat in buffer zones for 5 protected areas. Land development is expected to increase wildlife habitat disturbance (E) in 8-km- and 16-km-wide buffer zones around the 5 protected areas. The extent of the disturbance is expected to be greatest in the buffer zone for the Lost Trail National Wildlife Refuge and least in the buffer zone for the Bob Marshall and Great Bear wilderness areas. Consequently the protected areas in Flathead County that strictly control human activities (ie national parks and wilderness areas) have buffer zones that are less vulnerable to land development than buffer zones for protected areas that impose fewer controls on human activities (ie roadless areas and a national wildlife refuge). The areal extent of the disturbance to wildlife habitat from development increases as growth rates increase. Implementing a more restrictive land use policy than existed in 2005 appears to assuage future human disturbances to wildlife habitat.

For the most part, between 2005 and 2024, the security of wildlife habitat in the buffer zones for the 5 protected areas decreases between the low and moderate growth scenarios and increases between the moderate and high growth scenarios. For 87% of the cases evaluated, the security of wildlife habitat in the buffer zones improves between 2005 and 2024 as the land use policy becomes more restrictive. Wildlife habitat security is lowest in the buffer zone for the Lost Trail National Wildlife Refuge, second lowest in the buffer zone for the northern roadless area, and third lowest in the buffer zone for Glacier National Park for all 9 economic growth–land use policy scenarios. For the most part, habitat security is highest in the 8-km buffer zones for wilderness areas and second highest in the 8-km buffer zones for the southern roadless area. Habitat security is highest in the 16-km buffer zones for the southern roadless area and second highest in the 16-km buffer zones for wilderness areas.

The tradeoff analysis indicates that although increases in total output of goods and services in Flathead County between 2005 and 2024 would be beneficial for the economy, they degrade the suitability of wildlife habitat.

For most of the 9 scenarios, tradeoff elasticities between the extent of habitat disturbance and total output increase as growth rates increase and development expands. Also, tradeoffs are greater in the 16-km buffer zone than in the 8-km buffer zone. For all 9 scenarios, the tradeoff elasticities between the loss of wildlife habitat security and total output increase as growth rates increase and land development expands. For all 3 economic growth scenarios, a more restrictive land use policy reduces the tradeoffs between total output and wildlife habitat suitability in Flathead County. For the most part, however, implementing a more restrictive land use policy than existed in 2005 is most effective in reducing such tradeoffs when growth rates are low, moderately effective when growth rates are moderately high, and least effective when growth rates are high. Although this result suggests that lower growth rates would reduce tradeoffs between total output and habitat suitability, it is highly unlikely that Flathead County would develop a growth policy that limits economic growth as evidenced by the current growth policy for the county (Flathead County Planning and Zoning 2007). The ELMS can be used to quantify the tradeoffs between total output and suitability of wildlife habitat in buffer zones for protected areas in other mountain ecosystems provided the data/information required by the ELMS are available.

This study did not consider the potential negative impacts of land development on air and water quality, water supply, carbon sequestration, and other ecosystem services. Accounting for such impacts would result in a more comprehensive evaluation of the economic and environmental tradeoffs implied by future economic growth–land use policy scenarios than the one presented here.

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