Roadless Areas:

The Missing Link in Conservation

AN ANALYSIS OF BIODIVERSITY AND LANDSCAPE CONNECTIVITY IN THE NORTHERN ROCKIES

By

Michele R. Crist

and

Bo Wilmer

The Wilderness Society

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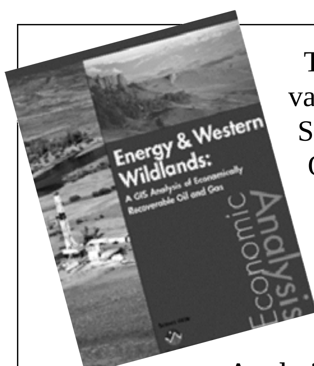

This science report is one of a series that stems from conservation research studies conducted by The Wilderness Society's Ecology and Economics Research Department. Other recent reports in the series include "Energy & Western Wildlands: A GIS Analysis of Economically Recoverable Oil and Gas" and "Fragmenting Our Lands: The Ecological Footprint from Oil and Gas Development (A Spatial Analysis of a Wyoming Gas Field)."

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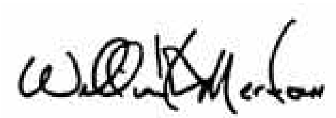
Preface

Americans have long recognized the vast natural heritage of our country's national forests and the spectacular wildlands they encompass. From their high alpine wilderness to low-lying grasslands, these pristine regions represent some of the last, best vestiges of wild areas anywhere in our nation.

This national forest "back country" includes almost 60 million acres of inventoried roadless areas. Free of the degradation associated with logging and other extractive activities that often follow road construction, these lands exist in a relatively natural state. Like the precious last pieces of a jigsaw puzzle, they possess the potential to augment our nation's vital system of public conservation lands of designated wilderness areas, national parks, and national wildlife refuges.

Using The Wilderness Society's state-of-the-art landscape analyses, Forest Ecologist Michele Crist of the TWS Boise office and Landscape Ecologist Bo Wilmer in the TWS Center for Landscape Analysis in Seattle vigorously interpreted the data for this significant report. Their findings bear out the critical missing link that inventoried roadless areas provide in ensuring the viability of native plant and wildlife species of the Northern Rockies ecosystem.

Moreover, while investigating the potential ecological impact roadless areas offer in a comprehensive conservation strategy for the Northern Rockies, "Roadless Areas: The Missing Link in Conservation" also contributes notably to the larger policy dialogue surrounding America's conservation goals and the federal land management decisions that can achieve those goals.



William H. Meadows
President
The Wilderness Society

G. Thomas Bancroft, Ph.D.
Vice President
Ecology and Economics
Research Department

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Report Highlights

In January 2001, the U.S. Forest Service adopted the Roadless Area Conservation Rule that seeks to conserve a large portion of unprotected wildland on national forests for posterity. The rule took nearly three years to complete and generated the greatest number of public comment in the history of federal rulemaking. The vast majority—95%—of the 1.6 million comments favored the strongest protection possible.

The rule has been suspended for an indefinite period of time. But it attempted to address the future of unprotected national forest roadless areas—relatively large blocks of generally undisturbed land that are often located adjacent to or near federal conservation lands (designated wilderness areas, national parks, and national wildlife refuges). Primarily because of their size and location, roadless areas hold huge potential for the conservation of native biodiversity. They can connect conservation lands into the large and intact areas needed by wide-ranging wildlife such as bears, elk, and wolves. And they can create stronger conservation bastions to accommodate ecosystem functions such as natural wildfire.

To prepare this report about the contributions of roadless areas to conservation goals, we incorporated state-of-the-art landscape analysis techniques across two scales. First, a regional scale that includes the northern Rocky Mountain states of Montana, Wyoming, and Idaho, and second, a local scale that encompasses the vast Central Idaho Ecosystem.

TABLE A.

Protection of land cover types

Adding national forest roadless areas to federal conservation lands in the Northern Rockies region (MT, WY, ID) and in the Central Idaho Ecosystem increases representation of each of the following land cover types by at least 100 percent.

Land cover type	Existing level of representation (%)	Potential level of representation due to roadless areas (%)	Percent increase due to roadless areas
Northern Rockies Region			
Mixed subalpine forest	32.3	68.6	113.1
Mixed conifer	17.0	37.2	119.4
Mesic upland shrub	11.0	16.1	143.4
Western red cedar	5.6	22.0	295.1
Aspen	4.5	26.0	480.0
Western hemlock	3.4	13.6	603.0
Ponderosa pine	4.9	9.9	99.7
Central Idaho Ecosystem			
Shrub-herbaceous dominated burn	37.8	79.5	110.1
Mixed lodgepole pine dominated forest	33.1	72.6	119.0
Mesic forest	19.0	53.4	180.4
Mesic shrublands	18.1	48.2	166.3
Mixed Douglas-fir / ponderosa pine forest	16.9	53.0	213.9
Ponderosa pine dominated forest	10.5	23.7	126.0

In this report, federal conservation lands refer to designated wilderness areas and national parks, national wildlife refuges. Roadless areas refer to unprotected portions of national forests that the Forest Service includes on its Inventoried Roadless Areas list.

The mountains and valleys, rivers and streams, and rich variety of vegetation across the entire region hold important values for wildlife and humans alike. Very few places in the lower 48 states can claim the diversity of species—including a full complement of top predators—that find refuge in the Northern Rockies. And few other regions can boast such an extensive conservation system of national parks, national wildlife refuges, and designated wilderness in addition to a significant number of unprotected national forest roadless areas.

Among the most significant findings of our study, we clearly show that protection of national forest roadless areas, when added to existing federal conservation lands in the study area, will:

Increase the representation of virtually all land cover types on conservation lands at both the regional and ecosystem scales, some by more than 100% (Table A.). In fact, roadless areas protect more rare habitat communities across the Northern Rockies than do the existing conservation areas.

- Help protect rare, species-rich, and often-declining vegetation communities such as aspen, whitebark pine, sage grassland, and xeric shrubland. The protection of roadless lands would increase representation of the aspen community on conservation lands by 480% and the western hemlock community by 603%.
- Protect one vegetation community—bur oak woodland—that is not currently represented on existing conservation lands.
- Help protect lower-elevation lands—and their communities of species—that have been greatly altered by road construction, settlements, and resource extraction.
- Connect conservation units, many of which were established for their scenic and recreation values and not as wildlife habitat, to create bigger and more cohesive habitat "patches" (Table B). One such "patch" in central Idaho would consist of designated wilderness areas connected by roadless areas.

We believe that our findings and the methods used in this study—particularly our emphasis on multiple-scale analysis—can assist the Forest Service, other land managers, and researchers who are studying the relationship between wildlands and conservation. Our results, combined with the ecological literature, make a compelling case for the permanent protection of roadless areas across national forests.

TABLE B.

Wildland connections

Protection of national forest roadless areas in the Northern Rockies region (MT, WY, ID) and in the Central Idaho Ecosystem (CIE) significantly increases the size of the federal conservation lands system, reduces the number of patches, creates larger intact patches of habitat, and decreases the distance between patches.

	CONSERVATION LANDS		CONSERVATION LANDS AND ROADLESS AREAS	
Area measures	N.R. Region	CIE	N.R. Region	CIE
Size of conservation system (ha)	8,814,900	2,094,300	15,673,600 (+)	3,987,700 (+)
Number of patches	770	73	722 (-)	46 (-)
Mean patch size (ha)	11,448	28,689	21,709 (+)	86,689 (+)
Nearest neighbor (meters)	7,014	7,251	5,353 (-)	4,307 (-)

1. Introduction

A growing body of scientific evidence points out that the current U.S. system of federal conservation lands (designated wilderness areas, national parks, and national wildlife refuges) may be too small and disconnected to protect against the decline and loss of native species, especially wide-ranging wildlife species, and to accommodate significant natural ecosystem processes such as large wildfires (MacArther and Wilson 1967, Baker 1992, Turner et al. 1993, Noss and Cooperrider 1994, Reice 1994, Newmark 1995, Sinclair et al. 1995, Soule and Terborgh 1999).

Over the past 150 years, expanded road networks and other encroachments on the landscape have increased the fragmentation and destruction of natural habitats. Such disturbances to the land are isolating many conservation units, causing them to function as “islands” in a sea of inhospitable habitat (Harris 1984, Pickett and White 1985, Wiens et al. 1985, Turner 1989, Saunders et al. 1991). Recognizing this problem, many ecologists and land managers are in the process of identifying relatively undisturbed lands that are integral to the federal conservation lands system before they too are lost or altered.

Roadless areas on national forest, as important large tracts of relatively undisturbed land, may become the missing link in a conservation reserve system for the United States. More than one-third of inventoried roadless areas on national forests are adjacent to federal conservation units (DeVelice and Martin 2001). They hold the potential to increase the size and connectivity of designated wilderness, national parks, and national wildlife refuges. This would increase the ability of conservation lands to support populations of species such as bears, wolverines, and wolves, and ecosystem processes such as natural wildfire that require large, contiguous, and relatively undisturbed areas. Smaller, isolated roadless areas may contain rare species, protect underrepresented habitat types, and function as “stepping stones” or corridors that connect to larger conservation units across a landscape (Strittholt and DellaSala 2001).

There is considerable precedent for the protection of national forest roadless areas. Congress has designated as Wilderness more than half—6 million hectares—of roadless areas that the U.S. Forest Service inventoried on national forests in the 1970s. These designations underscore the significant wildlife, ecological, biological, and recreation values of roadless areas. Some roadless areas were protected as potential wilderness areas, while many received no protection at all.

Scientific studies in the 1980s and 1990s demonstrated the negative impacts of roads on ecosystems, biological communities, and species populations (Usher 1987, Andrews 1990, Foreman and Wolke 1992, Reed at al. 1996, Spellerberg 1998). In 1998, the Forest Service began to devise regulations aimed at protection of roadless area characteristics on national forests. In May 2000, the agency released its proposed rule—familiarly known as the Roadless Rule—and draft environmental impact statement. Eight months later, the Forest Service adopted the rule, which is now in abeyance for an undetermined amount of time.

Included in the environmental impact statement was an evaluation of the potential contribution that protection of roadless areas could make to the conservation of biodiversity at the national scale (USDA Forest Service 2000b). In that evaluation, DeVelice and Martin (2001) found that the inclusion of roadless areas in the network of federal conservation lands would expand representation of ecoregions in protected areas, increase the acreage of reserved areas at lower elevations, and increase the number of areas large enough to provide refuge for certain wide-ranging species.

Strittholt and DellaSala (2001) focused on similar questions at an ecosystem scale in their study of the Klamath-Siskiyou area in southern Oregon and northern California. They found that roadless areas would provide a wide range of ecological attributes that are important in the Klamath-Siskiyou region, especially at lower elevations. They also concluded that roadless areas contribute significantly to the connectivity of ecoregions.

In this study, we investigate the potential contributions of national forest roadless areas to conservation units in the northern Rocky Mountain states of Montana, Wyoming, and Idaho, a region particularly rich in roadless areas. To extend the analysis across spatial scales, we also focus on the Central Idaho Ecosystem, an extraordinary complex of wilderness and roadless areas.

Biodiversity Representation

An important goal in the design and establishment of conservation reserves is to represent a full range of native biodiversity (Margules et al. 1988, Church et al. 1996, Possingham et al. 2000). In the United States, proposals to establish such representative reserves date back at least to 1917 (Shelford 1926). Even though this goal has been articulated for some time, most conservation reserves have been demarcated around areas with high scenic and recreational attributes (Davis et al. 1994). As a result, current conservation areas are, for the most part, concentrated at higher elevations and on sites with low soil productivity where important elements of biodiversity are most likely poorly represented (Scott et al. 2001).

Representation of a full range of biodiversity in reserves requires an understanding of all species and ecosystem processes operating within a given landscape. Because ecologists do not yet have a complete understanding of species and ecosystem functions, many have suggested using ecological communities and elevation ranges as coarse-scale surrogates for native biodiversity in the design of conservation reserves (Scott et al. 1993, Host et al. 1996). This concept is based on the idea that if a full range of ecological communities and elevation ranges are protected, it is more likely that many ecological communities, wide-ranging species, and ecosystem processes will be contained in the reserves.

In addition, ecological communities are associated with elevation ranges; that is, some ecological communities are found only at lower elevations or at higher elevations (Hansen and Rotella 1999). Some roadless areas are situated at middle and lower elevations on sites with relatively high soil productivity. Thus they may make valuable contributions in protecting many elements of biodiversity that are currently not well represented on conservation lands (DeVelice and Martin 2001).

Landscape Connectivity

Connectivity refers to the pattern of interconnectedness or "networking" in a landscape. It helps determine how individuals of a species and natural processes such as fire move or function within a landscape (Wiens et al 1985, Taylor et al. 1993, Noss and Cooperrider 1994, Bascompte and Solé 1996, With 1999). A "well-connected" area can sustain important elements of ecosystem integrity, namely the ability of species to move and natural processes to function, and is more likely to maintain its overall integrity compared to a highly fragmented area. Roads are a well-known agent of fragmentation, so the addition of roadless areas to conservation lands is likely to improve the connectivity, and therefore the integrity, of protected areas.

With the advent of landscape metrics, it is now possible to quantify connectivity for landscapes, species habitat, species movements, and ecosystem processes across a given region (O'Neill et al. 1988, McGarigal and Marks 1995, Gustafson 1998, With 1999). Landscape metrics are algorithms that quantify specific spatial characteristics and the configuration of patches or entire landscape mosaics.

Many different metrics have been described (Turner and Gardner 1991, Ritters et al. 1995, Hargis et al. 1998, Jaeger 2000, Dale 2000, McGarigal and Holmes 2002). To fully understand how roadless areas contribute to landscape connectivity, we chose metrics for this study that measure four elements: area, configuration , isolation , and aggregation . Each of these elements is related to different aspects of connectivity. For some species or natural processes, the isolation or aggregation of patches across the landscape may be more important; for others, size or shape may be the key element. Together, these four elements offer a more comprehensive assessment of the importance of roadless areas to the maintenance of overall landscape connectivity and ecosystem integrity.

Area. It is known that larger areas (patches) generally contain more species, more individuals of a given species, more species with large home ranges, more species sensitive to human activity, and more intact ecosystem processes than do small areas (Robbins et al. 1989, Turner et al. 1993, Newmark 1995, Schafer 1995). Larger numbers of patches will usually contribute to greater resilience of populations and may also increase the utility of patches that act as "stepping stones" or connectors across a landscape (Buechner 1989, Lamberson et al. 1992). Smaller reserve patches may also supplement larger reserves by protecting rare species that occur only in certain areas. Hence, greater variability in patch sizes may increase niche diversity and, consequently, regional biodiversity (Franklin and Forman 1987, Hansen et al. 1991).

Configuration. It has been shown that the extent (how far a patch extends across a landscape) and the shape of a

Ecological Impacts of Roads

A very pervasive threat to natural areas is roads—the common thread in land-altering activities such as logging, resource extraction, and conversion of wildlands to residential and commercial purposes. A wealth of scientific literature describes the effects that roads have on habitat and the many impacts of roads on various wildlife species (see, for example, Trombulak and Frissell 2000). Among these are increased erosion and air and water pollution, the spread of invasive non-native species, and wildlife mortality. Roads also fragment native ecosystems into smaller and smaller patches of various sizes and shapes.

Perhaps the greatest impact of roads concerns alterations and degradation of stream and riparian habitats. Studies show that road networks constructed for logging in forests appear to have increased the magnitude and frequency of peak flows and debris slides, thus altering the natural dynamics of stream and riparian areas that, among other things, are important as fish habitat (Jones et al. 1999). Many riparian areas and streams in roadless and conservation areas throughout the Northern Rockies still maintain their natural dynamics and are known to support many fish populations that depend on relatively undisturbed watersheds to spawn (Hauer et al. 1998, Hitt and Frissell 1999, Jones et al. 1999).

patch influence small mammal migrations and woody plant colonization (Wegner and Merriam 1979). The shape of a patch (for example, elongated or circular) can influence how species move within or among patches. Elongated patches may facilitate movement for certain species among patches, while more circular-shaped patches may increase movement within patches, especially for species that are negatively affected by edges. These findings may indicate that a range of reserves of different patch shapes and extents could provide protection for many species or ecosystem processes (Wiens and Milne 1989, O'Neill et al. 1996).

Isolation. The isolation of patches, or distance between patches, plays an important role in many ecological processes. Several studies have shown that patch isolation is the reason that fragmented habitats often contain fewer bird and mammal species than contiguous habitats (Murphy and Noon 1992, Reed et al. 1996, Beauvais 2000, Hansen and Rotella 2000). As habitat is lost or fragmented, residual habitat patches become smaller and more isolated from each other (Shinneman and Baker 2000), species movement is disrupted, and individual species and local populations become isolated. This puts them at greater risk of extinction from a single disturbance event.

Aggregation. Spatial aggregation of patches ranges from an even distribution to being "clumped" together across a landscape. Aggregation of patches helps to explain how it is that species may be found in patches that are close together and not found in patches that are more isolated, or vice versa (Ritters et al. 1996, He et al. 2000). This concept generally follows the ideas developed in island biogeography theory (MacArthur and Wilson 1967) and metapopulation theory (Levins 1969, 1970) and aids understanding of the function of patches within a landscape.

2. Methods

Study Area

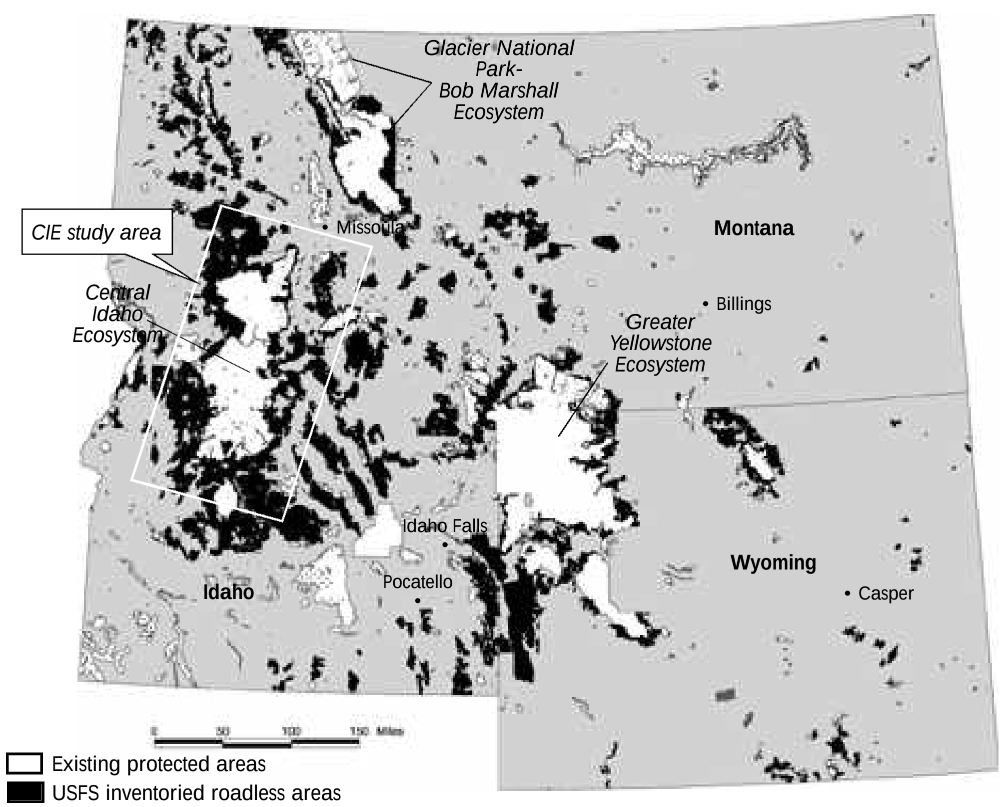
Regional scale. The northern Rocky Mountain states of Montana, Wyoming, and Idaho display a variety of non-forested and coniferous forest habitats. Ponderosa pine dominates low-elevation montane forests, while Douglas-fir and lodgepole pine dominate at mid-elevations and Engelmann spruce at higher elevations. The more mesic forests to the north and west largely contain western larch, grand fir, western red cedar, and western hemlock. Low-lying valleys are characterized by sagebrush shrubland and shrub steppe, much of which has been degraded by conversion to other uses or through invasion of non-native plants. Elevations range from 150 meters to 4200 meters. Average precipitation ranges from 28 centimeters to 51 centimeters (Franklin 1983).

Of the 84 million hectares that stretch across Montana, Wyoming, and Idaho, roadless areas cover a little more than 2.6 million hectares. Existing federal conservation areas protect almost 8.7 million hectares. Three large, relatively undisturbed mountain ecosystems in the region have been protected as national parks or wilderness areas. These include the Greater Yellowstone Ecosystem, Glacier National Park-Bob Marshall Ecosystem, and Central Idaho Ecosystem (Figs. 1 and 2).

Ecosystem scale. The Central Idaho Ecosystem, a vast mountainous area of high peaks and broad plateaus, is an excellent example of terrain and biodiversity representation in the Northern Rockies. This 6.4-million-hectare ecosystem contains nearly 2.2 million hectares of roadless areas and 2.1 million hectares of existing conservation lands. At its core lies the largest designated wilderness system in the conterminous United States, consisting of Selway-Bitterroot, Frank Church River of No Return, and Gospel Hump wilderness areas. The ecosystem extends from the Bitterroot Mountains in the east to the Clearwater River in the north, the headwaters of the Salmon River in the south, and the Snake River drainage in the west as the river bends toward Hell's Canyon.

Topographically, the ecosystem spans steep physical gradients in elevation, slope, aspect, temperature, and precipita-

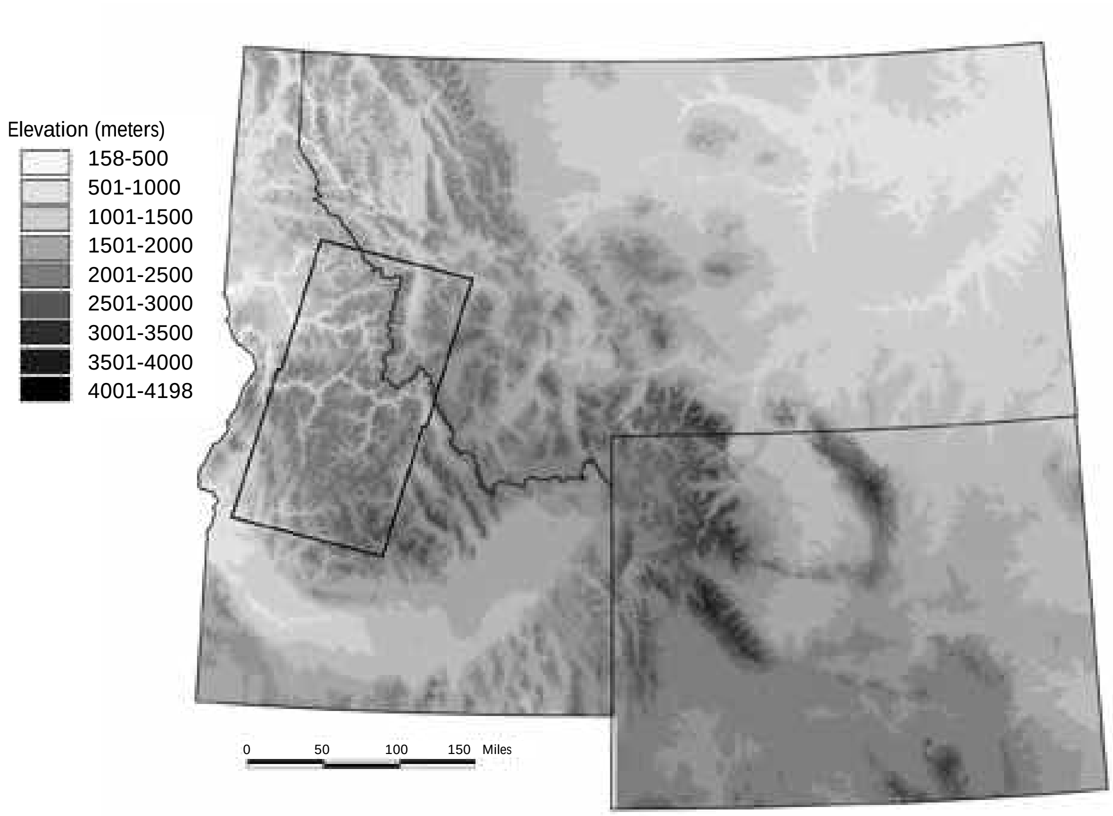
FIGURE 1.
Roadless and protected areas across the northern Rocky Mountain region



tion that give rise to diverse vegetation types. Vegetation communities, climate, and elevation gradients are similar to the Northern Rockies regional scale. At lower elevations, grasslands and sage are interspersed with lush riparian vegetation, including cottonwood, willow, and alder. Ponderosa pine forests are found at lower elevations, while slightly higher elevations contain mixed coniferous forests of Douglas-fir, western hemlock, western larch, and western red cedar. Lodgepole pine occurs at still higher elevations, giving way toward the treeline to subalpine forests of limber and whitebark pines, subalpine fir, and Engelmann spruce interspersed with subalpine meadows.

FIGURE 2.

Elevation ranges across the northern Rocky Mountain region



Biodiversity Representation

Data Collection

Conservation areas. To determine how roadless areas complement existing protected areas, it is important to specify which lands we consider to be "protected" and how we define a roadless area. We recognize that management strategies provide vastly different levels of protection, even within the same management agency, and that protection for one species may not adequately protect others.

For this reason, we adopted a classification system developed by the U.S. Geological Survey's Biological Resources Division in its nationwide GAP Analysis program (Scott et al. 1996). This program devised a ranking scheme to represent various levels of protection, ranging from the least protected lands (Category 4) to those with the highest level of protection (Category 1). Scientists from the Conservation Biology Institute and World Wildlife Fund then assigned the GAP categories to all public lands across North America and created a relatively comprehensive spatial database (DellaSala et al. 2001).

Table 1 lists the GAP categories and gives examples of the types of ownership they cover. For this study, we assumed that categories 1 and 2 represent adequate protection because conservation is their primary management objective (Scott et al. 1996).

We restricted our work to inventoried roadless areas on national forests (USDA Forest Service 2000a). We recognize that our decision leaves out smaller roadless areas that were not considered during the inventory of roadless areas and that these areas serve important conservation goals (Strittholt and DellaSala 2001).

Land cover representation. Analyses performed at multiple scales allow ecologists the flexibility to incorporate the best available data for a given area. To prepare our land cover maps, we relied on several different data sources.

At the regional scale, we downloaded three independently derived land cover maps for Montana, Wyoming, and Idaho from the GAP Analysis Program (Scott et al. 1996). For the Montana and Idaho GAP products, Michael Scott at the University of Idaho and Roly Redmond at the University of Montana classified raw Landsat Thematic Mapper (TM) satellite imagery according to techniques developed by Redmond et al. (1998). The spatial resolution of the imagery was 90 meters for Montana and 30 meters for Idaho. The Wyoming GAP Analysis Program relied on a different technique whereby land cover data were digitized in a vector format from Landsat TM satellite imagery at a scale of 1:100,000 (Gap Analysis, Wyoming 1996).

Because these three GAP analysis datasets were constructed differently, we needed to generate a single land cover map for the entire three-state region. To do this, we reclassified the three state maps into a common land cover classification (Appendix and Table 2). We converted Wyoming's vector

TABLE 1.

GAP Protection Categories

Categories refer to protected status of public lands. 1 represents the highest level of protection, 4 represents the lowest level of protection.

GAP protection category	Examples of ownership
1	National park National monument Wilderness area Nature reserve/preserve Research natural area
2	State parks State recreation areas National wildlife refuge National recreation area Area of critical environmental concern Wilderness study area Conservation easement Private conservation land
3	BLM holdings Military reservations National forests State forest Wildlife management areas Game and fish preserves Fish hatcheries State commemorative area Access area National grassland ACOE holding
4	Private land Tribal land City park Undesignated state land County land City land

Source: USGS, Biological Resources Division, GAP Analysis Program map into a grid format, the same format as the Montana and Idaho land cover maps, and resampled each dataset to 90-meter resolution. Then we merged the three statewide land cover maps into a single image (Fig. 3; see insert).

TABLE 2.

Land Cover Types

Land cover types and number of hectares across Montana, Wyoming and Idaho*

Land cover type	Hectares
Grasslands	18,730,802
Sagebrush	17,084,802
Agriculture	11,220,266
Mixed conifer	7,962,078
Mixed subalpine forest	4,013,714
Lodgepole pine	3,912,626
Salt-desert shrub flats	2,396,736
Ponderosa pine	2,368,772
Mesic upland shrub	1,880,156
Shrub-grassland associations	1,514,869
Xeric upland shrub	1,493,504
Exposed rock / soil	1,479,142
Subalpine meadow	1,437,352
Mixed barren lands	1,210,575
Aspen	1,069,742
Juniper	904,503
Forest-dominated riparian	885,357
Shrub-dominated riparian	827,115
Grass-dominated riparian	786,676
Water	720,898
Mixed whitebark pine	484,066
Western red cedar	416,487
Burned forest	412,558
Urban	268,378
Alpine meadow	153,930
Clearcut conifer	179,059
Wetlands	82,245
Western hemlock	79,664
Surface mining	65,729
Vegetated sand dunes	49,428
Snowfields or ice	34,174
Sand dunes	23,741
Bur oak woodland	10,066
Mud flats	2,480

**Statewide land cover maps from the USGS Biological GAP Analysis Program were merged and reclassified into the land cover types listed in this table. See Appendix A.*

At the ecosystem scale, Roly Redmond, this time in collaboration with Jack Hogg at the Montana Conservation Science Institute, provided land cover data. Working from just two Landsat TM scenes, these researchers developed the most accurate, field-validated land cover data available for the ecosystem (Hogg et al. 2001). The data were provided in ARC/INFO format at 30-meter resolution(Fig 4; see insert).

Elevation representation. In addition to assessing the representation of vegetation communities, we investigated the effect that protection of roadless areas would have on representation of various elevation classes. We downloaded a digital elevation model from the 30-meter National Elevation Dataset produced by the U.S. Geological Survey's EROS Data Center (http://edc.usgs.gov/geodata/). We reclassified the elevation range into 41 equal-interval classes ranging in 100-meter increments from 100 meters to 4200 meters for each scale.

The only difference between the regional and ecosystem scales was the extent. The regional scale encompassed Montana, Wyoming, and Idaho. Elevation data at the ecosystem scale were clipped to match the extent of the two Landsat TM scenes used for the land cover data.

Data Analysis

All data analyses were conducted in ARC/INFO and ArcView GIS software from Environmental Systems Research Institute.

Land cover representation. First, we intersected the protected areas database with the land cover maps at each scale. To calculate the percent representation of each land cover type, we divided the protected portion of each land cover type by the total area of each land cover type across the regional and ecosystem study areas. Next, we appended the national forest inventoried roadless areas to the existing protected areas and calculated the additional proportion of each land cover type that was represented within the potential conservation system. We then ranked these land cover types according to the level of representation within the existing protected areas.

Elevation representation. To investigate the representation of elevation ranges, we intersected the existing protected area database with the 30-meter digital elevation model at both the regional and ecosystem scales. Similar to the procedure for land cover types described above, we added the roadless areas to the existing conservation system, intersected this potential conservation system with the elevation data, and calculated the change in representation for each elevation class provided by protection of roadless areas.

Landscape Connectivity

To examine the potential contribution of roadless areas to landscape connectivity, we used ARC/INFO and FRAGSTATS (McGarigal and Marks 1995, McGarigal and Holmes 2002), a computer program developed to quantify fragmentation of the landscape. We identified seven landscape metrics available in FRAGSTATS to assess our four elements of landscape connectivity (McGarigal and Holmes 2002). To assess area, we used the metrics Percent Land (PLAND), Number of Patches (NP), and Patch Size (AREA). We include the metrics Number of Patches (NP) and Patch Size (AREA) here to help explain the context of an increase in Percent Land (PLAND). For example, an increase in PLAND and AREA and a decrease in NP indicates that the added patches were located next to existing patches, which results in an increase in the size of patches and a decrease in the number of patches across the landscape. Conversely, a decrease in AREA and an increase in NP would indicate that the added patches were smaller and not adjacent to existing patches.

To assess configuration, we used Correlation Length (GYRATE_AM) and Shape Index (SHAPE). An increase in GYRATE_AM indicates that patch extents increased across the landscape. Thus, the average traversability of the landscape increased for an organism that is confined to a single patch. An increase in SHAPE indicates that the boundary configuration of the patches became more complex; that is, the shape of the patch became more irregular compared to the standard shape of a square.

To assess isolation, we used Nearest Neighbor Distance (ENN). A decrease or increase in ENN indicates that patches are either located closer together or farther apart, respectively, across the landscape. To assess aggregation, we used Contagion (CONTAG). An increase in CONTAG would indicate that patches are more aggregated together across the landscape.

For each landscape metric, we computed the mean, area-weighted mean, and coefficient of variation where applicable. For both the regional and ecosystem scales, we applied all landscape metrics to the two conservation area grids described above (current conservation areas only and roadless areas plus current conservation areas). We then compared the differences in metrics between the two grids for both scales. In addition, the differences in the three distribution statistics for each metric—mean, area-weighted mean, and coefficient of variation—helped to fully explain how each metric was changing when roadless areas were examined in conjunction with existing conservation lands.

3. Results

Regional Scale: Northern Rockies

Biodiversity Representation

Land cover type representation. In existing conservation areas, burned forest and snowfields/ice have the highest representation—88% and 86%, respectively. Representation of other land cover types such as alpine meadows, whitebark pine, exposed rock/soil, subalpine meadows, wetlands, mixed subalpine forest, and lodgepole pine range from 31% to 71%.

The inclusion of roadless areas significantly increases the amount of all land cover types except for one—sand dunes (Table 3). Increases range from 5% to 600%. Fifteen land cover types increase by more than 40%, among them important ecological communities—western hemlock, aspen, ponderosa pine, western red cedar and sagebrush—each of which has less than 10% representation in

TABLE 3.

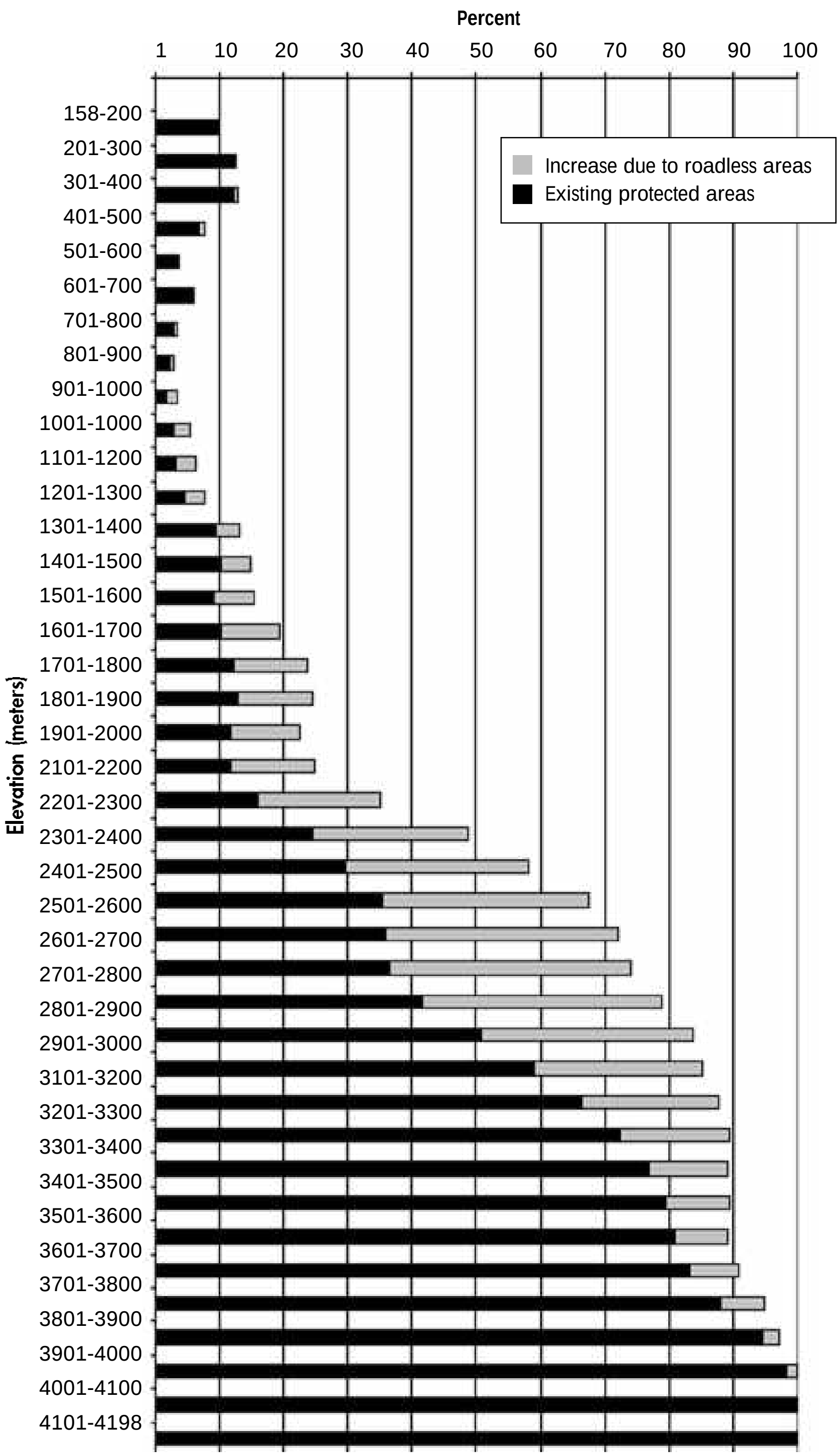
Increase in representation of land cover types: regional scale

Percent increase in representation of each land cover type across the region (MT, WY, ID) when national forest roadless areas are added to the conservation design.

Land cover type	Existing level of representation (%)	Potential level of representation due to roadless areas (%)	Percent increase due to roadless areas
Burned forest	88.12	93.09	5.65
Snowfields or ice	86.12	97.48	13.19
Alpine meadow	71.51	94.18	31.70
Mixed whitebark pine	59.62	84.94	42.46
Exposed rock/soil	44.67	59.92	34.12
Subalpine meadow	40.49	68.85	70.05
Wetlands	37.34	38.68	3.61
Mixed subalpine forest	32.20	68.63	113.11
Lodgepole pine	31.35	59.42	89.54
Mixed barren lands	21.66	22.61	4.37
Sand dunes	18.44	18.44	0.00
Mixed conifer	16.97	37.24	119.44
Mesic upland shrub	10.74	26.14	143.44
Shrub-dominated riparian	7.98	12.77	59.91
Forest-dominated riparian	7.18	12.14	69.11
Sagebrush	6.33	9.91	56.55
Juniper	5.87	6.80	15.95
Xeric Upland shrub	5.85	7.97	36.33
Vegetated sand dunes	5.69	6.03	5.89
Western red cedar	5.57	22.00	295.08
Mud flats	5.33	7.39	38.79
Ponderosa pine	4.94	9.88	99.97
Aspen	4.48	25.99	479.80
Shrub-grassland associations	4.25	5.89	38.46
Western hemlock	3.36	23.62	602.54
Grasslands	2.49	3.64	46.31
Grass-dominated riparian	2.15	3.07	43.01
Salt-desert shrub flats	1.58	1.71	8.63
Bur oak woodland	0.00	2.40	NA

FIGURE 5.

Contributions of roadless areas to the representation of elevation ranges across the northern Rocky Mountain states of Montana, Wyoming, and Idaho.



current conservation areas. Moreover, the addition of roadless areas represents one land cover type, bur oak woodland, that is not present in conservation areas.

Elevation representation. Our elevation analyses show that elevations in the range of 2300 to 4200 meters are well represented in conservation areas (Fig. 5). The addition of roadless areas results in a significant increase in representation of lands at elevations ranging from 1000 meters to approximately 3400 meters. For elevation ranges below 1000 meters and above 3400 meters, the contribution of roadless areas is small. However, the proportion of area represented at lower elevations increased greatly when we included roadless areas with conservation areas.

Landscape Connectivity

For the regional analysis, results from the landscape metrics show that the addition of roadless areas increases regional connectivity for all four of our connectivity elements (Table 4). Area metrics demonstrate that the addition of roadless areas almost doubles the amount of area protected, rising from 9% to 16%, and the mean patch size in conservation areas goes from 11,448 hectares to 21,709 hectares. The number of patches decreases from 770 to 722. Increases in the area-weighted mean patch size demonstrate that larger patches tend to dominate when roadless areas are added. The patch size coefficient of variation increases from 977 to 1070, which means that the addition of roadless areas results in more variation in the sizes of patches across the region.

Configuration metrics show an overall increase in the complexity of the shape and extent of patches in conservation areas when roadless areas are added. The mean, area-weighted mean, and variance for the shape index all increase (Table 4), but the area-weighted mean increases from 4.11 to 8.51, significantly more than the increase from 1.41 to 1.57 for the overall mean. This indicates that the addition of roadless areas increased the complexity of the shape of the larger patches more than the smaller patches. The increase in the coefficient of variation suggests that roadless areas add more patches of different shapes across the landscape. Correlation length also increases, from 45,295 to 67,822, implying that roadless areas increase the extent of conservation areas; that is, how far a patch extends across the landscape for species movements within each patch.

TABLE 4.

Connectivity at the regional scale: current conservation system and conservation lands with roadless areas

Landscape metrics comparing the spatial pattern of current conservation lands with a scenario that includes those lands plus national forest roadless areas. (+) and (-) indicate an increase or decrease, respectively, in the metric value caused by the addition of roadless areas.

Landscape Metrics	Montana, Wyoming, and Idaho		
	Conservation lands	Conservation lands and roadless areas	(+)/(-)
AREA			
Class area (ha)	8,814,900	15,673,600	(+)
Percent land	9%	16%	(+)
Number of patches	770	722	(-)
Patch size (mean, ha)	11447.92	21708.59	(+)
Patch size (area-weighted mean)	1105055.78	2505909.11	(+)
Patch size (coefficient of variation)	977.39	1069.74	(+)
SHAPE			
Shape index (mean)	1.41	1.57	(+)
Shape (area-weighted mean)	4.11	8.51	(+)
Shape (coefficient of variation)	50.37	66.98	(+)
Correlation length	45294.79	67822.22	(+)
ISOLATION			
Nearest neighbor (meters)	7013.72	5353.11	(-)
Nearest neighbor (area-weighted mean)	3153.73	2518.75	(-)
Nearest neighbor (coefficient of variation)	122.47	134.16	(+)
AGGREGATION			
Contagion index	72.56	58.64	(-)

Isolation metrics show a significant decrease in the mean and area-weighted mean nearest-neighbor metrics when roadless areas are added. The mean distance between centroids of protected patches decreases from 7014 meters to 5353 meters, demonstrating that roadless areas significantly reduce the distance between conservation unit patches. The decrease in the area-weighted mean signifies that the distance between the larger patches decreased as well, but not as much as the decrease in the overall mean where patches of all sizes were considered equally. While the mean and area-weighted mean nearest-neighbor metric decrease, the coefficient of variation for this metric increases, indicating more variation in distance between patches when roadless areas are included.

The aggregation metric (contagion) decreases from 72.56 to 58.64 when roadless areas are included. This means that when protected areas are considered by themselves, they are more "clumped" together in certain regions of the landscape. The addition of roadless areas results in patches that vary more in size and are more evenly distributed across the region.

Ecosystem Scale: Central Idaho Ecosystem

Biodiversity Representation

Land cover type representation. Permanent snow and rock and barren land cover types exhibit the highest representation (90% and 63%, respectively). Other land cover types that are well represented (ranging from 30% to 53%) include mixed whitebark pine, mixed subalpine fir, mixed Douglas-fir, mixed lodgepole pine, mesic grasslands, sage shrublands, and non-sage shrublands (Table 5).

The addition of roadless areas causes high percentage increases in the representation of all land cover types except one—snow. Fifteen of the 18 types exhibit an increase of more than 64%,

TABLE 5.

Increase in representation of land cover types: ecosystem scale

Percent increase in representation of each land cover type across the Central Idaho Ecosystem when national forest roadless areas are added to the conservation design.

Land cover type	Existing level of representation (%)	Potential level of representation due to roadless areas (%)	Percent increase due to roadless areas
Snow	90.0	98.2	9.18
Rock dominated or barren	63.3	93.1	47.06
Mixed whitebark pine forest	52.9	92.1	73.88
Conifer regeneration dominated burn	52.0	75.6	45.26
Mixed subalpine fir forest	50.2	83.3	66.09
Mesic grasslands	41.4	69.9	68.91
Mixed Douglas-fir dominated forest	39.8	70.6	77.27
Shrub-herbaceous dominated burn	37.8	79.5	110.10
Sage shrublands	33.3	55.0	65.03
Mixed lodgepole pine dominated forest	33.1	72.6	119.01
Non-sage shrublands	30.7	51.0	66.35
Herbaceous dominated riparian	21.5	35.7	66.01
Mesic forest	19.0	53.4	180.43
Mesic shrublands	18.1	48.2	166.34
Mixed Douglas-fir / ponderosa pine forest	16.9	53.0	213.86
Ponderosa pine dominated forest	10.5	23.7	125.65
Xeric grasslands	10.0	16.5	64.56

and all but permanent snow increase by 45% or more. For example, mixed whitebark pine increases 74%. Representation of ponderosa pine, mesic forest, mixed Douglas-fir/ponderosa pine, and mesic shrublands increases from 125% to 214% (Table 5).

Elevation representation. Conservation units in the Central Idaho Ecosystem protect higher proportions of areas occurring at higher elevations, generally ranging from 1900 meters to 3500 meters (Figure 6). When roadless areas are added to the conservation design, the increase in the percentage of representation for each elevation range is quite high, in some cases 100%. Representation is most prominent at mid- to higher-elevation ranges. However, roadless areas contributed significantly in representation of lower-elevation lands below 1700 meters that are not well represented in conservation units. In fact, representation of all elevation ranges below 1700 meters almost doubles.

Landscape Connectivity

All landscape metrics demonstrate that connectivity greatly increases when roadless areas are included in the current conservation design. Area metrics show that the addition of roadless areas almost doubles the amount of area protected (Table 6). Mean size of protected area patches almost triples, from 28,689 hectares to 86,689 hectares, while the number of patches decreases from 73 to 46. The patch size coefficient of variation decreases from 675 to 621, indicating that the addition of roadless areas results in less variation in the sizes of patches across the ecosystem. Configuration metrics show an overall increase in the complexity of the shape of patches and in the extent of patches for conservation units when roadless areas are included. The mean, area-weighted mean, and the coefficient of variation for the shape index all increase (Table 6).

Correlation length also increases substantially, from 54,209 to 85,437. Isolation indices show a significant decrease. The mean distance between patches in conservation units drops from 7350 meters to 4307 meters, and the coefficient of variation also drops, indicating less variation in all distances between patches. For aggregation, the contagion index decreases from 44 to 33.

TABLE 6.

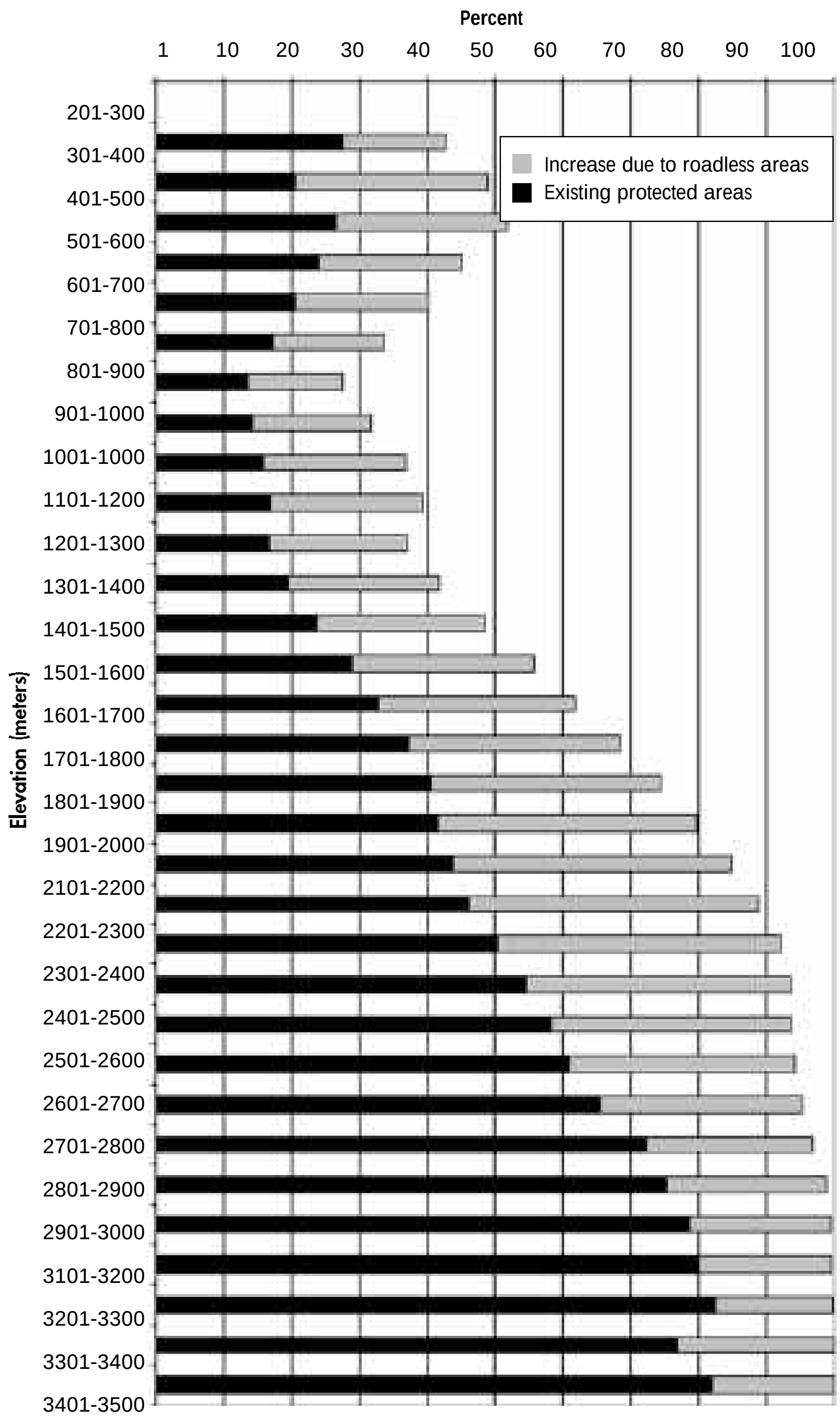
Connectivity at the ecosystem scale: current conservation system and conservation lands with roadless areas

Landscape metrics comparing the spatial pattern of current conservation lands with a scenario that includes those lands plus national forest roadless areas. (+) and (-) indicate an increase or decrease, respectively, in the metric value caused by the addition of roadless areas.

Landscape Metrics	Central Idaho Ecosystem		
	Conservation lands	Conservation lands and roadless areas	(+)/(-)
AREA			
Class area (ha)	2,094,300	3,987,700	(+)
Percent Land	32.6449%	62.1524%	(+)
Number of patches	73	46	(-)
Patch size (mean, ha)	28,689.0411	86,689.1304	(+)
Patch size (area-weighted mean)	1,337,583.608	3,428,078.925	(+)
Patch size (coefficient of variation)	675.4517	620.8422	(-)
SHAPE			
Shape index (mean)	1.3827	1.6173	(+)
Shape (area-weighted mean)	4.1867	9.448	(+)
Shape (coefficient of variation)	42.8176	84.1415	(+)
Correlation length	54,209.5185	85,437.4162	(+)
ISOLATION			
Nearest neighbor (meters)	7,250.724	4,307.129	(-)
Nearest neighbor (area-weighted mean)	2,624.7425	2,043.7928	(-)
Nearest neighbor (coefficient of variation)	98.23	59.944	(-)
AGGREGATION			
Contagion index	44.03	33.85	(-)

FIGURE 6.

Contributions of roadless areas to the representation of elevation ranges across the Central Idaho Ecosystem.



Most significant is our finding that roadless areas protect many land cover types, especially those characteristic of mid- to low elevations, that are underrepresented in conservation areas.

4. Discussion

Biodiversity Representation

A review of the literature suggests that a given vegetation community is adequately represented when 12% to 25% of it is included in a conservation area (World Commission on Environment and Development 1987, Noss and Cooperrider 1994), although it is not certain that these thresholds are truly adequate to protect vegetation communities. Based on this range for both the regional and ecosystem scales, we defined land cover types above 25% as "adequately protected," land cover types within the range of 12% to 25% as "minimally protected," and those below 12% as "underrepresented."

Our results show that in the Northern Rockies, roadless areas contribute significantly to the maintenance of native biodiversity. We found that conservation units adequately represent land cover types that are characteristic of higher elevations. This finding supports the generally accepted notion that wilderness and national parks contribute significantly to protection of higher-elevation ecological communities (Davis et al. 1994, Possingham et al. 2000). And contrary to other studies (DeVelice and Martin 2001, Strittholt and DellaSala 2001), we found that roadless areas contribute to protection of these land cover types as well.

Most significant, however, is our finding that roadless areas protect many land cover types, especially those characteristic of mid- to low elevations, that are underrepresented in conservation areas. This is important because these are among the last remnants of biologically productive lands that have not been significantly altered through settlements, logging, and road construction (Strittholt and DellaSala 2001).

At the regional scale, (Montana, Wyoming, and Idaho), conservation areas adequately represent nine land cover types, whereas five biologically important land cover types—western hemlock, aspen, ponderosa pine, western red cedar, and mesic upland shrub—are underrepresented in conservation areas. However, the addition of national forest roadless lands increases representation of two (western hemlock and western red cedar) to the minimally protected threshold and two (aspen and mesic upland shrub) to the adequately represented threshold (greater than 25%). Ponderosa pine, even though it increases by nearly 100%, remains underrepresented. Overall, the magnitude of the

PHOTO COURTESY DAVE POWELL, USDA FOREST SERVICE

Protection of roadless areas would improve representation of the biologically important ponderosa pine land cover type (from the "underrepresented" category to the "minimally protected" category) on federal conservation lands in the Central Idaho Ecosystem.

increased representation—from 100% to 600%—indicates that roadless areas can make substantial contributions to protection of land cover types that are not well represented in conservation areas.

In the Central Idaho Ecosystem, conservation areas adequately represent 11 land cover types, while six land cover types are either minimally represented or underrepresented. When roadless areas are included with conservation lands, four minimally represented land cover types—herbaceous dominated riparian, mesic forest, mesic shrublands, and mixed Douglas-fir/ponderosa pine forests—move to the adequately represented threshold. Two underrepresented types—ponderosa pine dominated forests and xeric grasslands—move to the minimally represented category.

Increased representation of certain rare ecological communities is particularly important. Aspen, for example, is declining in the Northern Rockies (Gallent et al. 1998). When roadless areas are added to conservation lands, aspen moves up two full categories—from underrepresented to adequately represented, a 480% increase in representation for this forest type on which many species of birds depend (Hansen and Rotella 2000).

At the ecosystem level in central Idaho, representation of whitebark pine increases from 42% in conservation areas to 73% when roadless areas are added. This is significant because whitebark pine is an important forest type for many bird species and carnivores. Like aspen, whitebark pine is declining. The primary culprit is blister rust, an invasive non-native disease.

Results at both the regional and ecosystem scales demonstrate that conservation areas are mainly located at higher elevations. We also found that roadless areas are generally concentrated at mid- to high elevations and represent a wider range of elevations—especially low to mid-elevations—than do conservation lands. Yet our results show that conservation areas protect more lower elevation lands at the regional scale than do roadless areas. This situation is somewhat deceiving. Representation of lower elevations in conservation areas is largely because of a few well-placed low-elevation conservation areas—Hell's Canyon National Recreation Area and Missouri Breaks National Monument. In fact, low-elevation lands below 1000 meters are not well represented in either conservation units or roadless areas.

Higher-elevation roadless areas across both the regional and ecosystem scales are often adjacent to designated wilderness and national parks. In most cases, these roadless areas have not been significantly altered by human activities. For example, they experience the infrequent, large stand-replacing fire regime that is characteristic of higher-elevation lands. But because most lower-elevation lands have been converted to other uses it is of utmost importance to increase representation of lower-elevation sites in conservation units (Strittholt and DellaSala 2001). Protection of lower-elevation roadless areas would contribute greatly to the conservation of lower-elevation species and ecological communities that are poorly represented in conservation areas.

We emphasize that analysis at multiple scales is needed to fully ascertain the extent to which roadless areas can contribute to conservation goals. Studies have shown that species and ecological processes operate at many different scales (Kotliar and Wiens 1990, Wiens 1989). Hence to maintain the long-term viability of populations of native species and to sustain overall ecosystem integrity, multiple-scale analysis is essential. Our results indicate that roadless areas contribute more to the representation of lower-elevation lands and ecological communities at the ecosystem scale in central Idaho than what we observed at the broader regional scale. These findings are important because even though this ecosystem contains large blocks of designated wilderness, it lacks representation of many land cover types in its conservation units, especially the mid- to lower elevation lands that are important to maintain ecological processes in this ecosystem.

Landscape Connectivity

In the Northern Rockies, roadless areas may well play an important role in the movement and dispersal of species (Wegner and Merriam 1979, Whitcomb et al. 1981, Buechner 1989). As examples, avian species are dependent on "stopover habitats" as they migrate through the landscape, and wide-ranging species such as elk, bear, and wolverine require large, connected regions for seasonal migrations and general movements through landscapes (Hillis et al. 1991, Freemark et al. 1993, Copeland 1996, Noss et al. 1997).

Many current studies are attempting to discover the ways that species move across landscapes and their use of corridors and "stepping-stone" habitats, especially in fragmented landscapes (Buechner 1989, Lamberson et al. 1992, With 1999, Beauvais 2000, Hansen and Rotella 2000). Being relatively undisturbed, roadless areas are top candidates for the design of future corridors and "stepping stones," particularly those that target rare or declining species and that take ecosystem processes into account.

Roadless areas also have the potential to enhance the survival of island populations such as source-sink populations that are becoming more common in fragmented landscapes (Wiens et al. 1985, Pulliam 1988, Gilpin and Hanski 1991, Murphy and Noon 1992). Source-sink populations are isolated populations that together, through continual migrations, act as a single regional population. A "source" is an area where populations grow and produce emigrants, and a "sink" is an area where populations cannot sustain themselves in the absence of immigration from source areas (Pulliam 1988). The loss or alteration of roadless areas may further reduce the movement of species among interdependent island populations located in conservation areas and roadless areas, resulting in greater isolation of populations of some species.

Our analyses of four elements of connectivity at two scales show that roadless areas are well positioned in the landscape to provide connectivity at both the regional and ecosystem scales. Roadless areas increase both the area of conservation lands and the size of conservation units. In addition, the number of patches in conservation units decreases with the addition of roadless areas because roadless areas unite with the conservation units to form one larger patch. Roadless areas also reduce the distance between conservation areas and create a more

Roadless Areas and Birds

Among the many species of birds that would benefit from protection of roadless areas in the Northern Rockies are neotropical migrants—many of them colorful songbirds—that winter in Central or South America and migrate to North America to breed. These birds are known to be largely affected by the spatial arrangement and size of habitat areas (patches). The less isolated the habitat patch, the more species will be found (Askins et al. 1987, Robbins et al. 1989, Gibbs et al. 1991, Freemark and Collins 1992).

Orientation of habitat patches may also influence migration movements and subsequent breeding. Any disruption or change that causes a reduction in habitat size and alters the orientation of habitat areas for migration movement is likely to result in a decrease in population persistence (Freemark et al. 1993).

Our study indicates the important ecological benefits that protection of roadless areas will likely yield for neotropical migrants. In particular, roadless areas enhance protection of many different habitat types at lower elevations, increase the size of conservation areas, and preserve connectivity across the region—including "stepping-stone" habitats that may be important to the migration movement of many species of birds.

Elk is one of several wide-ranging species in the study region that require large, connected areas for seasonal migrations and general movements across the landscape.

evenly dispersed conservation reserve system across the landscape.

Adding more variation in the extent and shape of patches, decreasing the distance between conservation areas, and adding more patches evenly dispersed across a landscape are important considerations in developing a conservation reserve system that is capable of maintaining the movements of many different species and ecological processes (Wilcove and Murphy 1991, Noss 1992, Noss et al. 1997). The addition of roadless areas to conservation lands in the Northern Rockies at the regional scale significantly increases connectivity, and almost all wilderness area and national park patches increase in size.

The three main wilderness/national park complexes—Glacier National Park-Bob Marshall Ecosystem, Greater Yellowstone Ecosystem, and Central Idaho Ecosystem—all increase in size and shape. Roadless areas not immediately adjacent to these complexes are dispersed in the surrounding landscape. This significantly decreases the degree of isolation between the complexes and possibly allows more species movement among these areas.

The addition of roadless areas to the mix of conservation units in the Central Idaho Ecosystem creates a highly connected landscape, as more overall area is protected and the size of patches increases while their number decreases. This is true of the regional landscape, although not to the extent exhibited in central Idaho. In fact, results of the contagion metric coupled with visual observations reveal that one large protected patch dominates the Central Idaho Ecosystem when roadless areas are added. The roadless areas connect Sawtooth, Gospel Hump, Frank Church River of No Return, and Selway/Bitterroot wilderness areas into one huge patch that may be important to the movement of local, wide-ranging species and to ecosystem processes such as wildfires that help maintain natural landscape dynamics (Pickett and Thompson 1978, Turner et al. 1993, Newmark 1995, Shafer 1995).

Our results at both scales demonstrate that roadless areas increase the effective size of wilderness and national parks, which, in turn, helps them to maintain ecological processes. The management plan for Yellowstone National Park implies that the park's managers are aware of this situation; the plan recognized that surrounding wilderness and roadless areas are necessary to preserve the ecological integrity of the Greater Yellowstone Ecosystem.

Whether or not to allow natural fires to burn on federal lands has become a hotly contested issue. For many reasons, including fire suppression policies and the growing number of settlements in fire-prone areas, large wildfires now pose a threat to more and more people. Enlarging the size of conservation units through the addition of roadless areas may make it possible for conservation lands to accommodate natural fire processes over time (Pickett and White 1985).

Management Implications

The scientific literature describes the importance of intact, functioning natural ecosystems to the maintenance of native biodiversity and ecological processes (McArthur and Wilson 1967, Usher 1987, Noss and Cooperrider 1994, Schafer 1995). The literature also demonstrates the negative overall and cumulative impacts of roads in natural areas (Andrews 1990, Reed et al. 1996, Spellerburg 1998, Trombulak and Frissell 2000 and McGarigal et al. 2001). The literature and the results of this study comprise a strong argument that roadless areas can enhance representation of land cover types and contribute to landscape connectivity in this country's federal reserved land system.

This study revealed information that is useful to determine the contributions of roadless areas to a conservation reserve strategy. The information has a direct bearing on management decisions regarding the protection of roadless areas. In addition, the methods used in this study can help land managers determine appropriate management guidelines for roadless areas at both the regional and ecosystem scales.

Our results, along with the findings of DeVelice and Martin (2001) and Strittholt and DellaSala (2001), highlight the significant role of roadless areas in U.S. conservation efforts. Existing roadless areas are among the few remaining pieces of the natural landscape that once covered this country, and the opportunity to protect them is rapidly diminishing. If they are not protected from activities that result in degradation or loss of their characteristics, it is possible that current conservation lands will also be degraded—perhaps beyond the reach of even the most extensive restoration efforts. If roadless areas receive full protection and are managed responsibly, they could function as an important missing link in the current conservation land system.

Roadless Areas and Management for Carnivores

Numerous top predators are native to the Northern Rockies. In fact, Waterton-Glacier International Peace Park in northwestern Montana and southern Alberta contains a complete suite of large- and medium-sized carnivores—from grizzly and black bears to the cougar, gray wolf, wolverine, lynx, fisher, and marten. All of these species require large areas that are somewhat connected across the landscape to breed, hunt prey, and move.

In the Northern Rockies, native carnivore populations are relatively intact, primarily because of the mountainous topography, relatively low human population density, and conservation areas such as Yellowstone and Waterton-Glacier national parks. But existing conservation areas alone are unlikely to ensure the viability of many of these populations (Paquet and Hackman 1995, Noss et al. 1996). Many are seriously threatened by illegal and legal hunting and trapping, direct mortalities from road and rail traffic, and loss or degradation of their habitat.

To address the threat of extinction in fragmented landscapes, conservation biologists have developed a set of guidelines (see Wilcove and Murphy 1991, Noss 1992, Noss et al. 1997) to help ensure the continued existence of top predator populations. They include:

- Species well distributed across their native range are less susceptible to extinction than species confined to small portions of their range.
- Large blocks of habitat, containing large populations, are better than small blocks with small populations.
- Blocks of habitat close together are better than blocks far apart.
- Habitat in contiguous blocks is better than fragmented habitat.
- Interconnected blocks of habitat are better than isolated blocks of habitat.
- Blocks of habitat that are roadless or otherwise inaccessible to humans are better than roaded and accessible habitat blocks.

The results of our study show that protection of national forest roadless lands in the Northern Rockies will significantly aid managers in meeting these guidelines.

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APPENDIX

Regional land cover reclassification

Reclassification of Wyoming, Montana and Idaho land cover maps from each state's GAP Analysis Program.

Land cover type	Wyoming	Montana	Idaho
Urban	Human settlements	Urban	Urban
Agriculture	Irrigated crops Dry-land crops	Agriculture—dry Altered herbaceous Agriculture—irrigated	Agriculture Disturbed grassland
Mining	Surface mining operations	Mines, quarries, gravel pits	
Sand dunes	Active sand dunes		Sand dune
Vegetated dunes	Vegetated dunes		Vegetated sand dune
Water	Open water	Water	Water
Rock	Alpine exposed rock / soil Basin exposed rock / soil	Rock	Exposed rock Lava
Barren	Unvegetated playa	Mixed barren sites Missouri breaks	Vegetated lava Mixed barren land Mixed barren land
Snow	Permanent snow	Snowfields or ice	Perenial ice and snow
Clearcut conifer	Clearcut conifer		Herbaceous clearcut
Alpine meadow	Meadow tundra	Alpine meadows	Alpine meadow
Burned conifer	Burned conifer	Standing burned forest	Burned standing timber
Riparian forest	Forest-dominated riparian	Conifer riparian Broadleaf riparian Mixed broadleaf and conifer riparian Mixed riparian	Cottonwood Conifer riparian Deciduous riparian Mixed conifer / deciduous riparian Mixed forest / non-forest riparian Mix non-forest riparian
Riparian shrub	Shrub-dominated riparian	Shrub riparian	Shrub dominated riparian
Riparian grasses	Grass-dominated riparian	Graminoid and forb riparian	Forb dominated riparian
Wetland	Grass-dominated wetland		Wet meadow Deep marsh Shallow marsh
Aquatic flats			Aquatic bed Mud flat
Desert shrub	Desert shrub Greasewood fans and flats Saltbush fans and flats	Salt-desert shrub / dry salt flats	Salt desert shrub Maple
Grasslands	Mixed grass prairie Great Basin foothills grassland Short grass prairie	Very low cover grassland Low / moderate cover grassland Moderate / high cover grassland	Foothill's grassland Perennial grass slope Perennial grassland Herbaceous burn Perennial grass slope
Sagebrush	Wyoming big sagebrush Mountain big sagebrush Black sagebrush steppe Basin big sagebrush	Silver sage Sagebrush	Mountain big sagebrush Wyoming big sagebrush Basin / Wyoming big sagebrush Black sagebrush steppe Silver sage Low sagebrush Mountain low sagebrush
Shrub-grassland steppe	Bitterbrush shrub steppe	Mesic shrub-grassland associations Xeric shrub-grassland associations	Shrub-steppe annuals Bitterbrush Rabbitbrush
Bur oak woodland	Bur oak woodland		
Juniper woodland	Juniper woodland	Rocky mountain juniper Utah juniper	Utah juniper Western juniper Pinyon pine / juniper
Mesic upland shrubs	Mesic upland shrub	Mixed mesic shrubs	Mesic upland shrubs Warm mesic shrublands

APPENDIX (CONTINUED)

Land cover type	Wyoming	Montana	Idaho
Xeric shrubs	Xeric upland shrub	Mixed xeric shrubs	Curlleaf mountain mahogany
Aspen / broadleaf forest	Aspen forest	Mixed broadleaf forest Mixed broadleaf and conifer forest	Aspen
Ponderosa pine	Ponderosa pine	Ponderosa pine	Ponderosa pine
Lodgepole pine	Lodgepole pine	Lodgepole pine	Lodgepole pine Western larch / lodgepole pine
Western red cedar		Western red cedar	Western red cedar Western red cedar / grand fir Western red cedar / western hemlock
Western hemlock		Western hemlock	Western hemlock
Mixed conifer / Douglas-fir	Douglas-fir	Low density xeric forest Mixed mesic forest Grand fir Douglas-fir Western larch Douglas-fir / lodgepole pine Mixed xeric forest	Grand fir Douglas-fir Wetern larch Douglas-fir / limber pine Mixed mesic forest Mixed seric forest Douglas-fir / lodgepole pine Douglas-fir / grand fir Western larch / Douglas-fir Mixed conifer / deciduous
Mixed subalpine forest	Spruce-fir Limber pine and woodland	Mixed subalpine forest Limber pine	Englemann spruce Subalpine fir Subalpine pine Subalpine fir / whitebark pine Mixed subalpine forest
Whitebark pine	Whitebark pine	Mixed whitebark pine forest	Mixed whitebark pine forest
Subalpine meadow	Subalpine meadow	Montane parklands and Subalpine meadows	Montane parkland