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Estimating visitor use of protected areas by modeling accessibility: A case study in Rocky Mountain National Park, Colorado

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ABSTRACT: Increasingly, land managers need to better understand the spatial distribution of visitor use in parks and protected areas to address possible impacts on natural and cultural resources. Common surrogates of visitor use in protected areas based on spatial data include distance from roads and density of roads and trails. We developed an approach to estimate visitor use by modeling the accessibility of a park by representing park entrances, road and trail infrastructure, trailhead locations, and off-trail travel. We illustrate our approach on a case study of Rocky Mountain National Park, Colorado, USA. We compared accessibility measured as one-way travel time to density of roads and trails, and found that accessibility better differentiates use levels, particularly with respect to front-country and backcountry zones. We also illustrate how accessibility can be used to examine potential pathways of invasive species. We recommend that accessibility modeling can provide a useful way to generate maps of visitor use for understanding potential effects on parks and protected areas.

Keywords: Visitor use, accessibility, protected areas, travel time, road density

INTRODUCTION

Developing estimates of the level of visitor use is important for managing protected lands in terms of maintenance, visitor services, spending in local communities, and natural resource protection (Eagles et al. 2000). Increasingly, managers have identified impacts from visitor use to natural and cultural resources as an important threat to parks and protected areas (USGAO 1994; Hall and Shelby 1998; Fancy et al. 2008). Guidelines have been promulgated by the United Nations to manage effects of tourism and visitation on conservation of biodiversity (UN 2009). National parks in particular have long struggled to balance their dual role of providing for the enjoyment of visitors while balancing the role of protecting natural resources as well (Cole and Landres 1996; Cole 2001). Even passive recreation (e.g., hiking) can lead to pronounced declines in carnivore density in protected areas (Reed and Merenlender 2008), and pronounced wildlife responses (flushing) do off-trail and trail use (Miller et al. 1996). This paper provides refined methods for to better understand the potential effects of visitor use on park natural resources through accessibility modeling.

Although many parks have some basic data on the number of visitors to a park, many land management agencies have insufficient visitor monitoring programs and little baseline data about visitor use, let alone data about broader, spatially-explicit patterns and trends. For example, a survey of wilderness managers by Watson et al. (2000) reported that 63% relied on best guesses to estimate visitor use. Lack of funding, logistical problems due to the size of protected areas, number of access points, lack of personnel time, and lack of knowledge and training about available methods to collect and analyze data have been identified as some reasons why visitor use has not been examined adequately (Watson et al. 2000).

Consequently, a number of methods to estimate the distribution of visitor use through surrogate data have been developed using spatial analysis techniques. One approach has focused on understanding park crowding and its effects on visitor experience, typically based on individual-based movement models to simulate encounters along a trail network (e.g., Wing and Shelby 1999; Gimblett et al. 2000; Lawson et al. 2006). These are often based on resource-intensive survey methods from trail counters (e.g., Cope et al. 1999; Lindsey and Lindsey 2004). A second approach has been to develop maps that represent landscape-level effects from both on-trail/road and off-trail use, which generally relies on mapping incremental buffers from roads (e.g., Lesslie et al. 1988; Kliskey 1998; Aplet et al. 2000; Stoms 2000; Sanderson et al. 2002; Theobald 2003; Leu et al. 2008) or distance as a continuous variable from roads (e.g., Riitters and Wickham 2003; Watts et al. 2007). A notable example of this approach to estimate visitor use specifically for protected areas was Shumacher et al.'s (2002) development of a "human use intensity" model, which was computed as an equal-weighting of population density and road/trail density rasters (weighted using 3 for improved roads, 2 for unimproved roads, and 1 for trails) using a 1 km radius moving window. A third approach has relied on developing relationships between land cover types and the degree of human modification (e.g., Brown and Vivas 2005), but this tend to be more appropriate for urban watersheds.

Our overall goal in this paper was to develop an approach to estimate the spatial patterns of visitor use in parks and protected areas. Our approach was to model accessibility (Geertman and van Eck 1995; Nelson 2001, 2008) in a geographic information system (GIS). Accessibility is defined as the one-way travel time for an average visitor to any location within a park, and is similar (perhaps the opposite) to modeling remoteness (Fritz and Carver 1998; Carver et al. 2002). Accessibility is measured as travel time and has found to be related to distance from a trailhead (van Wagtendonk et al. 1980; Ode and Fry 2006; Pettebone et al. 2006).

Our specific objectives in this paper were to: a) develop a methodology to estimate the spatial distribution of visitor use based on accessibility in a GIS and illustrate its application to a case study area of Rocky Mountain National Park (RMNP), Colorado; b) examine how differences in transportation infrastructure changes accessibility to the park, as represented by three scenarios; c) illustrate how accessibility can be used to inform pressing management issues such as the relationship between invasive species and visitor use; and d) compare accessibility to measures based on road and trail density (Schumacher et al. 2000) and distance from roads (Watts et al. 2007).

Our case study park is located in north-central Colorado, is adjacent to the Town of Estes Park (population 5,413 in 2000), and contains roughly 250,000 acres composed mostly of montane and alpine ecosystems reaching from 7,500 to 14,000 feet. For nearly two decades, RMNP has experienced about 3 million visitors per year. A study of wilderness use in RMNP found that about 525,000 users per year accessed backcountry areas (Bates et al. 2006). Roughly 1% of these visitors were overnight (campground and back-country) visitors (NPS 2001).

METHODS

Our approach described in this paper is similar to two accessibility models published previously (Theobald 2005; Frakes et al. 2008) that estimated travel time to all locations within RMNP using least-cost distance techniques in ArcGIS v9.2 (ESRI, Redlands, CA). Building on these efforts, in this paper we describe three novel innovations: combining multiple access locations; including parking lot locations and trailheads; and exploring three scenarios of transportation infrastructure. We conducted this analysis using 10 m resolution raster datasets to match the finest resolution topography dataset available using roads, trails, slope, streams, and land cover (vegetation) types (Table 1, page 4).

We used four steps to develop an accessibility surface to compute the time it would take a visitor to travel (one-way) to a given location. First, we identify a starting location, which is where a visitor typically gains access to a park or protected areas (e.g., gate or entrance station). From the starting location, we then assume that a visitor will travel along the road infrastructure to a parking lot at a developed site (e.g., picnic area, rest stop, trailhead, etc.). Typically visitors travel in an automobile, but other modes of travel such as bus systems could be incorporated with adjustments to the route and travel speed. From the trailhead site, we assume a visitor would then travel along the trail infrastructure, at average speeds appropriate to the mode of travel (i.e. hiking, horseback, motorized). Finally, we model off-trail travel by a visitor across the landscape that will likely be modified significantly by topography and vegetation cover.

TABLE 1 Spatial Datasets Used to Represent Various Factors Included in the Accessibility Model for Rocky Mountain National Park

Factor	Source	Attribute variables	Scale
Roads	ESRI StreetMap (1:100k)*	Posted speed limit	1:100,000
Trails	Colorado Trails dataset (Linn et al. 2008)*	Surface type, mode of travel, trail gradient, trail heads, parking lots	1:1,000-24,000
Topography	USGS National Elevation Dataset	Elevation (m), off-trail slope	10 m
Hydrography	USGS National Hydrography dataset, RMNP hydrography	Streams, lakes, stream order	1:24,000
Land cover	RMNP vegetation (Salas et al. 2005)	Reclassified to major land cover types	10 m

**We used these datasets because some trails were not identified correctly, and these provide infrastructure outside of the park (e.g., north access from Pingree Park area).*

A basic diagram of the accessibility model, constructed in Model Builder in ArcGIS, is shown in Figure 1, page 5. We employed cost-distance methods, where cost weights reflect the resistance to movement, though we express these weights in terms of permeability (i.e. low permeability signifies high weight or resistance).

First, we defined the starting (initial) locations to be the entrances to the park. There are three formal entrances: two on the east side (Beaver Meadows and Fall River), and one on the west (Kawauneechee). We added an additional "informal" trail entrance on the north side of the park near Long Draw Reservoir to account for visitors hiking in from adjacent national forest lands. We developed a separate accessibility surface from each of the four starting locations measured as minutes of travel time from the entrance to all locations in the park. We combined these by finding the weighted average travel time — weighted to reflect the approximate distribution of visitors entering each gate, based on the most current information about visitor use by park entrance (a 1995 survey, Table 2, page 5). We also adjusted the weights for each layer spatially so that locations close to each entrance were more important in determining the overall travel time (using inverse distance as a relative weight). This was necessary so that extremely long (and unrealistic) travel times did not outweigh nearby estimates. Note that although roughly 1.4% of visitors spent the night in back-country areas, the pattern of overnight visitors, such as around campsites, is not explicitly accounted for here.

Our second step was to incorporate travel time from the starting locations, along the road infrastructure. We assumed that visitors would travel via automobile along the roads at the assigned speed limit, and leave their automobiles only at parking lots and designated trailheads. This is an important difference from most accessibility models (including Theobald 2005; Frakes et al. 2008) — which assume that a visitor can stop at any location along a road, leave the car, and begin hiking away from the road. To reflect this assumption we assigned a permeability of 0.01 to off-road and off-trail cells that were directly adjacent to road cells. For gravel and 4-wheel drive roads, we assumed a speed limit of 15 mph. Note that we assumed automobile travel was unaffected by road gradient.

FIGURE 1 A diagram of the logic for the accessibility model (Theobald 2005).

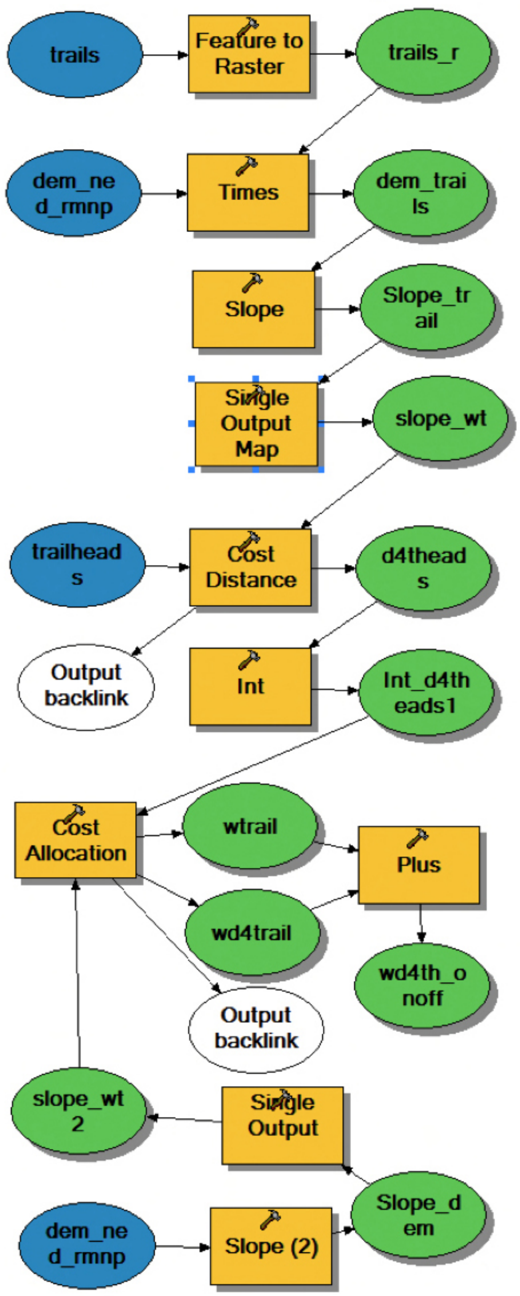


TABLE 2 Weights Used to Reflect the Proportion of Park Visitors Entering RMNP from Each of Four Park "Entrance" Locations

Entrance	No. of respondents	Weight
Beaver Meadows	1,388	0.43
Kawaneeche	721	0.22
Fall River	1,134	0.34
northern*	40	0.01

estimated by authors.

The third step was to model travel time from trailheads and parking lots, along trails where visitors presumably would be hiking. The typical velocity of a hiker is 5 km/hr on flat terrain but diminishes on steeper terrain, and we used a hiking velocity equation (Tobler 1993) to reflect changes in travel speed as a function of trail slope:

$$h = 6 * \exp(-3.5 * |S + 0.05|)$$

where h is the hiking velocity in km/hr and S is the trail slope or gradient. Note that we did not distinguish travel time based on direction (i.e., hiking up a steep trail might take longer than down a steep trail).

The fourth step was to incorporate travel time for off-trail hiking. Travel speed was assumed to be the same as on-trail (which includes the slope of the terrain being hiked across), but with an additional decrease in permeability to reflect the difficulty of moving through dense vegetation and crossing rivers and lakes. We generalized 46 vegetation associations from the fine-grained vegetation dataset (Salas et al. 2005) to 25 classes, and then we estimated a permeability value for each land cover class to reduce the travel speed (1.0 for no effect to 0.0001 for difficult to move through; Table 3, page 6). Our permeability values were based on Frakes et al. (2008), who developed their estimates in consultation with park

TABLE 3 Estimated Permeability Values for Computing Off-trail Hiking Speed*

Vegetation Class	Permeability value
Barren	1.00
Blue Spruce	0.60
Cottonwood	0.90
Dead and Down Woodland	0.30
Glacier	0.50
Herbaceous Upland Alpine	0.85
Herbaceous Upland Alpine Fell Field	0.65
Herbaceous Upland Montane	0.85
Herbaceous Wetland Cross Zone - Marsh	0.45
Herbaceous Wetland Cross Zone - Wetland	0.45
Herbaceous Wetland SubAlpine	0.45
Juniper	0.75
Krummholz	0.40
Lodgepole Pine	0.50
Mixed Conifer with Aspen	0.65
Montane Douglas Fir	0.65
Ponderosa Pine	0.75
Riparian Aspen	0.70
Riparian Montane Mixed Conifer	0.65
Shrub Riparian Cross Zone	0.35
Shrub Upland Alpine	0.45
Shrub Upland Lower Montane	0.45
Sub-alpine Conifer	0.50
Upper Montane Aspen	0.65
Water (lakes & reservoirs)	0.0001
Tributaries (1^{st} order)	0.80
Small streams (2^{nd} order)	0.65
Large streams (3^{rd} order)	0.20
Rivers (>3^{rd} order)	0.02

**These modifiers reflect the permeability of movement, and are multiplied times the on-trail travel time, so smaller values mean slower travel speeds. For vegetation classes that crossed over with the coarser USGS National Land Cover Dataset cover types we used permeability values developed by Frakes et al. (2008), for other vegetation classes we estimated values consistent with similar vegetation types. Also, our weights for crossing larger streams (3rd order and greater) is 3-10 times smaller (less permeable, more time to cross).*

managers. We maintained consistency with their estimates based on 10 classes from the USGS National Land Cover Dataset when assigning permeability values to the 25 vegetation classes. We assumed that hikers who plan to travel off-trail use an existing trail to access the closest point to their off-trail destination. Areas where vegetation is denser (e.g., shrublands) were assigned a lower permeability value to reflect the difficult of movement. Lakes, large rivers, and wetlands were given a very low permeability value assuming travel through these areas is difficult.

To make the results of the accessibility of the park more useful for park managers, we computed summary statistics for a variety of spatial management zones that were defined in parks management plan (NPS 2001): for the entire park, for the park divided into the east versus west side of the continental divide (that is often used as functional administrative units), for research natural areas that serve as reference sites of “pristine” ecological condition versus “front-country”, and by major ecological system or life zone (alpine, upper montane, lower montane, riparian, and savannah). For each zone, we computed both average and standard deviation of travel time by finding the raster cells that intersected a given management zone.

To meet our second objective, we wanted to understand how the degree of threat to resources has changed from previous “natural” conditions to the current state of transportation infrastructure. Consequently, we developed accessibility surfaces to reflect three scenarios that were developed to inform a Natural Resource Condition Assessment that we conducted for RMNP:

⇒ *Scenario A. Current roads & trails:* This scenario is based on the current transportation infrastructure (i.e. roads and trails), and travel time is the weighted average from the four park entrances.

⇒ *Scenario B. Current roads without trails:* This scenario reflects the road transportation infrastructure, but does not include the trail system. This allowed us to examine how the current trail infrastructure modifies the “natural” accessibility to ecological systems in the park.

⇒ *Scenario C. “Natural” conditions without roads or trails:* This scenario reflects an absence of transportation infrastructure (i.e. roads or trails) in the interior of the park. This allowed us to examine how the “natural” accessibility to ecological systems varies within in the park.

To meet our third objective, we examined the relationship between the presence of invasive species and accessibility. Managers were particularly concerned about pathways for exotic species, and in particular the relationship between visitor use and distribution (and future spread) of exotic species. We highlight the pattern of “cheat grass” (*Bromus tectorum*) because it is the most extensive exotic species in the park and can increase wildfire severity and out-compete native grasses.

To compare our measures of accessibility to existing density and distance based approaches, we computed the average travel time, road/trail density and distance from road within park management zones. We also examined the spatial distribution of the different methods by normalizing the raw travel time (minutes) and density (km/km^2) into ranked values (0.0 to 1.0) and overlayed the normalized values and computed their ratio.

RESULTS

We ran the accessibility model to calculate average travel time within the entire park, as well as for areas east versus west of the continental divide. The resulting maps are shown in Figure 2, page 9. For the current road and trail infrastructure (Scenario A), the average one-way travel time for RMNP is 3.5 hours (Table 4, page 12). This means that the average travel time from *all* entrances to *all* locations in the park is, on average, 3.5 hours with a standard deviation of 2.3 hours. Roughly 7% of the park is within 1 hour, 50% is within 4 hours, and 80% of the park is within 8 hours. The west side of the park (west of the Continental Divide) is slightly less accessible, with an average one-way travel time of 3.8 hours, while it is 3.4 hours on the east side. The most accessible ecological systems were savannah (2.0 hrs) and lower montane (2.3 hrs). Note that these values are averages for the entire zones — there are some parts of each of these systems that are much more (and less) accessible than the average value.

Our second objective was to examine how accessibility changed with different scenarios of transportation infrastructure (Figures 2, 3, and 4, on pages 9, 10, and 11 respectively). Table 5, page 12, shows that we found that average travel time increases from 3.5 (with roads and trails) to 3.9 (no trails but roads) to 7.4 hours (no roads or trails). We also examined the accessibility of three Research Natural Areas (RNA; Table 6, page 12) — set aside to protect their pristine nature and to serve as reference. Travel time to West Creek RNA (located in the eastern part of the park, north of the Town of Estes Park) increases from 4.8 to 5.8 hours (Scenarios A and C, respectively) suggesting that it is relatively accessible because of its geographic location within the park, not because of the existence of any internal transportation infrastructure. In contrast, travel time to Specimen Mountain RNA (located in the northwest corner of RMNP) increases from 3.2 to 10.5 hours (Scenarios A and C), showing that accessibility has changed substantially with recent transportation infrastructure.

Our third objective was to illustrate how accessibility could be used to inform a pressing management concern: for example, the spread of invasive species. Figure 5, page 13, shows the 1,290 randomly-located vegetation plots from the RMNP vegetation dataset (Salas et al. 2005) placed over the accessibility surface (Scenario A). The average time to plots that contain cheat grass was 0.86 hrs (SD=0.432), while the plots without cheat grass were 3.24 hours away (SD=9.1; Figure 6, page 14). Cheat grass occurs in more accessible areas — roughly 80% of plots with cheat grass are within one hour's travel time.

Our final objective was to compare accessibility to measures of human use that were calculated using road and trail density or distance from roads. Figure 7, page 15, shows the "human use intensity" metric (Schumacher et al. 2000) for RMNP, with the town of Estes Park clearly visible in the right side (east) of the park, and more remote areas shown by a low density of use. Nearly 50% of the park has a use intensity value of 0.0 (i.e. no use), even though some of these areas are just beyond 1 km from a road or trail. Moreover, human use intensity does not differentiate locations that are either close to or far from the entrances to the park. Figure 8, page 16, shows a map that compares human use intensity values based on road and trail density to travel time as a ratio of the ranked values. This shows that in general the human use intensity metric over-estimates impacts in developed/ urban areas, while it under-estimates impacts in areas close to, but not on, roads and trails (as compared to accessibility).

Figures 9 and 10, page 17, show the measures of impact as a proportion of the front country and back country management zones. The vast majority (~95%) of the proportion of the front country zone has low (<10%) values of distance from trails and low travel times, showing that they conform well to the expectation of fairly developed, close, and accessible areas in the park (e.g., visitor center, main campgrounds, etc.). In contrast, the human use intensity index (road & trail density) shows a mixture of low, moderate, and high values within the front country zone and does not differentiate between front-country and other areas in the park. (Note that the interpretation for road & trail density should be switched compared to the other metrics; that is, small values mean low impact and large values mean high impact). For back-country areas where the expectations would be switched so that low levels of visitor use occur, the majority (~90%) of backcountry areas have very low human use index.

FIGURE 2 Accessibility within RMNP from park entrances, assuming current transportation infrastructure (Scenario A), shown as one-way travel time assuming shortest travel time along roads, trails, and off-trail.

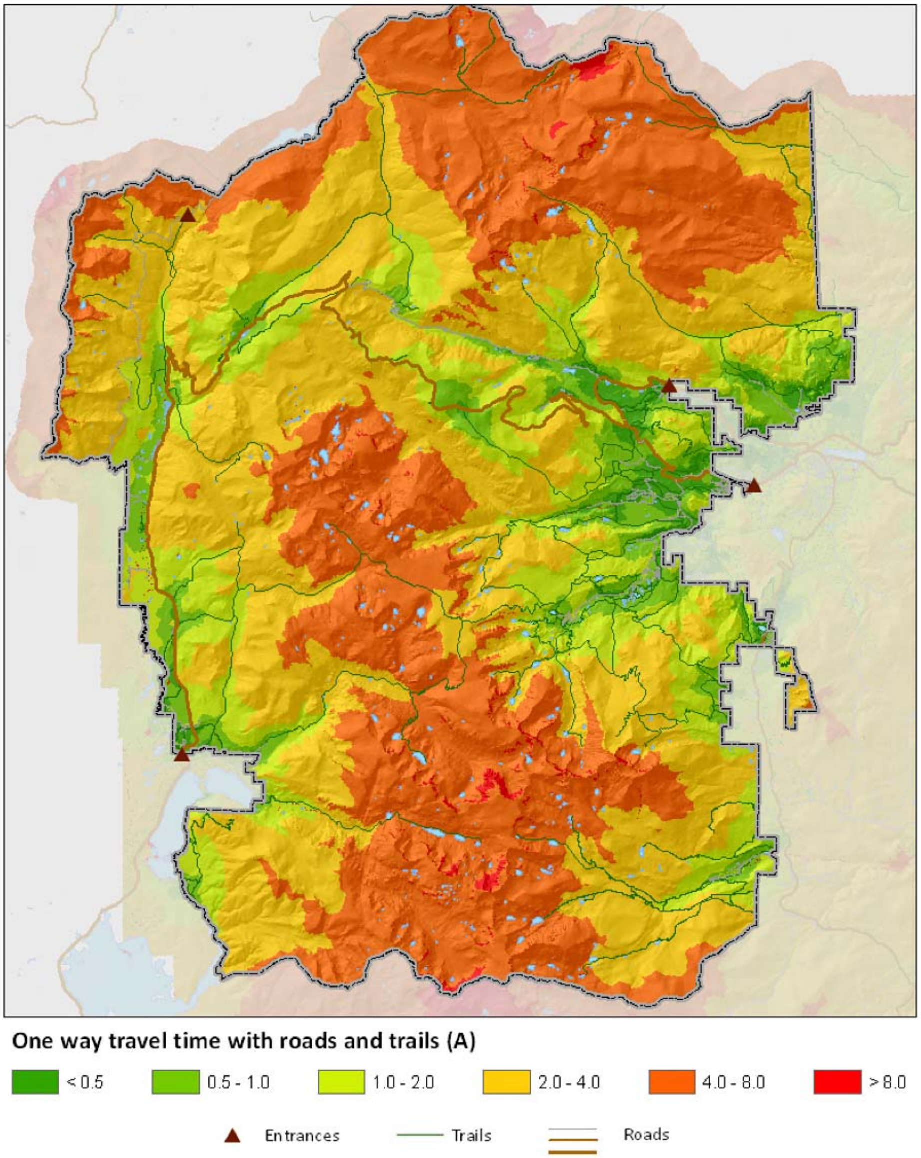


FIGURE 3 Accessibility within RMNP from park entrances, assuming no trails but roads as transportation infrastructure (Scenario B), shown as one-way travel time assuming shortest travel time along roads.

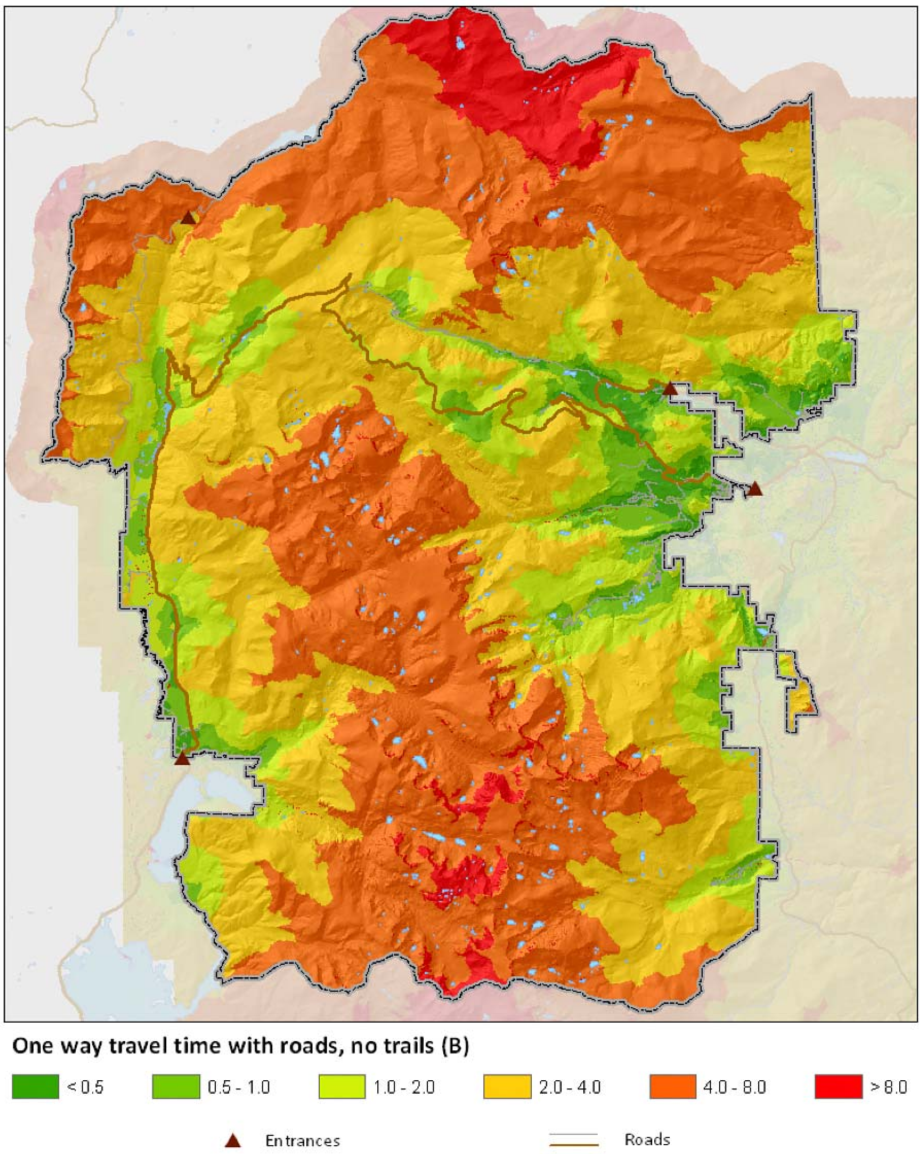


FIGURE 4 Accessibility within RMNP from park entrances (Scenario C) shown as one-way travel time assuming shortest travel time without roads or trails.

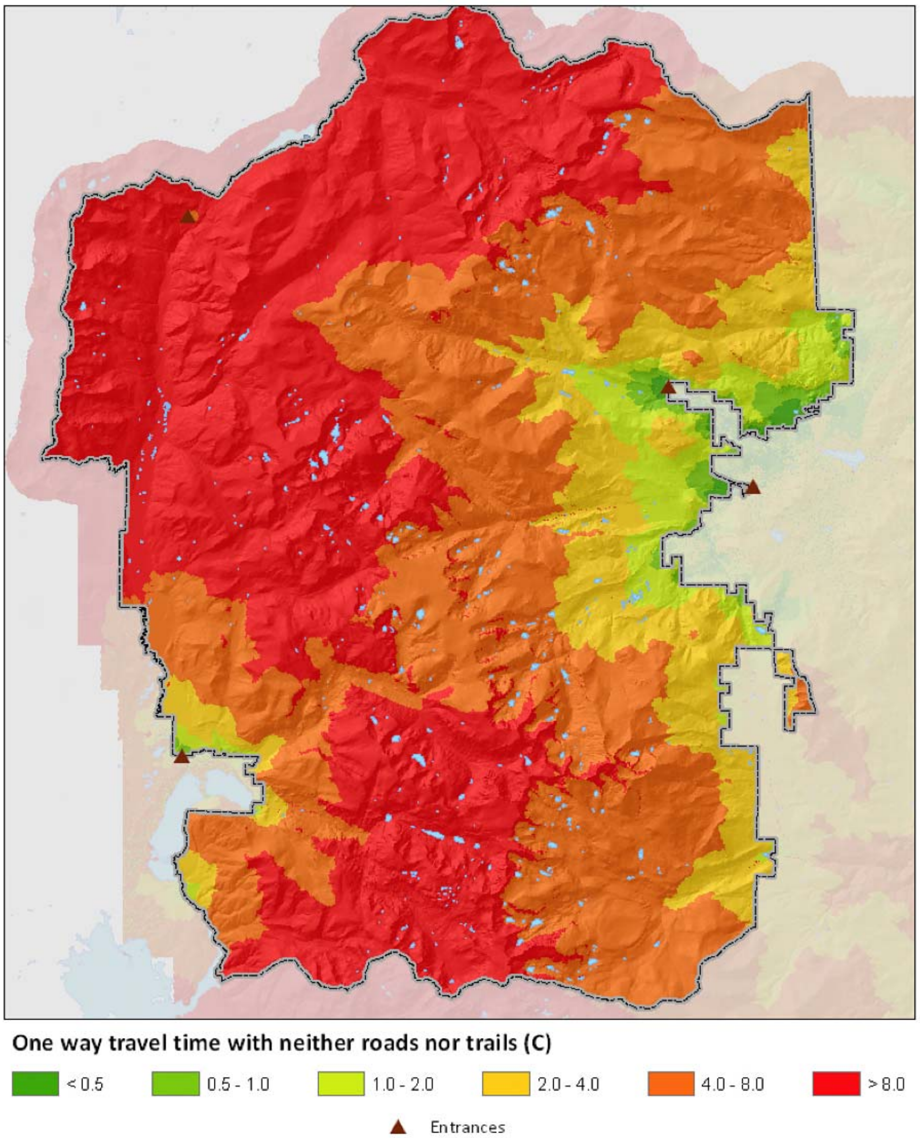


TABLE 4 Travel Time (hours) to Locations within RMNP from Four Entrances for Scenario A (current road and trails infrastructure)

	Averaging Unit	Mean (hr)	STD (hr)
RMNP		3.5	2.3
Continental divide	East	3.4	2.2
	West	3.8	2.4
Ecological systems	Alpine	4.8	1.7
	Upper Montane	3.2	1.8
	Lower Montane	2.3	1.2
	Riparian	3.0	2.6
	Savanna	2.0	1.0

TABLE 5 Summary of Average Travel Time (hours) for Different Accessibility Scenarios in Rocky Mountain National Park

Accessibility Scenario	Average (hr)	Standard Deviation (hr)
A. Roads and trails (current)	3.5	2.4
B. Roads only	3.9	2.6
C. No roads or trails ("natural")	7.4	3.4

TABLE 6 Average One-way Travel Time to Research Natural Areas in Rocky Mountain National Park Reflecting Different Infrastructure Scenarios

Research Natural Area	A. Roads and Trails		B. Roads only		C. No roads or trails	
	Avg. (hr)	STD (hr)	Avg. (hr)	STD (hr)	Avg. (hr)	STD (hr)
Specimen Mountain	3.2	1.4	3.6	1.6	10.5	1.2
West Creek	4.8	1.0	5.2	1.1	5.8	1.5
Paradise Park	6.8	3.1	7.3	3.1	9.6	2.7

FIGURE 5 The distribution of plots containing cheat grass (*Bromus tectorum*) and accessibility based on current transportation infrastructure in RMNP.

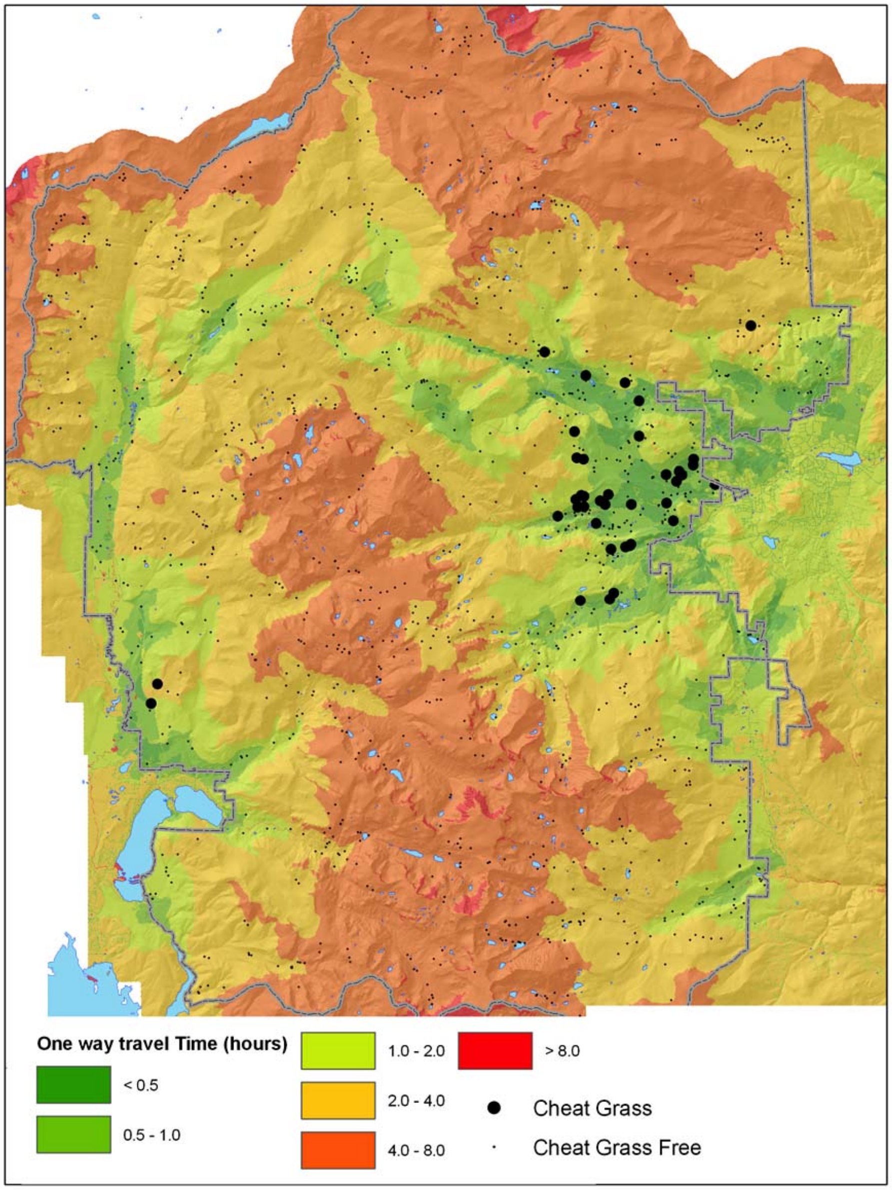


FIGURE 6 A cumulative distribution plot showing how the proportion of plots with cheat grass relates to accessibility. The majority (80%) of the plots that have cheat grass are within 1 hour travel time, whereas the majority (80%) of locations throughout the park are much less accessible (~3 hours travel time).

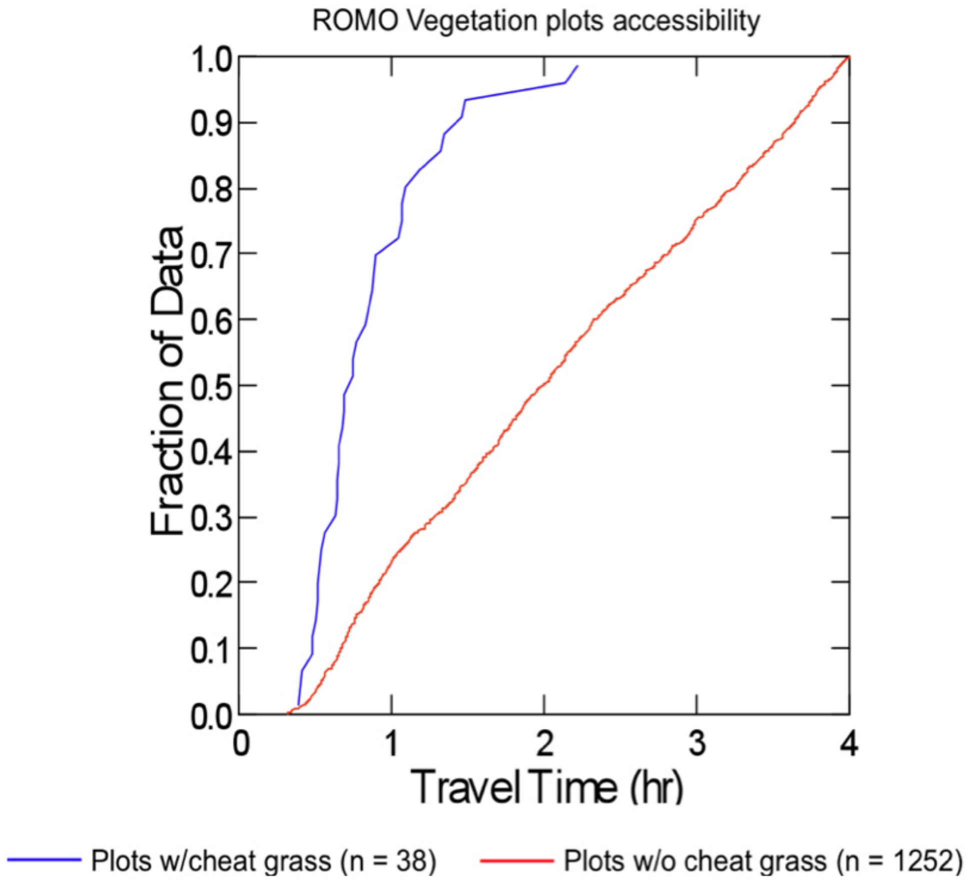


FIGURE 7 Measuring "human use intensity" using weighted road and trail densities computed with a 1 km radius kernel density function, following Schumacher et al. (2000).

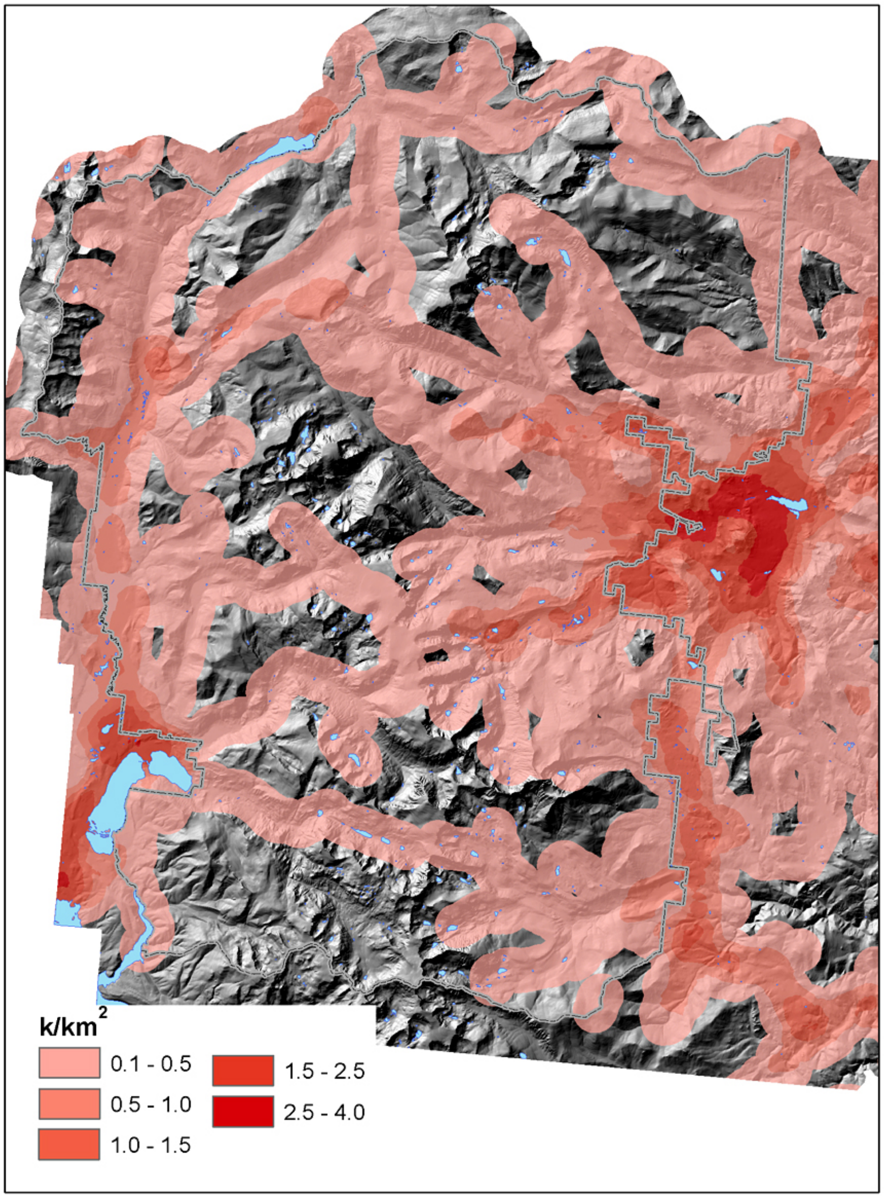
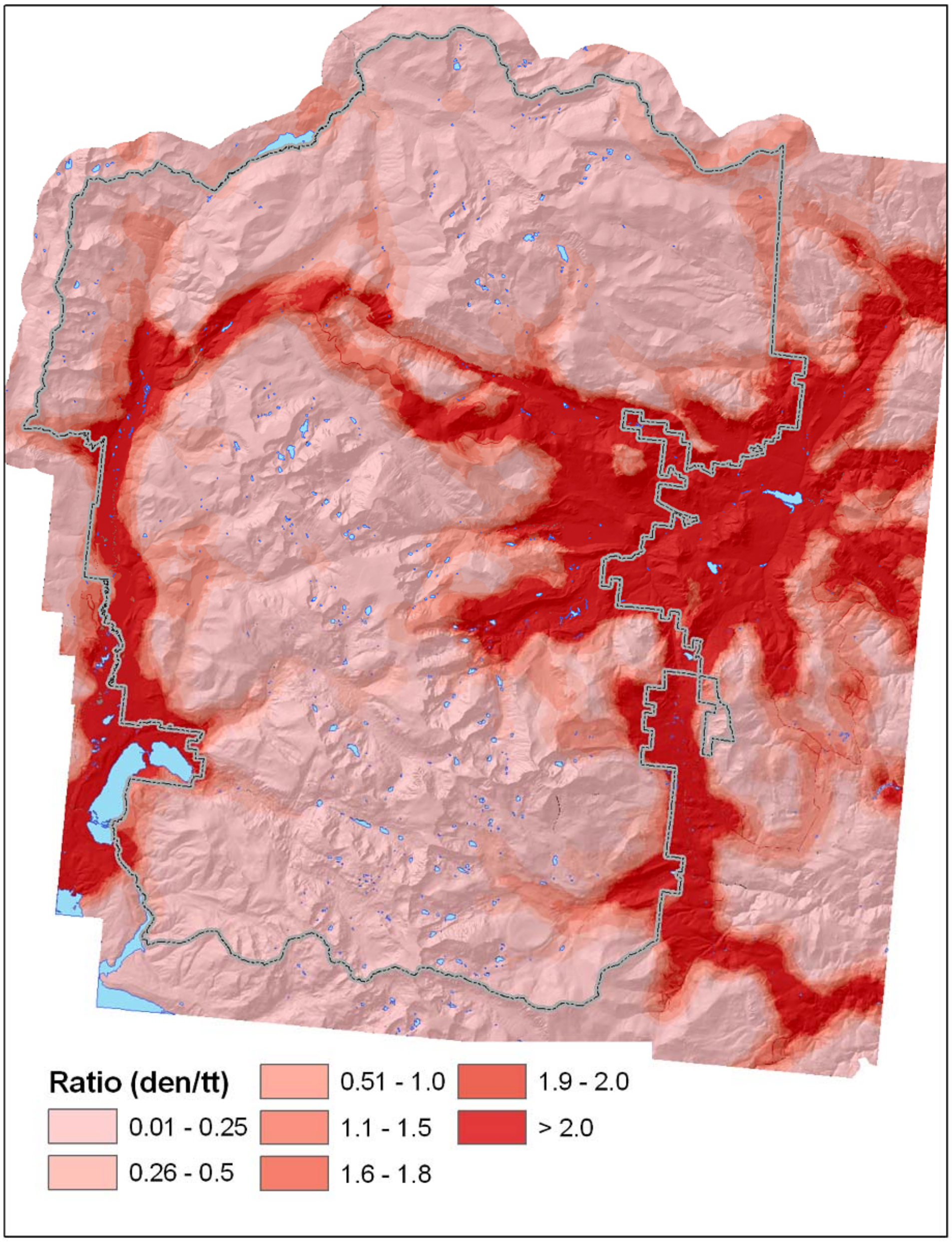


FIGURE 8 A comparison of the "human use intensity" surface to the accessibility surface. This was computed by first converting the road/trail density values (km/km^2) and accessibility (travel time in minutes) to rank order of values (i.e. a cumulative distribution function). "Den" are values from density values and "tt" is from travel time in minutes (accessibility).



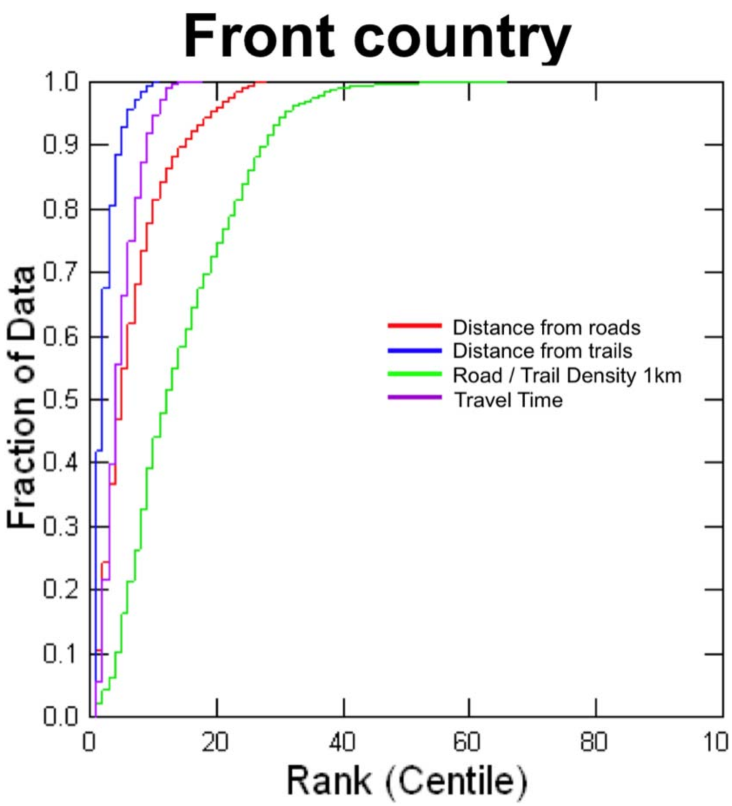


FIGURE 9 A cumulative distribution function comparing different metrics of visitor use within the "front country" management zones within Rocky Mountain National Park. Road/trail density values in particular do not represent the spatial variability of front country areas well. To enable comparison of different units, we normalized the distance, density, and travel time units to a 0 to 100 rank (percentiles).

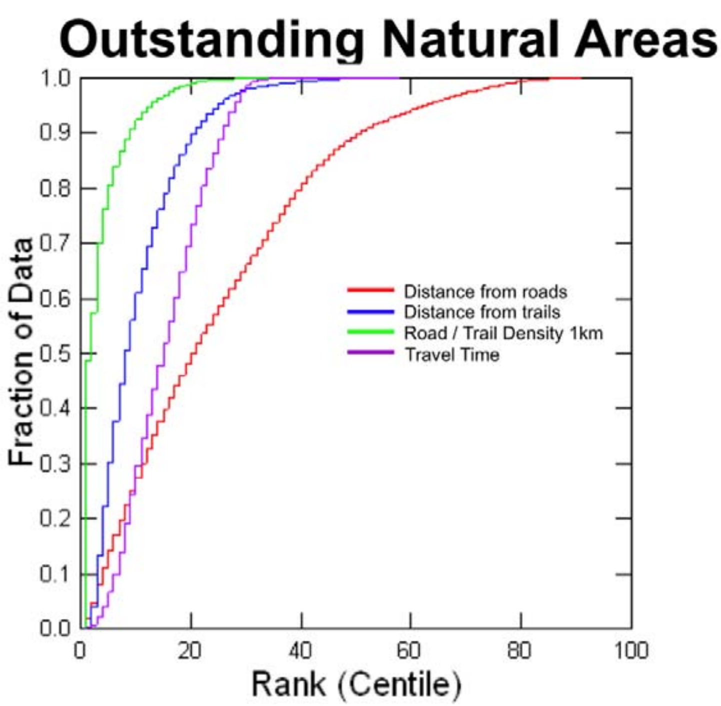


FIGURE 10 A cumulative distribution function comparing different metrics of visitor use within the "outstanding natural areas" (or back-country) management zones within Rocky Mountain National Park. Road/trail density was not able to distinguish much spatial variation in back-country areas because it does not quantify patterns beyond the 1 km radius from road/trail features. Distance from roads underestimates the accessibility to back-country areas because it does not account for trails that provide access to these areas. To enable comparison of different units, we normalized the distance, density, and travel time units to a 0 to 100 rank (percentiles).

DISCUSSION

We developed models of accessibility to understand the spatial distribution of potential visitor use in Rocky Mountain National Park, and illustrated how these patterns of use could be summarized for managers who are interested to understand the resource condition of different areas of the park. We provided a brief illustration of how the accessibility measure can inform an issue of management concern in the park – specifically about pathways for exotic species such as cheat grass, and in particular the relationship between visitor use and distribution (and future spread) of exotic species. We showed that cheat grass occurs in more accessible areas – roughly 80% of plots with cheat grass are within one hour's travel time.

We also placed our work into a decision making framework by examining how levels of accessibility varied for different management zones within the park. That is, as specified in park planning documents, the expectation is that "front country" areas have high levels of visitor use, while "back country" areas (called "outstanding natural areas") should have low levels of use. Travel time shows that there is a mixture of values, showing more variability of impacts due to visitation. Travel time tracks more closely to road distance in the front-country zone, while it tracks more closely to the trail distance for the back-country zone.

A few limitations to our approach should be noted. Most data we used were fine-scale (1:24,000), but the spatial position of the roads in particular (from 1:100,000 scale) should be refined in future efforts. The goal of accessibility modeling is not to estimate the distribution of visitors (e.g., a density map of visitors); rather to estimate how accessible any location in a park is to an average visitor, with the explicit assumption that more accessible areas tend to have more visitor use. A useful next step would be to estimate the number of park visitors moving across the landscape by incorporating destinations/ attractions (e.g., peaks, lakes, waterfalls, etc.), perhaps using recreation choice modeling (e.g., Termansen et al. 2004). This might also include more nuanced aspects of visitor use such as type of use (day/overnight), mode (hike, bike, horse, motorized, etc.), duration, and values orientation to use. Finally, although we have verified accessibility times in the field in an informal way, a rigorous study that develops empirical estimates of travel time for different users, mode of use, and permeability modifiers as a function of different land cover types would make estimates of travel time more precise.

CONCLUSION

Wildlife managers are increasingly concerned about assessing potential effects of visitor use on the natural resources in parks and protected areas. Although some monitoring programs have been developed (e.g., US Forest Service National Visitor Use Monitoring program), there remains a paucity of information about detailed use levels and especially the spatial patterns of use (White et al. 2007). Consequently, developing estimates of visitor use through landscape modeling provides critical information to managers. We described several important refinements to accessibility modeling and illustrated our method for Rocky Mountain National Park. We found that our accessibility model better differentiates front- and back-country use patterns compared to more traditional measures, and demonstrated its utility as a strong explanatory variable to understand important management issues such as monitoring of exotic plant species distribution.

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