Oecologia Australis
17(1): 96-110, Março 2013
http://dx.doi.org/10.4257/oeco.2013.1701.09

MONITORING INTENSITY AND PATTERNS OF OFF-HIGHWAY VEHICLE (OHV) USE IN REMOTE AREAS OF THE WESTERN USA

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ABSTRACT

The continued growth of off-highway vehicle (OHV) activities – demonstrated by the dramatic increase in OHV sales, number of users, and areas experiencing OHV use – has elevated concerns about their ecological effects, the impacts on wildlife, and the sustainability of OHV use on secondary and tertiary road networks. Conflicts between visitors and wildlife are raising concerns about system resiliency and sustainable management. In order to quantify the spatial and temporal impacts of OHV use it is imperative to know about the timing and patterns of vehicle use. This study tested and used multiple vehicle-counter types to study vehicular OHV use patterns and volume throughout a mountainous road network in western Colorado. OHV counts were analyzed by time of day, day of week, season, and year. While daily use peaked within a two to three hour range for all sites, the overall volume of use varied among sites on an annual basis. The data also showed that there are at least two distinct patterns of OHV use: one dominated by a majority of use on weekends, and the other with continuous use throughout the week. This project provided important, but rarely captured, metrics about patterns of OHV use in a remote, mountainous region of Colorado. The techniques described here can provide land managers with a quantitative evaluation of OHV use across the landscape, an essential foundation for travel management planning. They also provide researchers with robust tools to further investigate the impacts of OHV use.
Keywords: Road ecology; rural roads; traffic monitoring; off-highway vehicles; Colorado.

RESUMO

MONITORAMENTO DA INTENSIDADE E PADRÕES DE USO DE VEÍCULOS *OFF-ROAD* (OHV) EM ÁREAS REMOTAS DO OESTE DOS EUA. O crescimento contínuo das atividades com veículos *off-road* (OHV) – demonstrado pelo crescimento dramático das vendas de OHV, do número de usuários e áreas em que ocorre o uso de OHV – tem elevado a preocupação com os seus efeitos ecológicos, com os seus impactos sobre a vida selvagem e a sustentabilidade do uso do OHV nas vias secundárias e terciárias. Os conflitos entre visitantes e a vida selvagem estão levantando preocupações sobre a resiliência do sistema e sua gestão sustentável. Para quantificar os impactos espaciais e temporais de uso de OHV é imperativo conhecer os momentos e padrões de uso do veículo. Este estudo testou e utilizou diversos tipos de contadores de veículo para investigar os padrões e intensidade de uso de OHV em uma rede de estradas em uma região montanhosa no oeste do Colorado. As contagens de OHV foram analisadas por hora do dia, dia da semana, estação e ano. Enquanto o uso diário atingiu o pico dentro de um intervalo de duas a três horas para todos os locais, o volume global de utilização variou entre os locais em todos os anos. Os dados também mostraram que existem, pelo menos, dois padrões distintos de uso de OHV: um dominado pela utilização majoritária em fins-de-semana e o outro pelo uso contínuo ao longo da semana. Este projeto proporcionou importantes, mas raramente coletadas, métricas sobre os padrões de uso de OHV em uma região remota e montanhosa do Colorado. As técnicas descritas aqui podem fornecer aos gestores da terra uma avaliação quantitativa do uso de

OHV em toda a paisagem, uma informação essencial para o planejamento estratégico de deslocamentos. Elas também fornecem aos pesquisadores ferramentas robustas para investigar mais profundamente os impactos da utilização de OHV.
Palavras-chave: Ecologia de estradas; estradas rurais; monitoramento de tráfico; veículos *off-road*; Colorado.

RESUMEN

MONITOREO DE LA INTENSIDAD Y EL PATRÓN DE USO DE VEHÍCULOS TODO TERRENO (OHV) EN ÁREAS REMOTAS DEL OESTE DE LOS EUA. El crecimiento continuo de las atividades con vehículos todo-terreno (OHV) – demostrado por el aumento dramático de las ventas de OHV, número de usuários y áreas en las que se usan OHV – ha elevado la preocupación relativa a sus efectos ecológicos, sus impactos sobre la vida silvestre y la sostenibilidad del uso de OHV en redes viales secundarias y terciarias. Los conflitos entre los visitantes y la vida silvestre están generando preocupación con respecto a la resiliencia del ecosistema y su manejo sostenible. Con el objetivo de cuantificar los impactos espaciales y temporales del uso de OHV es imperativo tener conocimiento sobre los tiempos y patrones de uso de este tipo de vehículos. En este estudio se probaron y emplearon múltiples tipos de contadores de vehículos para estudiar los patrones y volúmenes de uso de OHV en una red vial en las montañas del occidente de Colorado. Los conteos de OHV fueron analizados por hora del día, día de la semana, estación y año. En tanto que el uso diario alcanzó su máximo dentro de un rango de dos a tres horas para todos los sítios, el volumen total de uso varió entre los sitios y anualmente. Los datos también mostraron que hay al menos dos patrones distintos de uso de OHV: uno dominado por un uso mayoritario en los fines de semana y el otro con un uso continuo durante toda la semana. Este proyecto proporcionó métricas importantes, pero raramente capturadas, sobre los patrones de uso de OHV en una región montañosa y remota de Colorado. Las técnicas descritas aqui pueden proporcionar a los tomadores de decisiones una evaluación cuantitativa del uso de OHV a escala paisajísitca, esencial para el establecimiento de planes de manejo para los viajes. También proporciona a los investigadores unas herramientas robustas para investigar en el futuro los impactos del uso de los OHV.
Palabras clave: Ecología de vias; vías rurales; monitoreo del tráfico; vehículos todo-terreno; Colorado.

INTRODUCTION

The ecological effects of extensive road networks on wildlife populations has rapidly gained attention among conservation biologists, with recent research describing the effects of roads on animal behavior and population dynamics (for example, Canaday 1996, Groot Bruinderink & Hazebroek 1996, Mumme *et al*. 2000, Kerley *et al*. 2002, Clevenger *et al*. 2003, Marsh *et al*. 2005, Riley *et al*. 2006). Many animal species are negatively affected by roads and their associated traffic. Roads destroy and dissect otherwise intact areas of land cover, degrading and fragmenting existing habitat, introducing novel conditions and species in road verges. Large areas of contiguous unfragmented habitat are critical for biodiversity conservation and preservation of ecosystem services (Selva *et al.* 2011). Motorized vehicle use contributes to mortality and changes in behavior of wildlife (van Langevelde *et al.* 2009), destruction of native vegetation, and vehicles can act as a vector for the introduction of invasive species (Gelbard & Belnap 2003). Indirect effects of roads include changes to local climate, acoustics, hydrologic and biogeochemical processes (Coffin 2007), that exacerbate effects of roads on ecosystems. Together, the direct and indirect effects of roads and their associated traffic have profound negative effects on the survival and reproductive success of many species. While some species benefit from the presence of road networks, for example, by taking advantage of increased carrion or cleared spaces, the research shows that most wildlife is affected negatively by roads, road clearings and vehicular traffic (Fahrig & Rytwinski 2009). There are a number of research studies that examine the ecological effects of roads, many of which focus on the physical presence of roads or the structure of road networks across the landscape (Forman *et al.* 2003, Ouren *et al.* 2007). However, many effects of roads result from patterns of use, which are not as widely studied, particularly in rural areas. The ecological effects of the motorized use of secondary roads are significant and are quantifiable. Characterizing the spatial and temporal patterns of traffic along these roads is essential for deriving an understanding about the variability and trends in motorized use in these remote rural networks. For managers of landscape resources, this information is fundamental, but rarely available, for decision making, and building sustainable resource management plans.

Many previous studies base their analysis on metrics that describe the static nature of roads including road densities, distance to roads or some variant (for example, Ouren *et al*. 2007). Studies characterizing ecological effects from vehicular traffic tend to be concentrated along major routes, where traffic volume and speed are high (for example, Saeki & Macdonald 2004). Missing from the analysis are investigations that directly address traffic intensity, vehicle type, and their derivatives. We suggest that such measures are viable metrics of human use in remote areas with lower human population densities, where patterns of road density and use are approaching thresholds that can affect some species, such as large carnivores, wide-ranging species, or animals with very specific habitat and life history requirements.

Patterns of variation in traffic volumes are often associated with factors relating to time (season of year, day of week, hour of day), road classification (rural or urban), type of service (commuter travel, recreational travel or agricultural) and type of vehicle, among others (Berry 1965). High seasonal variability is typical of rural roads and is most pronounced in recreational areas (Berry 1965). While few data exist, there is a general assumption that traffic patterns in rural areas follow a bi-modal distribution throughout the day, reflecting people entering the area in the morning and leaving in the evening.

The use of off-highway vehicles (OHVs) in the western United States has greatly increased over the last several decades. As vehicles have evolved to negotiate ever more rugged terrain, 'OHV-ing' has become a popular recreational past-time, especially in remote areas of the West. Its importance as a public land use has grown so much, that OHVs must now be registered in many western states in order to operate on public lands.

Land management agencies in the United States have differing definitions of OHVs. The Colorado Department of Natural Resources (CDNR) defines OHVs to include motorcycles, dirt bikes, three-wheelers, all-terrain vehicles (ATVs), and dune buggies (Colorado State Parks 2012). This study uses the definition previously used by Ouren *et al*. (2007), which substantially broadens CDNR definition by adding "any other civilian vehicles capable of off-highway, terrestrial travel" (p. ix) (for example, sport utility vehicles).

In 2002, we compared four distinct types of vehicle counting technologies to determine which of them were the most effective for monitoring traffic on unpaved roads, in remote locations. The counter types included pneumatic tube, passive magnetic, passive infrared, and seismic counters. Given their relative low cost, familiarity to the public, and the ancillary data provided, we concluded that the pneumatic counters provided the most consistent and robust data sets for our application and study area.

Our goal was to identify and characterize patterns of OHV use in a study area where no data exists. We were interested in understanding the daily, seasonal and annual patterns of motorized use in this area, relating these patterns to types of vehicles driven and the relative location of observation points within the road network. We had an *a priori* expectation of a bi-modal daily traffic pattern (peaking in the morning and evening), typical of non-urban areas.

METHODS

STUDY AREA

This study was conducted in Western Colorado, USA. The entire area covers approximately half a million hectares and is managed by various federal, state and private land owners including the U.S. National Park Service (NPS), Bureau of Land Management (BLM), and the U.S. Forest Service (USFS; Figure 1). This area includes the BLM's Gunnison Gorge National Conservation Area, which is a popular year-round recreation destination for OHV use, hiking, fly-fishing, camping, horseback riding, hunting, cross-country skiing, mountain biking and snowmobiling. It is also home to a scattering of seasonal and year-round residents, and provides resources for logging and livestock grazing. This diverse, and sometimes conflicting, mix of human activities and wildlife needs typifies many areas throughout western Colorado and the western U.S., making it ideal for the purposes of our study. Decisions about the study area selection and the monitoring strategy were based on the expert advice of a group of natural resource and wildlife managers convened by us for this purpose. With their assistance, we identified the overall study area, and monitoring sites for the placement of the monitoring devices, which would capture most of the OHV traffic in the area. The study road network was chosen for its importance in providing motorized access to the area of interest. Here, the network is characterized by a dendritic pattern, and monitoring sites were located at each junction in the network.

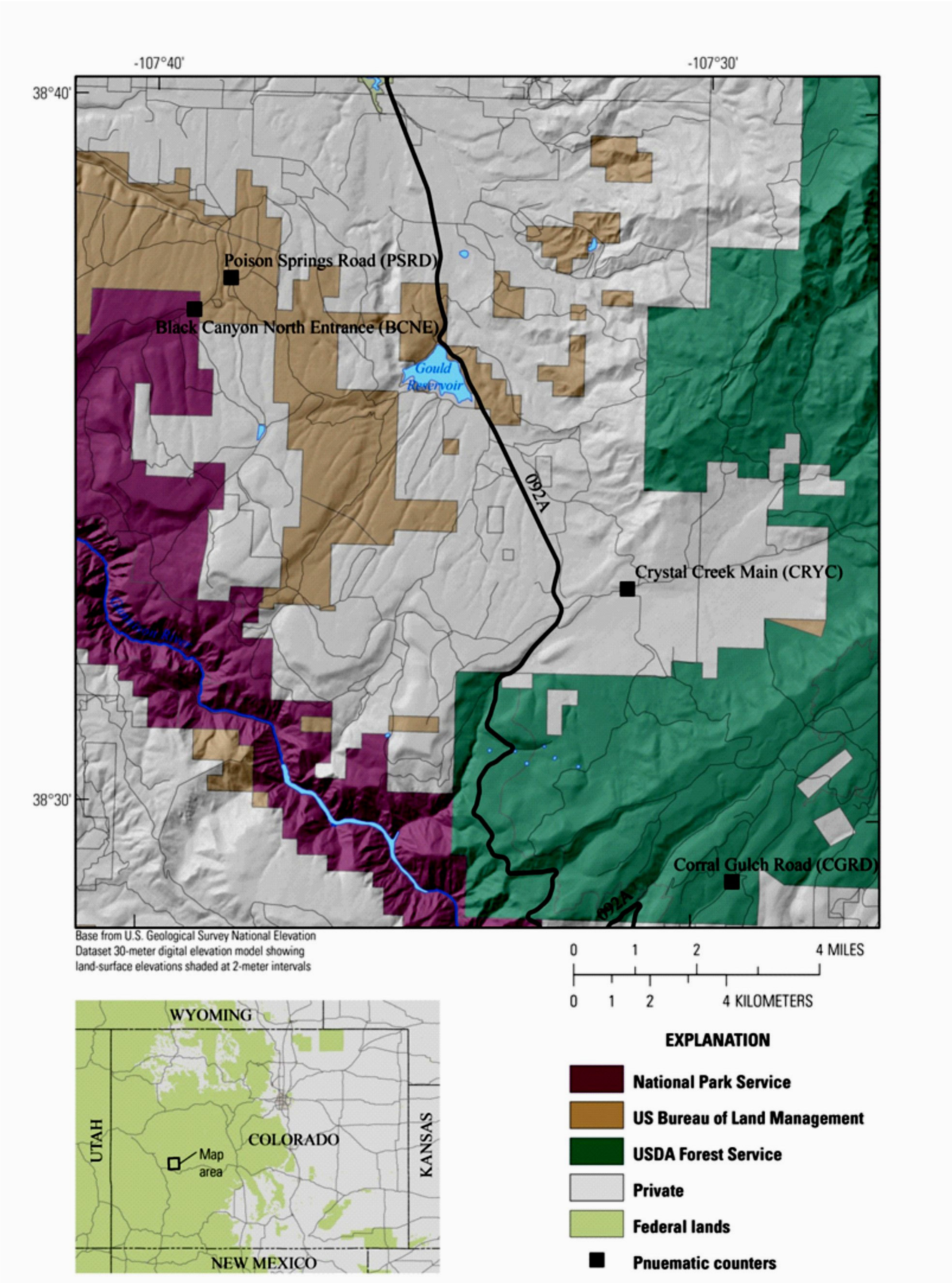

Figure 1. Map showing the study area and locations of pneumatic counters.

There are approximately 1,460km of roads in the study area. Of that, about 117km (8%) are paved, including highways, county roads and urban areas; 1,220km (84%) are rural roads; 97km (7%) are private access routes; and <2% are road accessible only by vehicles with four wheel drive. Excluding private and paved roads, 85% of the roads in the study area provide access to OHVs.

Study area elevation ranges from 2,130m to 3,920m above mean sea level. Vegetation in the study area transitions from saltbush (*Atriplex* spp.) and greasewood (*Sarcobatus vermiculatus*) dominated zones at lower elevations, to alpine tundra meadows at higher elevations, including Subalpine fur (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), quaking aspen (*Populus tremuloides*), lodgepole pine (*Pinus contorta*), Douglas fir (*Pseudotsuga menziesii*), and bristlecone pine (*Pinus aristata*). This vegetative mosaic provides ideal habitat for several species of wildlife. Notable wildlife species in the area include elk (*Cervus elaphus)*, mule deer (*Odocoileus hemionus*), black bear (*Ursus americanus*), mountain lion (*Felis concolor*), Gunnison sage grouse (*Centrocercus minimus),* and Northern goshawk (*Accipter gentilis*).

DATA COLLECTION

Within the study area, four monitoring sites were selected for the location of pneumatic traffic counters. The four sites were similar with respect to the type of roads they were monitoring, all being secondary roads. Here, we define secondary roads as roads that are differentiated from primary roads by their overall use to access the landscape, as opposed to routes designed to connect major population centers. A major difference in the designation of these road types has to do with the societal importance afforded by road access. Primary roads support populations which are orders of magnitude greater in size than populations sustained by secondary roads.

At each of the monitoring sites the roads are ~12m wide, have an improved gravel surface, are crowned for drainage purposes, and receive some maintenance. However, the monitoring sites differ in relation to the land management and use activities permitted in the areas accessed by each particular road. The Black Canyon North Entrance (BCNE) monitoring site is 16km from the nearest population center, measured access to the northern portion of the Black Canyon of the Gunnison National Park. By NPS mandate, this National Park does not allow for extractive uses, such as hunting, firewood gathering, or other similar activities. The Corral Gulch (GGRD) monitoring site is 40km from the nearest population center, and the Crystal Creek (CRYC) monitoring site is 21km from the nearest population center. These two sites measured access to lands managed by the USFS, BLM, and private inholdings. In contrast to the National Park, these areas do permit extractive uses, according to their respective multiple use management plans and private management objectives. The Poison Springs road (PSRD) monitoring site is 17km from the nearest population center, and measured access to several ranches and other private inholdings, along with significant areas managed by the BLM under a multiple use management plan. The majority of land use at this site is agricultural and related to fall season activities (for example, hunting).

The pneumatic tube counters consist of hollow rubber tubes anchored in place across the lanes to be monitored and connected to a battery-powered electronic monitoring device (Figure 2). The tubes detect vehicles by sensing changes in air pressure generated when a vehicle tire passes over the tube. The change in pressure is recorded as a vehicle axle count. Device software converts the axle counts to vehicle counts, and reports speed and vehicle classification.

The counters were placed in the field upon visiting the site and, with first-hand observation of the road conditions, placed at points in the road close to the desired monitoring site, but where the road alignment was straight, and adjacent area was relatively flat and dry. Trees, signs, or fence posts near the roads were used to secure the data storage devices.

Data were downloaded every 2 to 3 months to avoid exceeding the memory limits of the counters and to adequately monitor and maintain counter operations. During each maintenance visit, notations were made regarding whether it was full or recording, and any conditions that may have affected the quality of the data. Some years the pneumatic tubes were damaged by snow-clearing plows and needed replacement.

Traffic counts were observed during the boreal summer and fall seasons from 2005 through 2008. The length of the field season varied by counter and depended on the ability of vehicles to access the site. The beginning dates were limited by the spring thaw, making the roads passable, while ending dates were limited by first (impassable) snow accumulations. Table 1 gives the total dates of operation for the counters.

Figure 2. Images of a pneumatic counter, clockwise from top left: author installing pneumatic tube on the road surface; battery-powered electronic monitoring device; parallel pneumatic tubes across the road; typical view of a pneumatic counter across a road in the study area.

Table 1. Field observation dates for traffic counters from 2005-2008 (DOY = day of the year; CGRD = Corral Gulch Road; PSRD = Poison Springs Road; CRYC = Crystal Creek Main; BCNE = Black Canyon North Entrance).

Monitoring site	Year	Begin date (Calendar/DOY)	End date (Calendar/DOY)	Total days of operation
CGRD	2005	28 June / 179	14 November / 318	140
	2006	7 June / 158	24 November / 328	171
	2007	5 June / 156	17 November / 321	166
	2008	1 July / 182	23 November / 327	146
PSRD	2005	18 May / 138	30 November / 334	197
	2006	8 June / 159	18 December /352	194
	2007	6 June /157	8 December / 342	186
	2008	30 April /120	25 November /329	210
CRYC	2005	17 May / 137	15 November / 319	183
	2006	7 June / 158	29 November / 333	176
	2007	4 May / 124	5 December / 339	216
	2008	29 April / 119	24 November / 328	210
BCNE	2005	30 June / 181	29 November / 333	153
	2006	8 June / 159	5 December / 339	181
	2007	6 June / 157	17 November / 321	165
	2008	2 July / 183	25 November / 329	147

To standardize the observations for analysis, we selected a subset of the annual observation period when data were available from all sites in 2005-2008. This standardized subset comprised the traffic counts from all four pneumatic counters for 136 days each year, beginning with 3 July (184th day of the year, DOY) and ending with 15 November (319DOY). These dates also correspond to the summer months and fall season, when recreational OHV use for the area is at its highest for the year. Fall season in this area begins on the fourth weekend in August. For this study, we used 25 August (237DOY) as the nominal beginning of fall season. We partitioned the data into summer observations, 3 July to 24 August (53 days), and fall season, 25 August to 15 November (83 days).

DATA ANALYSIS

Vehicle counter data were checked for data abnormalities. A script in R statistical software (http://www.r-project.org/) was written to check for any data abnormalities. These included ghost counts which were counts that occurred at the exact same date and time, single hose counts which were indicative of a damaged, submerged, or frozen hose, or a count from domestic livestock or wildlife. All abnormalities were removed before data analysis.

To analyze the OHV traffic count data, we carried out a number of simple summary calculations, which we compared using basic graphing techniques to observe overall variability and changes. While the data were consistently grouped according to monitoring site, we further differentiated the data according to season, day of the week and time of day to compare traffic patterns. These simple comparisons allowed us to characterize OHV traffic in the study area, and form a fundamental picture about how traffic was flowing through the road network and how it was changing over time.

The OHV traffic counts were differentiated by location, and then summarized by year, season, day of the week and hour of the day, by monitoring site. To account for differences in lengths of the seasons, seasonal patterns were analyzed using mean values and standard deviations to characterize daily and hourly traffic. We compared OHV traffic patterns by season, day of the week and hour of the day.

To compare seasonal changes in patterns of use throughout the day, we differentiated hourly traffic counts into summer and fall seasons for each of the four counters, giving eight groups. The values within each group were rescaled, normalized, to a value between 0 and 1, using the following equation:

$$c_{t,0\ to\ 1} = \frac{c_t - C_{min}}{C_{max} - C_{min}}.$$

where, C represents an hourly traffic count value within a group, c_t is the hourly count at time = t; C_{min} is the minimum hourly count within the group, and C_{max} is the maximum hourly count within the group.

Values were then plotted to compare relative seasonal traffic patterns by the time of day. Normalization of these values permitted the comparison of average hourly traffic flows between seasons.

We assessed variability in OHV traffic patterns by calculating the standard deviation for mean daily traffic patterns, by monitoring site and by season. We analyzed trends in the traffic by calculating percent change for several groupings of the data: annual and overall changes to total OHV counts by monitoring site; seasonal changes in mean daily and hourly traffic counts; and daily changes in mean traffic counts by day of the week. The percent change was calculated by dividing the difference between the new and old values by the old value.

RESULTS

Traffic counts for each monitoring site generally increased from 2005 to 2008 in the fall and summer seasons (Figure 3). Traffic counts ranged from 2,931 vehicles at CGRD in 2005, to 11,114 at BCNE in 2007. The relative volume of traffic among monitoring sites, was consistent among years with the monitoring site ranks (by traffic volume) staying constant throughout the study period. Of all monitoring sites, BCNE had the highest overall volumes of OHV traffic, where CGRD had the lowest. Mean daily use also exhibited this consistent difference between monitoring sites (Table 2). While BCNE and CGRD recorded declines in some years, all of the counters had higher volumes by the end of the study period.

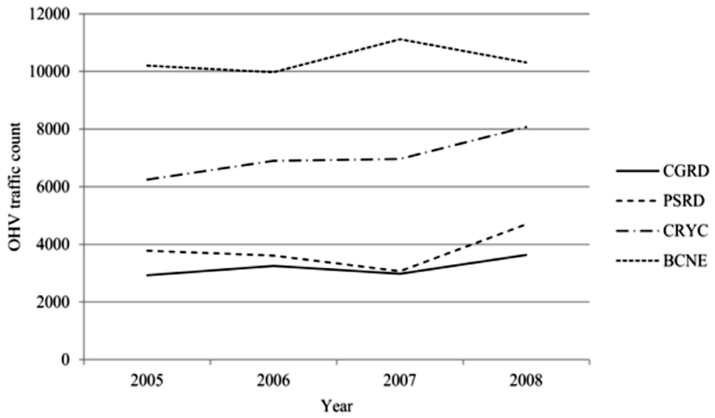

Figure 3. OHV traffic count by year for each monitoring site

Traffic volumes differed according to season for all of the four monitoring sites (Table 2). The highest mean daily values occurred at BCNE during the summer, at ~104 vehicles per day (v/d), while PSRD recorded the lowest mean daily values, at ~14v/d. This resulted in a slight shift in the rank of monitoring sites by traffic volumes, where CGRD ranked higher than PSRD during summer seasons. In the fall season, the relative increase in traffic at PSRD outpaced the increase at CGRD, causing PSRD to rank higher than CGRD.

Table 2. Mean and standard deviation of daily OHV traffic counts for 2005-2008, by season; and percent change in the mean, for each monitoring site (maximum and minimum values in bold).

Monitoring Site	Entire period		Summer season		Fall season		% change mean (F-S/S)
	Mean	*Std. dev.*	Mean	*Std. dev.*	Mean	*Std. dev.*	
BCNE	77.89	*38.53*	**103.63**	*25.78*	60.96	***36.09***	-41.18
CGRD	24.13	*15.12*	18.46	*11.10*	27.92	*16.24*	51.26
CRYC	51.79	*28.29*	45.98	*24.32*	55.51	*30.00*	20.71
PSRD	27.95	*22.17*	**14.30**	***8.00***	36.59	*23.86*	155.94

Mean daily use ranged from a minimum of 19.81v/d at CGRD on Tuesday, to a maximum of 97.28v/d at BCNE. The rank of locations by relative volumes mimicked broader seasonal and annual patterns, with BCNE experiencing the highest volumes and CGRD the lowest, throughout the week (Figure 4). Most of the sites experienced the highest volumes of traffic on the weekends (Saturday-Sunday), and lowest during mid-week (Tuesday-Wednesday).

Mean hourly traffic ranged from 1 vehicle per hour (v/h) to 701v/h. Volume patterns were consistent from one site to the next, with traffic peaking between 1400 and 1700 across the network. Likewise, minimum mean hourly traffic was in the early morning hours of 0300 to 0500. BCNE experienced the greatest mean hourly traffic during peak flows (Figure 5), while PSRD and CGRD were similar in rank as the lowest volumes during peak flows. PSRD experienced a local peak in traffic from 0700-0800, which was unique to its location, making it the highest trafficked road during that hour.

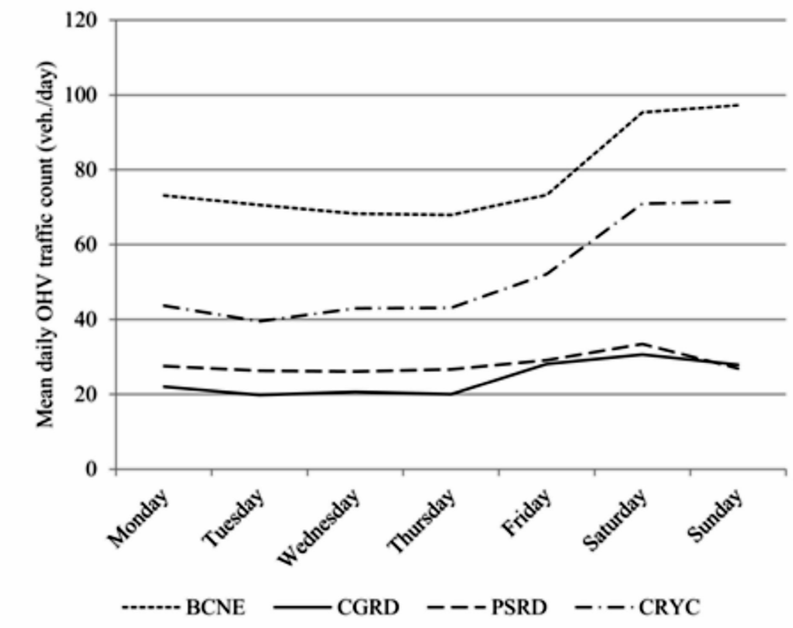

Figure 4. Mean daily OHV traffic count by day of the week for each monitoring site in 2005-2008.

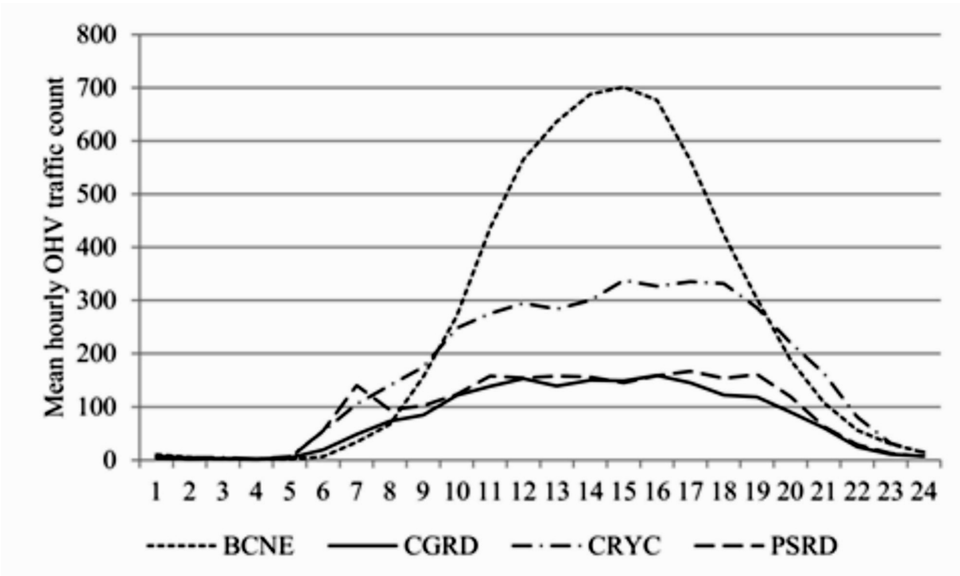

Figure 5. Mean hourly OHV traffic count for 2005-2008, by hour of the day for each monitoring site.

We examined patterns in OHV traffic in the study area by considering variability, and change over time. We examined differences in seasonal, daily and hourly patterns, and how these patterns changed on an annual and seasonal basis.

Variability was measured by calculating the standard deviation of daily traffic counts by season (Table 2) and day of the week (Figure 6). Patterns in variability tended to follow patterns in traffic volume. That is, higher variability was noted where there were higher traffic counts. Seasonal variability ranged from a minimum standard deviation of 8v/d in the summer at PSRD, to a maximum of ~36v/d in the fall season at BCNE. As traffic volume increased in the fall, variability in daily traffic counts also increased. While at BCNE, traffic volumes decreased in the fall, there was nevertheless a higher level of variability in mean daily use than in the summer season. Likewise, higher trafficked roads were more variable on a day-to-day basis. Daily variability ranged from a minimum standard deviation of ~12v/d on Tuesdays at CGRD, to a maximum of ~46v/d on Sundays at BCNE.

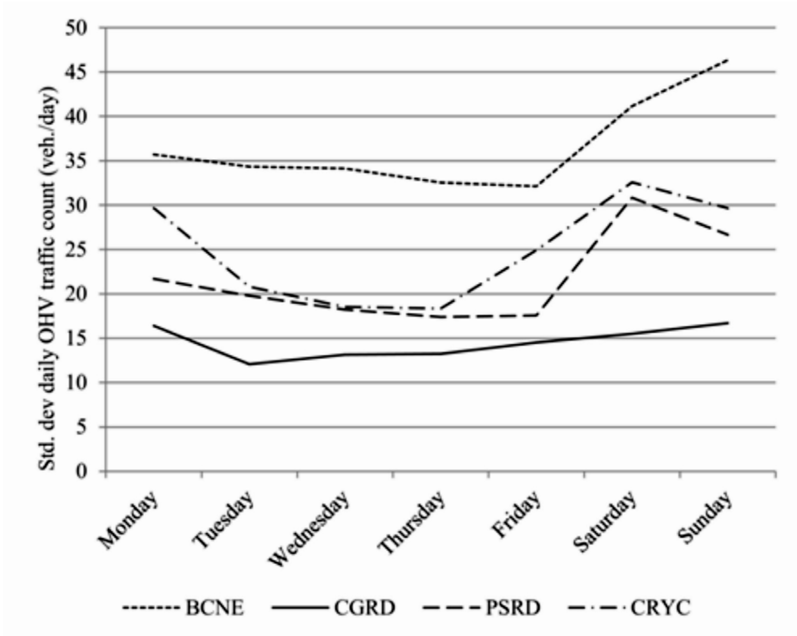

Figure 6. Standard deviation of mean daily OHV traffic counts by day of the week, for each monitoring site.

Normalized traffic counts re-scaled the data to a range of 0 to 1 (Figure 7). The normalized counts show that hourly traffic flowed in similar patterns in both summer and fall seasons. While overall volumes changed, the patterns of traffic use were nearly identical in BCNE from one season to the next. Both CGRD and PSRD showed some differences between summer and fall hourly patterns. In the fall season, traffic flows peaked earlier in the day and stayed higher until later in the day.

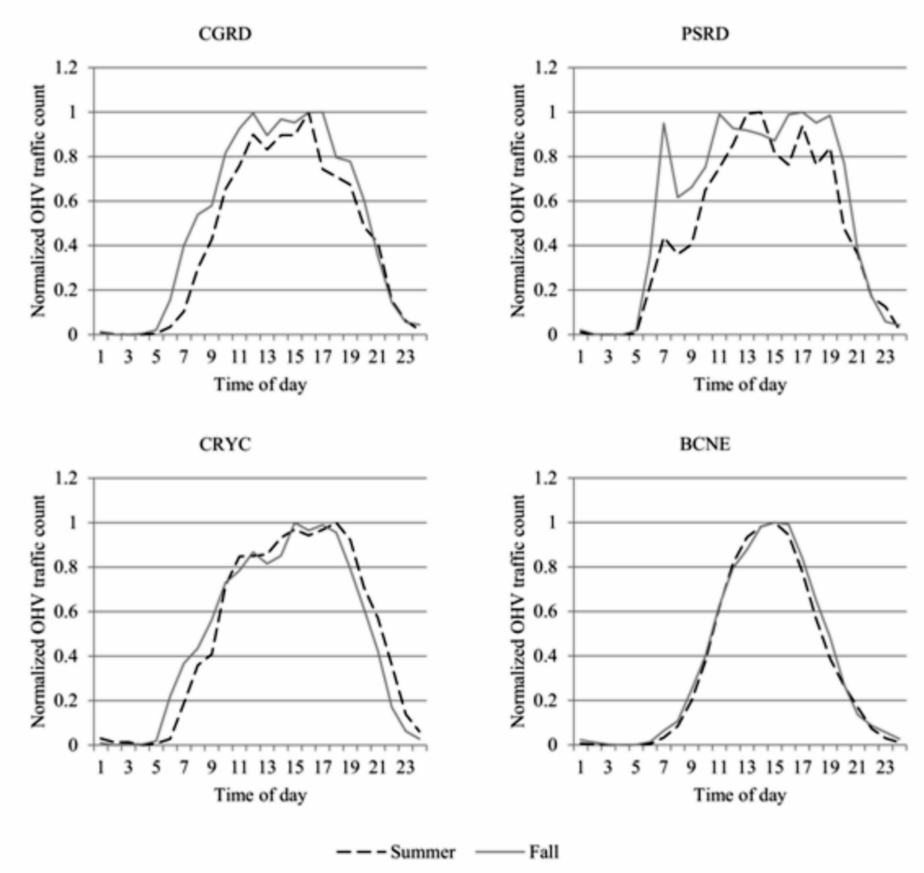

Figure 7. Normalized OHV traffic counts by hour of the day and season for each monitoring site.

While traffic counts at all counters increased during the 2005-2008 study period, the change was not uniform or consistent (Table 3, Figure 3). Of all the counters, CRYC had the highest mean annual increase (8.06%), with increased traffic flow during each of the three time intervals.

Table 3. Percent change in OHV traffic count by monitoring site for each time interval, including mean annual change for 2005-2008.

Date interval	Monitoring site (%)			
	CGRD	PSRD	CRYC	BCNE
2005-06	9.90	-4.82	9.55	-2.32
2006-07	-9.27	-17.68	0.85	10.28
2007-08	17.99	34.67	13.79	-7.80
Mean 2005-08	6.21	4.06	8.06	0.06

The change in mean daily traffic from one season to the next for each of the four monitoring sites is shown in Table 2. Of the four sites, BCNE showed the only decrease in mean daily traffic from summer to fall seasons, while PSRD increased the most (155.94%). The detailed day-of-week patterns of these changes provide more information as to the timing of the seasonal changes (Figure 8). For BCNE, CGRD and CRYC, the greatest changes occurred during mid-week periods, as opposed to weekends for PSRD. Detailed hourly use patterns also showed differences between seasons at all four monitoring sites (Figure 9). BCNE was the only site where traffic decreased during the middle of the day. While traffic at the other three sites increased during mid-day, the greatest changes from summer to fall seasons occurred between 0500 and 0700.

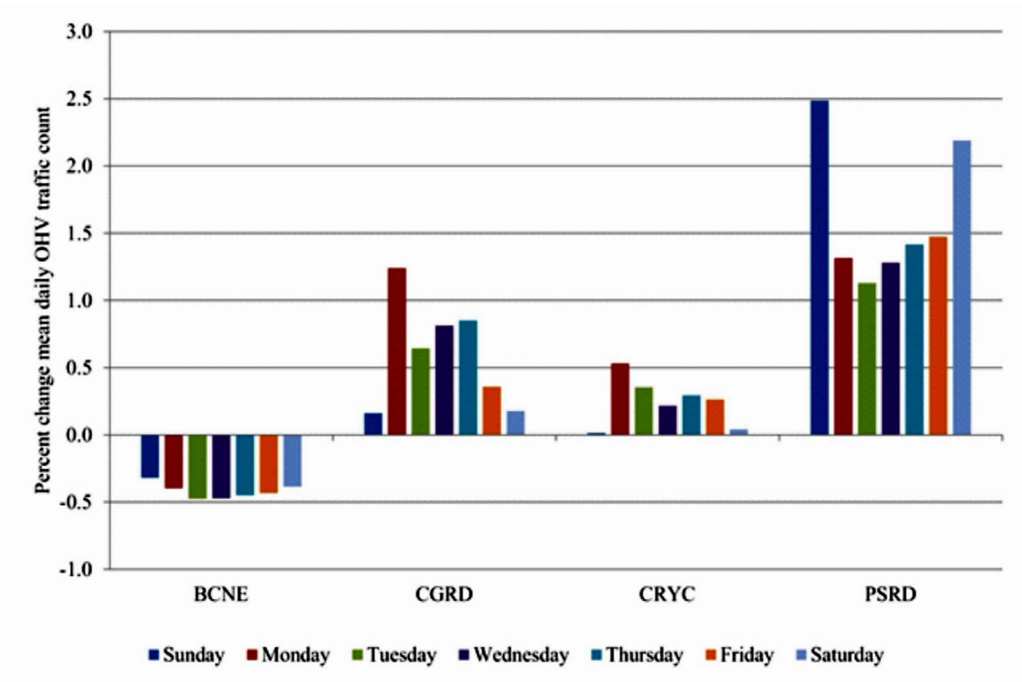

Figure 8. Percent change in mean daily OHV traffic count from summer to fall seasons, by monitoring site, for each day of the week.

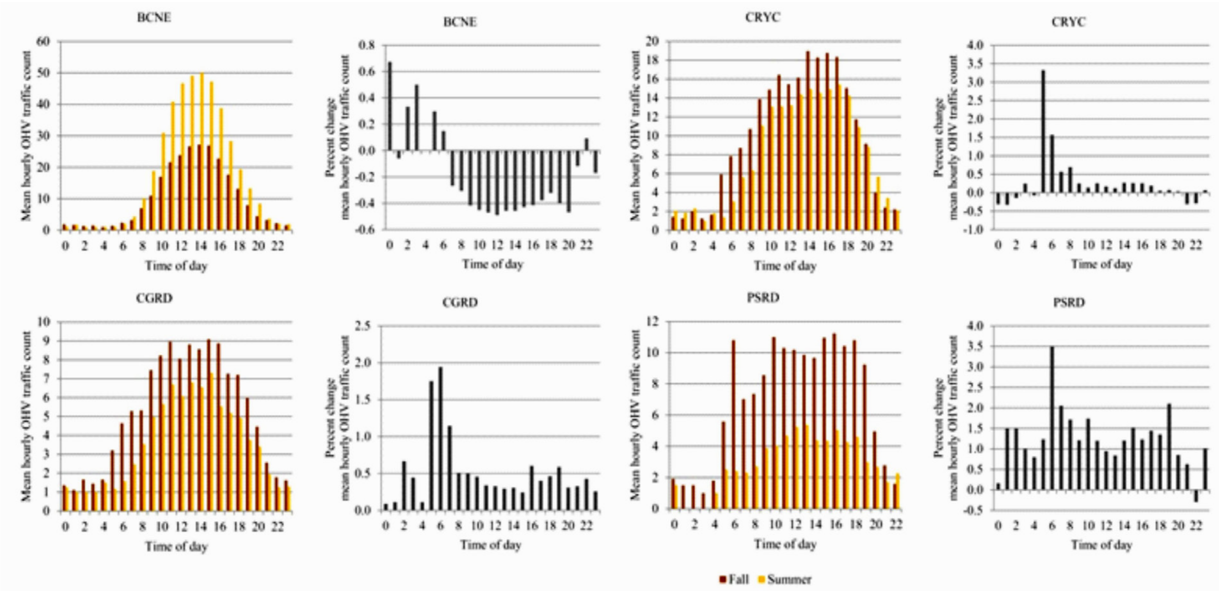

Figure 9. Comparison of traffic counts for summer and fall seasons for each monitoring site: left side – mean hourly OHV traffic by time of day for fall and summer seasons at each location; right side – percent change in mean hourly OHV traffic count by time of day from summer to fall seasons.

From 2005 to 2008, daily patterns of traffic increased, for the most part (Figure 10). The greatest increases occurred during the middle of the week, with the exception of BCNE, where daily traffic increased only on Friday and Saturday, and actually decreased during all other days of the week. The greatest mean annual change (increase) occurred at CGRD on Tuesdays (18.79%).

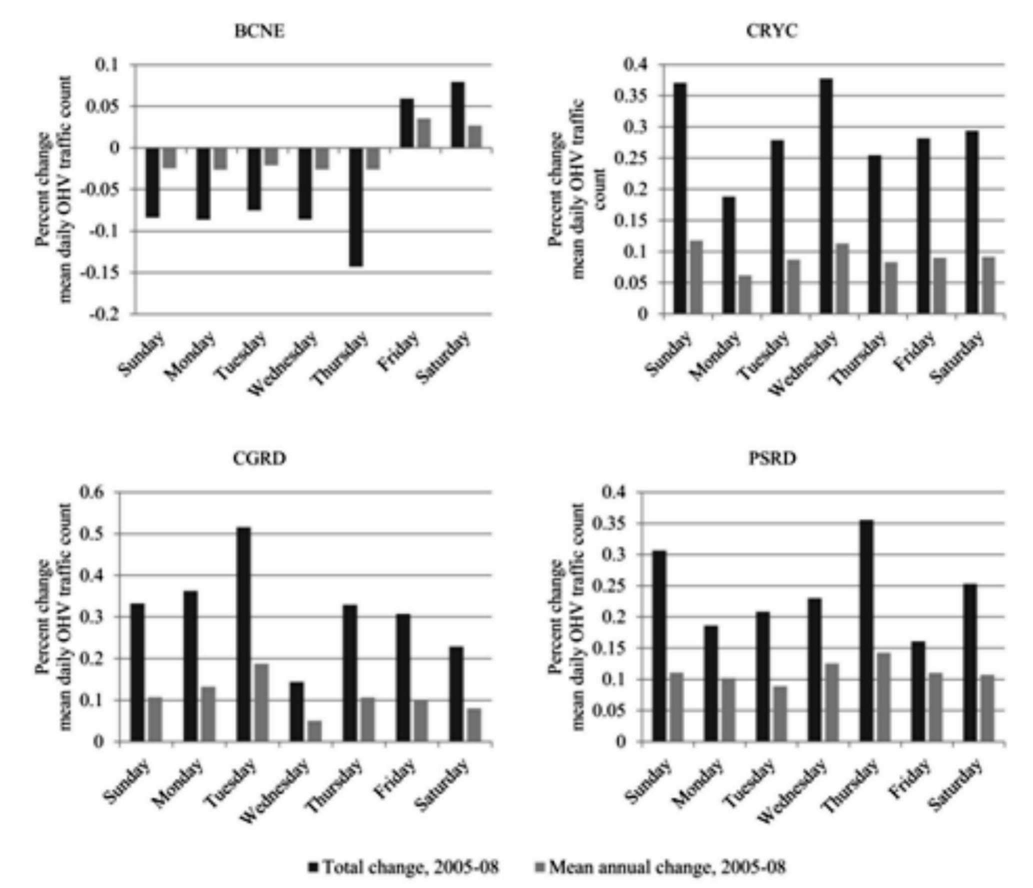

Figure 10. Trends in OHV counts at each monitoring site, by day of the week for 2005-2008.

DISCUSSION

We observed some important differences in traffic patterns between summer and fall seasons at all of the monitoring sites. Most showed higher mean daily use in the fall season. Hunting is a popular sport in the area, but it is strictly regulated by date to occur during the fall, and not the summer season. Our field experience has shown higher traffic observed during fall season can be attributed to seasonal activities such as hunting, fishing, fall foliage observation, and firewood collection. We also noted that traffic increased in early morning hours in the fall, when people were most likely traveling into these areas for hunting activities. The higher values at BCNE during the summer season are due to National Park visitation.

We found that most sites recorded higher traffic volumes on weekends, as opposed to mid-week periods. The higher traffic on weekends is likely attributable to people accessing the areas for recreational uses – the sites with the highest weekend uses are notable recreational destinations. This was particularly true for monitoring sites that provided access to public lands. By contrast, a relatively uniform weekly traffic pattern was noted at the monitoring site (PSRD) most associated with private land ownership, where agricultural land uses, such as cattle ranching, predominate (Figure 1).

Daily use at all of the monitors followed a normal distribution pattern, peaking within a two to three hour range for all sites (1400-1700), while minimum traffic volumes occurred in the early hours of the morning (0200-0400). This contrasted with our *a priori* view that there must be a bi-modal distribution of traffic in this area, with morning and evening peaks reflecting typical daily travel patterns associated with settled areas.

Patterns of variability generally followed patterns of use, where high traffic roads experienced the highest levels of variability in traffic. The overall volume of use varied by site on an annual basis with greater volumes and greater variability in traffic occurring nearest population centers and popular tourist destinations, such as Black Canyon of the Gunnison National Park.

While weather is certainly a constraint in the use of rural, unpaved roads, and can affect the timing and intensity of traffic flows, the drivers of change and variability in OHV use are broadly related to social and economic factors. Assessments of these factors were beyond the scope of this study. However, we hypothesize that factors impacting the feasibility or popularity of OHV use are important. These might include: the condition of secondary roads, an increasing desire to vacation close to home, changes in gasoline prices, the popular appeal of back-country visitation or activities, or the need for resources readily available in rural areas (for example, game meat or firewood).

The patterns of daily variation in traffic throughout the week suggest to us a potential area for further research. As Berry (1965) noted, seasonal traffic variability was related to nearby recreational land uses. We suspect that the weekly traffic patterns we observed were also related to nearby land uses. If so, then we expect to find a generalized set of relationships between land use and weekly traffic patterns. In areas where the land use is primarily recreational (for example, hunting on public lands), we expect traffic patterns on access roads to reflect periodic peaks and troughs throughout the week, corresponding to the travel demand patterns of recreationists. On the other hand, in areas where the land use is part of a 'working landscape,' or an area of continuous resource use, as is the case in areas where agricultural uses are significant, we expect to find more uniform traffic patterns consistent with the travel demands of those resource users.

The importance of site selection should not be overlooked in the design of traffic monitoring studies. We found that site selection is very important to the design of rural traffic studies, particularly when measuring the responses of flora and fauna to traffic in rural areas. We suggest that the land management context of the monitoring sites will be an important driver of certain ecological responses, for example, the behavior of hunted species, to road traffic. We speculate that, for many wildlife species, the avoidance of roads is not solely a function of the volume of traffic, but is also related to the access afforded to people by the road, and their intended activities. In areas, for example, where hunting is prohibited, elk have been observed to respond very differently to road traffic, than in similar areas where hunting is allowed (Stankowich 2008). The dispersal of people from vehicles into the landscape is also a key consideration, as wildlife have been observed to respond very differently to human presence, depending on whether people are walking, riding or driving (Wisdom *et al.* 2004). A point for further research is, therefore, to understand the relationship between traffic volume and the dispersal of people into the landscape.

Other areas for further research include identifying traffic thresholds for keystone species in remote rural areas. According to Forman & Alexander (1998), large carnivores tend to disappear from the landscape when road densities approach .6 km/km^2, but this rule of thumb does not address the dynamic nature of road traffic, which can vary substantially according to season, day of the week and time of day.

Secondary roads in remote areas provide critical access to the network of services in support of rural communities; on the other hand, the traffic is not unimportant and can have significant ecological effects on the local flora and fauna. Understanding patterns of traffic intensity and location can help managers to identify hot spots of potential conflict between wildlife and OHV users, and adjust traffic management plans accordingly. OHV use data can be used to model effects on a variety of species habitat use and movements. For example, these data could be used to justify the seasonal closure of roads that affect sensitive species during critical times of the year. The techniques described in this paper can provide land managers with robust methods for the quantitative evaluation of off-highway traffic in remote areas. With the technology available today it is neither cost prohibitive nor an over taxing load on the work force to collect motorized vehicle use data for a significant proportion of a road network.

DISCLAIMER: Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

ACKNOWLEDGEMENTS: We would like to thank each of the collaborating agencies involved in this project including, Bureau of Land Management, National Forest Service, National Park Service and Colorado Parks and Wildlife. The authors would also like to thank the following individuals who without their help this project would not have been possible, including Melissa Siders, Karen Tucker, Dennis Garrison, Doug Homan, Brandon Diamond, Kyle Banks, Theresa Childers and Ray Watts. We also thank the Information Science's Group at Fort Collins Science Center, including Robert Waltermire, Tammy Fancher, Colin Talbert and Steve Garman, and several anonymous reviewers for improving earlier drafts of this manuscript.

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Submetido em 17/07/2012
Aceito em 19/12/2012