Biological Conservation 144 (2011) 2666–2673

Contents lists available at SciVerse ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Efficacy of road removal for restoring wildlife habitat: Black bear in the Northern Rocky Mountains, USA

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ARTICLE INFO

Article history:
Received 2 December 2010
Received in revised form 15 July 2011
Accepted 18 July 2011
Available online 23 August 2011

Keywords:
Black bear
Ursus americanus
Road removal
Road decommissioning
Road closure
Habitat restoration

ABSTRACT

Forest roads reduce habitat quality for wildlife, in part by increasing susceptibility to hunting and poaching. Road removal is an increasingly common strategy for restoring habitat; however, little is known about responses of wildlife to road removal versus other methods of road closure. We assessed effects of different types of road closure (gated, barriered, and recontoured) on black bear (*Ursus americanus*) frequency and habitat on 18 open and closed road pairs in the western USA. Over 4 years, 44 bears were photographed during 3545 camera-trap days. Bear frequency was significantly higher (2.4 versus 0.6/100 days, respectively) and human frequency was significantly lower (2.4 versus 361.6/100 days, respectively) on closed than on open roads. Additionally, abundance of fall foods was higher (23.9% and 12.8%, respectively) and line-of-sight (a measure of habitat security) shorter (54.9 versus 69.4 m, respectively) on closed compared to open roads. Bears were detected on closed but not on open roads during daytime, suggesting avoidance of humans. Among-road-treatment differences included significantly higher frequency of bears on recontoured than on gated or barriered roads (4.6, 1.6, and 0.5/100 days, respectively), and significantly higher cover of fall bear foods on recontoured than on gated or barriered roads (39.3%, 12.1% and 16.4%, respectively). Frequency of bears was negatively correlated with frequency of humans and line-of-sight distance and positively correlated with abundance of fall foods and hiding cover. Results suggest that while all types of road closure benefit sensitive wildlife, removal by recontour may be the most effective strategy for restoring habitat.

1. Introduction

Roads are a leading cause for global biodiversity loss (Fahrig and Rytwinski, 2009; Benítez-López et al., 2010), and their closure and removal is often the first step to restoring ecosystem function and resilience (Robinson et al., 2010). The negative impacts of roads on wildlife are persistent and include fragmentation, disturbance, and loss of habitat amongst others (Trombulak and Frissell, 2000; Coffin, 2007; Fahrig and Rytwinski, 2009; Benítez-López et al., 2010; Robinson et al., 2010). Bears, in particular, are highly sensitive to roads, which are a key contributor to their decline worldwide (e.g., Clevenger et al., 1997; Wong et al., 2004; Liu et al., 2009); globally, bears have been eliminated from more than half of their historic ranges, and six of eight species are experiencing significant population declines due to human persecution and habitat loss (IUCN, 2011).

In North America, where most investigations of the effect of roads on bears has been conducted, both black (*Ursus americanus*) and grizzly (*Ursus arctos horribilis*) bears have been found to become nocturnal or entirely avoid open roads in response to increased hunting pressure or disturbance (e.g., McLellan and Shackleton, 1988; Brody and Pelton, 1989; Powell et al., 1996; Mace et al., 1996). Studies have also found that bears resume using roads when they are closed (Miller, 1975; Brody and Pelton, 1989; Mace et al., 1996; Gibeau et al., 2002; Wielgus et al., 2002; Kasworm and Manley, 1990). Land managers are attempting to mitigate the negative impacts of roads on bears and other wildlife by closing them with gates or barriers, or removing them entirely by ripping the roadbed, removing culverts, and/or fully recontouring the roadbed to restore hillslope hydrology, ecosystem processes, and fish and wildlife habitat (Switalski et al., 2004). Although wildlife habitat security in general, and bear habitat security in particular, is an increasingly important objective of road removal (Powell et al., 1996; Nielsen et al., 2006, 2008; Roever et al., 2008a,b), to date there has been no study of the response of any wildlife species to road removal compared to other methods of road closure.

There are several different methods of road closure and removal, and each has different effects on bear habitat quality. Whether the road is simply closed or fully recontoured to a natural state can influence the degree of hunter access, availability of hid-

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doi:10.1016/j.biocon.2011.07.026

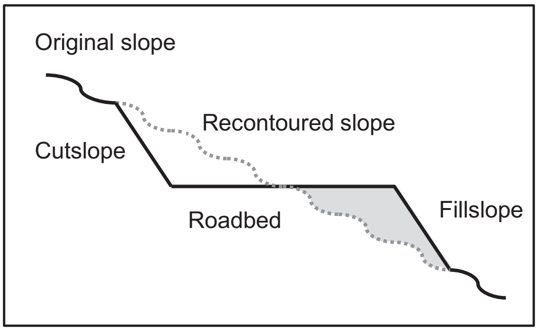

Fig. 1. Cross section of a typical road (including cutslope, fillslope, and roadbed), and slope after recontour (gray dotted line).

ing cover, and presence of food. While abandoning old forest roads or closing them with gates and barriers is common around the world (e.g., Guariguata and Dupuy, 1997; Zang and Ding, 2009), active removal of roads through full recontour is primarily occurring in North America (e.g., Madej, 2001; Switalski et al., 2004; McCaffery et al., 2007), although there are examples from Africa (Burke and Cloete, 2004) and Europe (Dolan and Whelan, 2007; Tarvainen et al., 2008).

Closing roads with gates can limit motorized access to hunters and poachers; however, gated roads allow non-motorized travel (e.g., foot and horse) and, although closed to public traffic, receive management-related and occasional illegal motorized use. In comparison, barriers block most motorized access (except illegal off-road vehicle use), thereby more effectively preventing human use. In addition, barriers also allow for some regrowth of vegetation on the former roadbed, potentially increasing two critical habitat factors for bears: hiding cover (Young and Beecham, 1986; McLellan and Shackleton, 1989) and food availability (Lyons et al., 2003; Vander Heyden and Meslow, 1999). Fully recontoured roads block all motorized access and entirely eliminate the roadbed by re-establishing the original hillslopes (Fig. 1). In addition, after roads are recontoured, early-seral vegetation in general, and fruiting shrubs in particular may increase either through colonization from the soil seedbank, planting of seed or salvaged material as part of road removal treatments, or vegetation spread from areas adjacent to the former roadbed (Grant et al., 2011). Thus, over time vegetation establishment and growth may be substantially higher on fully recontoured roads than on roads closed by other methods, leading to the greatest gains not only in protection from humans but also in hiding cover and food resources. For these reasons, we hypothesized that black bears would use recontoured roads more than those closed by other methods. We further hypothesized that time of day of bear use of roads would vary by road closure treatment, with only nocturnal use of open roads, but 24-h use of closed and removed roads.

Despite the fact that restoring bear and other wildlife habitat is a key objective of road closure and removal, this is the first study to directly test the effect of road closure and removal method on bear

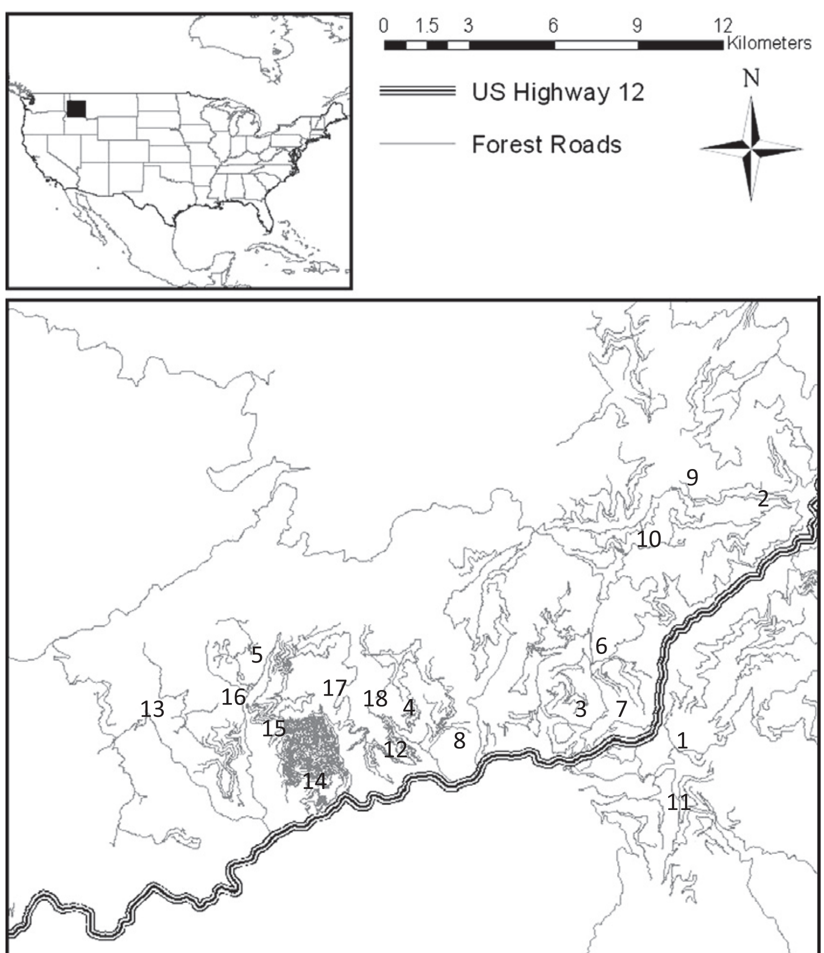

Fig. 2. Field site locations on the Powell Ranger District of the Clearwater National Forest in north-central Idaho. Numbers represent paired study sites and can be cross referenced with Table 1.

frequency and habitat characteristics. Using camera traps, we assessed responses of black bears to the three most commonly employed road closure and removal practices – gating, barriering, and removal through recontour. We asked the following questions: (1) Does black bear frequency or habitat characteristics (abundance of humans, hiding cover, line-of-sight, and cover of bear foods) differ between closed and open roads? (2) Does the type of closure influence black frequency or habitat characteristics? (3) Which habitat characteristics are correlated with frequency of bear detection?

2. Materials and methods

2.1. Study area

The study was conducted on the Powell Ranger District of the Clearwater National Forest (CNF) in the Bitterroot Mountains of north-central Idaho (Fig. 2), within the checkerboard of private and US Forest Service lands and adjacent to large roadless and wilderness areas. The CNF has a history of intensive forest management and a road infrastructure totaling almost 10,000 km (Connor and Bradbury, 1998), with among the highest road densities (up to 12 km/km^2) in the region (Chadwick and Vander Meer, 2003). However, this Forest also has one of the most active road removal programs in the US, with full hillslope recontours completed on over 1100 km. Additionally, they have closed roads by constructing gates and barriers. The CNF is known for high-quality bear habitat; bear hunting with dogs or bait is legal and popular.

2.2. Sampling sites

We assessed black bear frequency and habitat characteristics on 18 paired open and closed (gated, barriered, or recontoured) roads (Table 1). We selected for sampling all gated (n = 6) and barriered roads (n = 5) located within 25 km of the Powell Ranger Station and accessible by open roads; we also selected seven roads within this same geographic area that had been recontoured within the previous 10 years (Table 1). For each paired site, the sampling site for the closed road segment was located 1.6 km from the intersection with the paired open road. The sampling location for the open road segment was located near the beginning (<100 m) of the intersection with the closed road segment. All sites were located between 1108 and 1562 m elevation within the *Thuja plicata* Series (Cooper et al., 1991) at distances of 0.3–12.0 km from the highway (US Route 12). Roads in the study area receive little human use, except during the hunting season.

2.3. Camera stations

At all open and closed road sites, a single StealthCam® or Cuddeback® remotely-triggered camera was mounted on a subjectively selected tree that had an unobscured view of the road and was not easily detectable by humans. Cameras were mounted along existing wildlife trails and positioned in an area along the road with low levels of cover to reduce false detections from wind-induced vegetation movement and to ensure equal rates of detection among treatment sites. The two types of cameras were randomly assigned to the paired road sites. Cameras were in place during the 2006–2009 bear hunting seasons (April 1–June 30 and again August 30–November 3), with each open and closed road pair sampled in a single year. Cameras automatically photographed all animals that interrupted the infrared "trip" beam. A visible or infrared flash allowed animals to be clearly photographed during the night or under low-light conditions. For each photograph of an animal, we recorded species, date, and time of day. Although cameras were checked regularly to ensure proper functioning, the number of camera days varied per site (mean for all years = 69,

Table 1
For each paired open and closed road segment at each site, habitat characteristics including slope, aspect, line-of-sight distance, hiding cover, fall food cover, frequency of detection of people, and date of road removal for recontoured roads. Date of implementation was not available for other road closure types.

Site name	Open road segment						Closed road segment						
	Slope (°)	Aspect (°)	Line-of-sight (m)	Hiding cover (%)	Fall foods (%)	Freq. of people (%)	Date of removal[a] (yr)	Slope (°)	Aspect (°)	Line-of-sight (m)	Hiding cover (%)	Fall foods (%)	Freq. of people (%)
Gated roads													
(1) Crooked Fork	15	225	87.5	0	4.0	5.70	–	5	270	87.5	0	14.5	0.17
(2) Lower Shotgun	20	0	87.5	0	14.5	1.90	–	15	0	87.5	0	12.0	0.35
(3) Middle Parachute	15	225	87.5	0	15.5	4.60	–	5	270	62.5	0	7.0	0.20
(4) Middle Wendover	0	225	62.5	0	17.5	2.60	–	25	180	87.5	0	18.5	0.04
(5) Upper Fishing	0	–	62.5	0	26.0	2.30	–	35	270	37.5	0	11.0	0.30
(6) Upper Parachute	25	90	87.5	0	20.5	12.83	–	25	225	62.5	0	9.5	0.06
Barriered roads													
(7) Lower Parachute	5	180	87.5	0	9.0	9.94	–	25	135	87.5	7.5	8.5	0.04
(8) Lower Wendover	15	180	37.5	0	2.5	1.50	–	0	–	37.5	3.0	2.0	0.10
(9) Middle Shotgun	35	0	87.5	0	8.0	3.80	–	20	45	37.5	0	10.5	0.02
(10) Upper Shotgun	20	0	87.5	0	15.0	1.10	–	30	270	12.5	37.5	16.0	0.01
(11) Walton	25	315	62.5	0	16.0	3.52	–	25	45	100	3.0	45.0	0.04
Recontoured roads													
(12) Cold Storage	35	180	62.5	0	1.5	2.37	2001	30	90	37.5	3.0	74.5	0.04
(13) Doe	25	90	37.5	0	15.5	2.35	2000	0	–	12.5	3.0	31.0	0.01
(14) Lower Badger	35	135	37.5	0	12.0	0.89	2005	35	180	37.5	3.0	17.0	0.0
(15) Lower Fishing	0	–	87.5	0	23.0	1.80	1998	35	315	37.5	17.5	45.5	0.03
(16) Middle Fishing	0	–	62.5	0	13.5	0.60	1998	0	–	62.5	17.5	43.5	0.06
(17) Upper Badger	0	–	62.5	0	7.5	2.10	2005	30	0	37.5	7.5	19.0	0.01
(18) Upper Wendover	0	–	62.5	0	9.5	0.70	2001	0	–	62.5	17.5	44.5	0.01

[a] Only information on date of recontour was available.

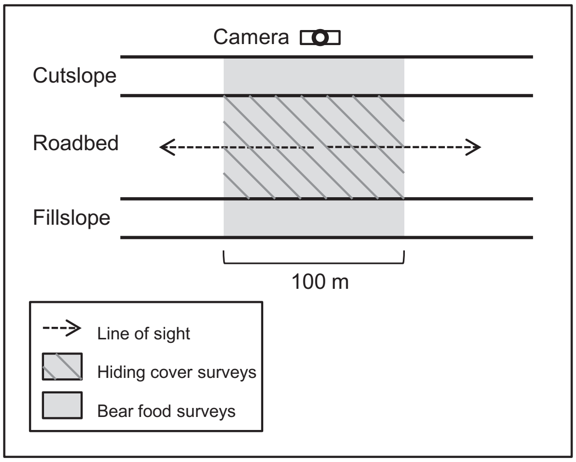

Fig. 3. Habitat survey design including line-of-sight measurement, hiding cover (cover of shrubs and trees greater than 1 m tall) plots, and bear food plots relative to camera location.

range = 21–106) due to stolen cameras, camera malfunctions, and battery failures.

2.4. Habitat surveys

In 2009, at each camera station we assessed hiding cover, line-of-sight, and bear food availability, using three different sampling designs. Hiding cover was assessed in a large plot 100-m in length and the entire width of the roadbed (typically, about 4 m wide). For this variable, we limited sampling to the roadbed area and excluded the cutslope and fillslope (Fig. 1) in order to limit sampling to the area bears frequent for traveling or foraging; however, because the roadbed was no longer evident on recontoured roads, for this treatment we surveyed the entire road-disturbance area (top of the cutslope to the bottom of the former fillslope). The 100-m long sampling plot extended 50-m along the roadbed (or former roadbed) on either side of the camera station (Fig. 3). Within the approximately 100 m $\times$ 4 m plot, we measured percent cover of woody understory plants (tall shrubs and regenerating trees >1 m high recording) using coarse cover classes (<1%, 1–5%, 6–10%, 11–25%, 26–50%, and >50%).

Line-of-sight accounts for both sinuosity of the roadbed and cover of tall vegetation, and is a measure of the distance over which an animal could be sighted by a hunter. Standing at each camera station, we measured (to the nearest 25 m) the longest distance that could be viewed in each direction along the road corridor without obstruction by tall vegetation. The two distances at each site were averaged for analysis.

Finally, we visually estimated percent cover of bear foods in a large plot that was 100-m in length and the entire width of the roadbed disturbance area (typically, about 8 m wide). Like the hiding cover plots, the 100-m long plots for measuring food availability were located 50-m along the roadbed (or former roadbed) on either side of the camera station (Fig. 3). Within each plot, we estimated percent cover of individual plants identified as black bear foods (Table 2; Tisch, 1961; Beecham and Rohlman, 1994) using coarse cover class (<1%, 1–5%, 6–10%, 11–25%, 26–50%, and >50%). Plant nomenclature followed Hitchcock and Cronquist (1973) and Eyde (1988).

2.5. Statistical analysis

Due to among-site variation in camera-detection days, we calculated frequency of detection (#/100 days) of bears and humans at each site. The large number of zero values resulted in skewed distributions of response variables; thus, nonparametric procedures were used for all statistical tests. We performed several tests to ensure that variation in camera days and year of sampling were not confounding results: Spearman correlations (Zar, 1999) were used to test whether frequency of bear detections were related to number of camera days, Wilcoxon signed rank tests (Zar, 1999) were used to assess if number of camera days differed between open and closed road pairs, and Kruskal–Wallis one-way analysis of variance (Zar, 1999) was used to assess whether there were differences among sample years in frequency of detection of bears.

To assess the effect of road closure on frequency of bear detection and habitat variables (frequency of detection of humans, spring bear food, fall bear food, hiding cover, and line-of-sight), we used Wilcoxon signed rank tests (Zar, 1999), with separate tests for each response variable. We did not test for differences in hiding cover between open and closed road pairs because there was no vegetation >1 m tall on open roads.

We assessed whether time of day of bear detections varied among road closure type by comparing the percent of detections among three time-of-day periods: day (8:00–18:59), dawn/dusk (05:00–7:59 and 19:00–21:59), or night (22:00–4:59). We conducted Kruskal–Wallis one-way analysis of variance to test among-road-type differences in proportion of detection at each time of day with separate tests for each time of day. To assess differences in frequency of bear detections and habitat variables among road-closure methods (gated, barriered, or recontoured), we used Kruskal–Wallis one-way analysis of variance, with the difference in value between open and closed sites as response variables. To test the relationship between frequency of bear detection and habitat variables, we used Spearman correlations.

All statistical analyses were conducted using SYSTAT version 12 (SPSS, 2007).

Table 2
Plants assessed as spring bear foods (including graminoids, sporophytes, ferns and forbs) and fall bear foods (including fruiting shrubs and sub-shrubs) (adapted from Tisch (1961) and Beecham and Rohlman (1994)).

Spring foods		Fall foods	
Scientific name	Common name	Scientific name	Common name
Graminoids	Grasses	*Vaccinium globulare*	Black huckleberry
Equisetum spp.	Horsetails	*Amelanchier alnifolia*	Serviceberry
Adiantum pedatum	Maidenhair fern	*Sorbus scopulina*	Western mountain-ash
Athyrium filix-femina	Lady fern	*Cornus sericea*	Red-osier dogwood
Gymnocarpium dryopteris	Oak fern	*Rubus parviflorus*	Thimbleberry
Trifolium repens	White clover	*Ribes* spp.	Black and red currants
Taraxacum officinale	Dandelion	*Sambucus racemosa*	Red elderberry
Heracleum maximum	Cow parsnip	*Rubus leucodermis*	Black raspberry
		Symphoricarpos albus	Snowberry
		Fragaria virginiana	Wild strawberry

3. Results

Number of camera days did not vary significantly between open and closed road segments ($p = 0.155$). In addition, frequency of detection of bears was not significantly correlated with number of camera days ($p = 0.216$) and did not vary by sample year ($p = 0.274$).

Significantly more bears were detected on closed versus open roads (average of 2.4/100 days and 0.6/100 days, respectively; $p = 0.008$; Fig. 4a). In addition, frequency of detection of humans was significantly lower ($p = 0.001$; Fig. 4b), line-of-sight distance shorter ($p = 0.005$; Fig. 4f), and cover of fall foods higher ($p = 0.041$; Fig. 4c) on closed versus open roads. Mean spring bear foods was higher on closed than open roads, but the difference was not significant ($p = 0.080$; Fig. 4d). Hiding cover was never present on open roads; however, on closed roads it averaged 2.3% (Fig. 4e).

The time of day that bears were detected differed among road treatments, however, the results were not significant ($p = 0.210$–0.870; Fig. 5). During the day, bears were commonly detected on closed roads, but were never detected on open ones. On open road sites with bear detections ($n = 4$), bears were found equally during dusk/dawn and night. On gated road sites with bear detections ($n = 1$) and barriered roads with detections ($n = 4$), half of bear detections were during daytime hours and half at night. On recontoured roads with detections ($n = 7$), bears were detected 42% of the time during daytime hours, 31% during dawn/dusk, and 27% at night.

Human detections were very low on all closed roads and were not significantly different among road closure treatments ($p = 0.317$). However, frequency of bear detections, fall bear foods, and hiding cover varied significantly by road-closure method ($p = 0.015$, 0.005, and 0.005, respectively). Compared to gated and barriered roads, recontoured roads had higher mean bear detections (0.5/100 days, 1.6/100 days, and 4.6/100 days, respectively; Fig. 6a) and greater cover of fall bear foods (12%, 16%, and 39%, respectively; Fig. 6b). Hiding cover was absent on gated roads, but averaged 10.2% on barriered roads and 9.9% on recontoured ones (Fig. 6c). Frequency of detection of bears was significantly negatively correlated with frequency of detection of humans and line-of-sight distance, and significantly positively correlated with fall foods and hiding cover (Table 3).

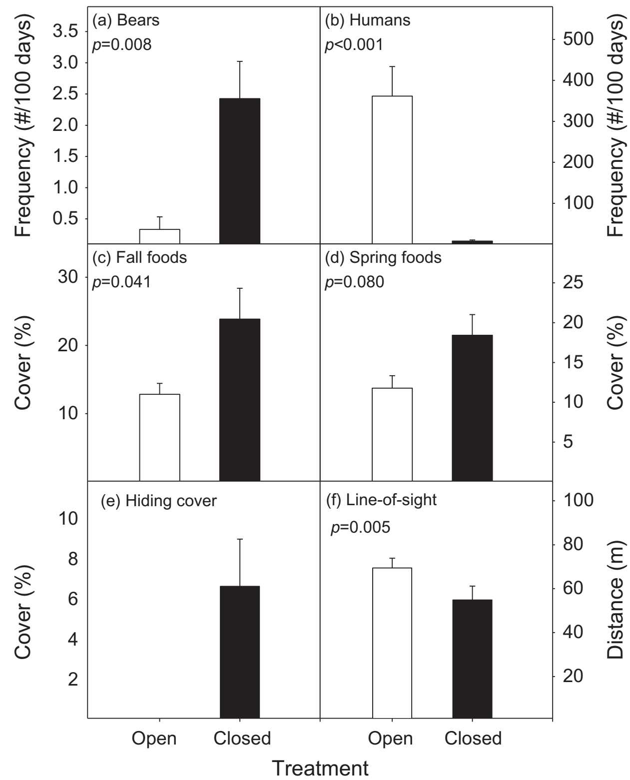

Fig. 4. Comparison of mean (+1 SE) frequency of detection of (a) bears and (b) humans, percent cover of (c) fall bear foods, (d) spring bear foods, (e) hiding cover, and (f) line-of-sight distance on open (white bars) and closed (black bars) roads. *P* values are from Wilcoxon signed rank tests (see Section 2).

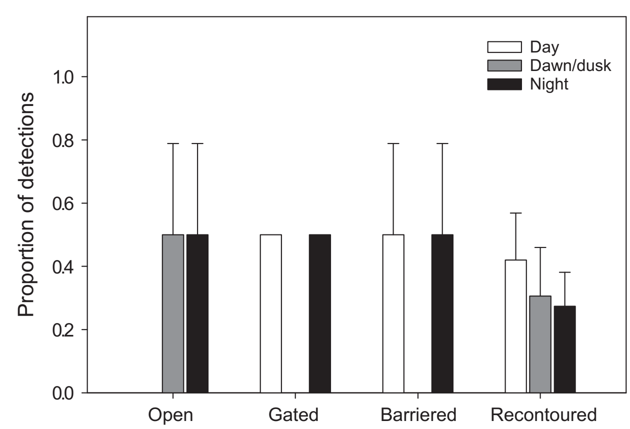

Fig. 5. Comparison of mean (+1 SE) proportion of black bear detections on open, gated, barriered, and recontoured roads during different times of day [day (8:00–18:59), dawn/dusk (5:00–7:59 and 19:00–21:59), and night (22:00–4:59)]. White bars represent daytime detections, gray represent dawn/dusk detections, and black represents nighttime detections. Bars for gated roads do not contain error bars because bear detections only occurred at one gated road site.

4. Discussion

4.1. Effect of road closure on black bear habitat use

Managers are increasingly using road closure and removal to restore wildlife habitat, however, few previous studies examine effects of road closure (but see Miller, 1975; Brody and Pelton, 1989; Mace et al., 1996; Wielgus et al., 2002; Kasworm and Manley, 1990) and none examine the efficacy of complete removal of roads. On our sites, although detections were relatively low overall, frequency of bears was much higher on closed or removed roads than on open ones. Other investigators have found similar patterns of bear habitat use. In West Virginia, Miller (1975) reported higher black bear use of closed roads than of open ones, and in North Carolina black bears were found to cross abandoned roads more than gated or open roads (Brody and Pelton, 1989). In Montana, Kasworm and Manley (1990) found that displacement of both grizzly and black bears was lower on closed roads than on open roads and trails, while Mace et al. (1996) found that grizzly bears had neutral or positive selection towards habitats close to closed roads. In addition to bears, road closure has been reported to benefit rare forest carnivores (Bull et al., 2001), cavity nesting birds (Bull and Wales, 2001), and western toads (*Bufo boreas*) (Bradley, 1997). However, even when a road is closed or abandoned for several decades, habitat quality may be lower than in an unroaded system. For example, a study in the southern Appalachian Mountains found lower abundance of woodland salamanders (*Plethodon metcalfi*) on an 80-year-old, overgrown logging road than in the surrounding undisturbed forest (Semlitsch et al., 2007).

On our sites, patterns of bear use of roads appear to be due, in part, to avoidance of humans. We found that frequency of humans was significantly higher on open than closed roads, and that bear

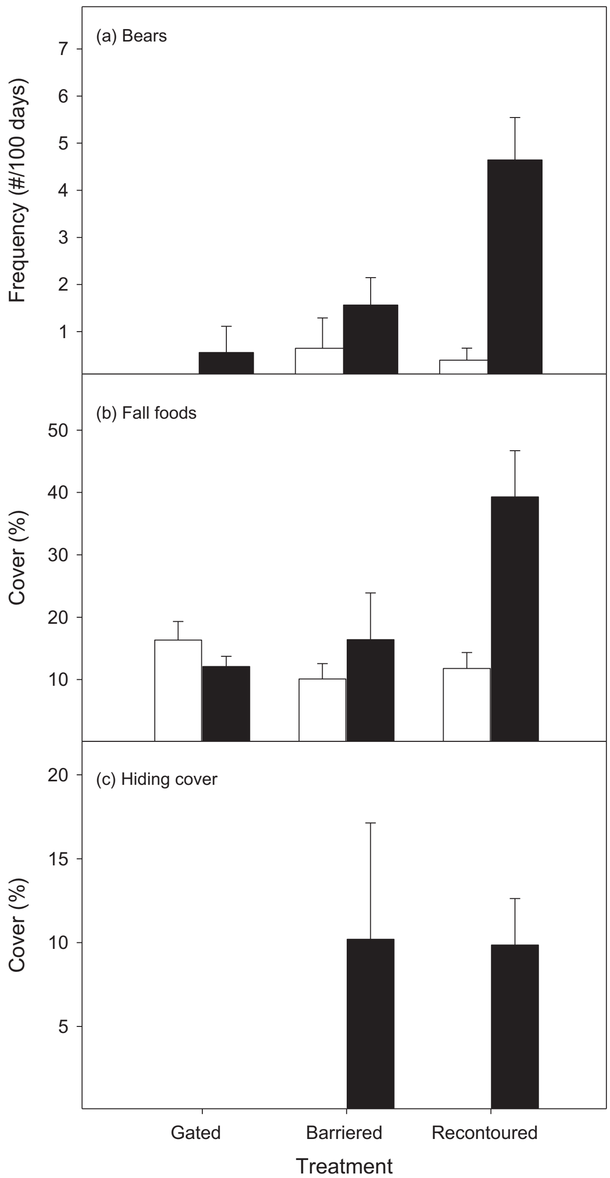

Fig. 6. Comparison of mean (+1 SE) (a) frequency of detection of bears, (b) cover of fall bear foods, and (c) hiding cover among open roads (white bars) paired with gated, barriered, and recontoured roads (black bars).

Table 3
Results of Spearman correlations (*r* and *p* values) of relationship between frequency of detection of bears and each of the following variables: camera days, line-of-sight distance, hiding cover, fall food cover, spring food cover, and frequency of detection of people. Bold font indicates significant relationships.

Variable	*r*	*p*
Camera days	−0.211	0.216
Line-of-sight distance	**−0.364**	**0.029**
Hiding cover	**0.723**	**<0.001**
Fall food cover	**0.350**	**0.036**
Spring food cover	0.156	0.363
Frequency of detection of people	**−0.588**	**<0.001**

frequency was significantly negatively correlated with human frequency. Hunters drive roads to locate bears, and presumably bears avoid roads to reduce risk of mortality. In our study, bears rarely frequented open roads and, when they did, it was only during the cover of darkness when hunting was not allowed; in contrast, bears were detected throughout the day on closed roads. Other investigators also have found that black and grizzly bears will become nocturnal to avoid humans (McLellan and Shackleton, 1988; Gibeau et al., 2002; Bridges et al., 2004).

Availability of hiding cover, important in black and grizzly bear habitat selection (Young and Beecham, 1986; Gibeau et al., 2002; McLellan and Shackleton, 1989), may have also contributed to observed differences in bear frequency on open and closed roads. Hiding cover (>1 m high) was present on barriered and recontoured roads, but absent on open and gated ones and was significantly correlated with bear detections. Line-of-sight was also significantly lower on closed versus open roads and significantly correlated with bear detections.

In addition to habitat security, food availability has been found to influence bear habitat selection (Lyons et al., 2003; Vander Heyden and Meslow, 1999). In fact, bears may be attracted to roads when preferred foods are present (Munro et al., 2006; Roever et al., 2008a). We found significantly higher cover of fall bear foods on closed versus open roads and a significant positive relationship between bear detections and cover of fall foods. Additionally, our cameras documented bears traveling and actively foraging along closed roads.

4.2. Differences in closure method

Road-closure method was a significant driver of bear detections. Frequency of detection of black bears was higher on recontoured roads than on those closed by either gates or barriers, despite the fact that there was no difference in human detections among these road closure types. This higher use of recontoured roads by bears is likely due to higher cover of fall foods on the recontoured sites. Barriered roads were often overgrown with fast growing deciduous trees (*Alnus* spp.), growing along the cut- and fill slopes, that outcompeted fruiting shrubs. These fruiting shrubs, which were significantly more abundant on recontoured roads, are an important food source in fall when bears must engage in hyperphagia in order to put on enough body fat to survive winter. While spring foods were not significantly different among treatments, native grass seeded immediately after road recontouring may limit weed invasion and promote native grasses (Grant et al., 2011) that may be an additional source of bear food.

Increased hiding cover may also explain higher bear frequency on recontoured roads than gated or barriered ones. For instance, Wakkinen and Kasworm (1997) attributed differences in grizzly bear use of gated and barriered roads to higher vegetative cover on the barriered roads. On our sites, line-of-sight did not differ by road-closure method; however, hiding cover did. Open and gated roads, which were mechanically brushed and graded, had no tall vegetative growth along the roadbed, while barriered and recontoured roads both offered similar amounts of this hiding cover. The fact that bear detections differed while hiding cover levels were similar might suggest that bear use is driven more by food availability than by hiding cover. However, bear detections were more highly correlated with hiding cover than with fall foods.

4.3. Conservation implications

Although other researchers have suggested that removing roads may benefit bear populations (Powell et al., 1996; Nielsen et al., 2006, 2008; Roever et al., 2008a,b), this is the first study to demonstrate that removing roads by recontour may be the most effective way to mitigate negative effects of roads and to restore bear habitat. This is an important observation because of the differences in cost associated with these treatments: gates cost from $1000 to 2800 US and barriers $800–1000 US (Switalski et al., 2004), while costs of a full recontour can range from $3000 to

200,000 km depending on the amount of fill at stream crossings. In order to keep costs low, many managers consider gating or barriering to be sufficient for securing wildlife habitat and only recontour roads to reduce stream sedimentation when fisheries concerns are a priority. In fact, managers in the US consider areas with barriered roads as secure habitat, and these roads are not included in road-density calculations for determining "core" habitat for grizzly bears. While blocking road access with barriers, or other passive restoration measures, can contribute to the protection of endangered populations of bears, our results suggest that managers should pay more attention to method of closure and road removal when assessing habitat availability.

Our research was limited to black bears in North America; however, findings may also be relevant for bear species around the world that face similar threats of habitat loss and human persecution. Grizzly bears, a species of considerable conservation concern in North America, live sympatrically with black bears and tend to be equally or more wary of humans than are black bears (e.g., Kasworm and Manley, 1990). Furthermore, these bears have similar diets (Jacoby et al., 1999) and requirements for habitat security (Kasworm and Manley, 1990), suggesting that they would likely respond similarly to road-closure efforts. Although currently unoccupied by grizzly bears, much of our study area has been identified as a priority for grizzly bear habitat restoration (Bader and Bechtold, 1996; Merrill et al., 1999). Restoration of this high-quality habitat could provide key linkages between expanding grizzly bear populations to the north and extensive habitat areas to the south in the Salmon–Selway region – the largest roadless complex in the US outside Alaska. Our results may also have implications for taxa other than bears that are sensitive to humans and require hiding cover and early successional food resources. For example, Hebblewhite et al. (2008) suggested that removing roads may benefit ungulate populations following post-fire logging. Although our study focused on bears, we did detect other rare carnivores such as wolves (*Canis lupus*), mountain lions (*Puma concolor*), and bobcats (*Lynx rufus*) on removed roads, suggesting benefits to species other than bears as well.

4.4. Future research

There is an urgent need for increased information on the impacts of road removal on wildlife. Bears are only one of numerous species that are adversely impacted by roads and may benefit from road removal (Switalski et al., 2004); thus there is a need to expand research on the efficacy of road removal to a wider array of taxa. Our study was limited to addressing issues of habitat use, because we employed remotely-triggered cameras, a relatively low-cost, non-invasive method for detecting bear presence. Although this method of sampling provides reliable information on habitat use, it does not provide demographic information, such as age or gender. An important extension of this research would be to examine changes in bear and other wildlife survival rates, and population and meta-populations dynamics (including the restoration of connectivity), in response to road closure and removal. The knowledge that these types of studies could provide would be immediately applicable, given the tens of thousands of kilometers of roads slated for removal in the next decade.

Acknowledgements

We thank S. Aguilar, A. Boland, W. Boyd, K. Court, G. Fast, M. Fiebig, A. Holden, A. Kindle, G. Peters, and G. Porter for assistance with fieldwork. Additional assistance was provided by L. Broberg, A. Connor, D. Forestieri, R. Frederickson, C. Hagen, and R. Lloyd. J. Brodie, B. Gilbert, S. Miller, T. Peterson, and two anonymous reviewers provided helpful comments to earlier versions of this manuscript. Financial support was provided by the National Forest Foundation, Norcross Wildlife Foundation, Page Foundation, Patagonia, and Yellowstone to Yukon Conservation Initiative.

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