Comparison of Methods of Monitoring Wildlife Crossing-Structures on Highways

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ABSTRACT Wildlife crossing-structures (e.g., underpasses and overpasses) are used to mitigate deleterious effects of highways on wildlife populations. Evaluating performance of mitigation measures depends on monitoring structures for wildlife use. We analyzed efficacy of 2 noninvasive methods commonly used to monitor crossing-structure use by large mammals: tracking and motion-activated cameras. We monitored 15 crossing-structures every other day between 29 June and 24 October 2007 along the Trans-Canada Highway in Alberta, Canada. Our objectives were to determine how species-specific detection rates are biased by the detection method used, to determine factors contributing to crossing-event detection, and to evaluate the most cost-effective approach to monitoring. We detected 3,405 crossing events by tracks and 4,430 crossings events by camera for mammals coyote-sized and larger. Coyotes (*Canis latrans*) and grizzly bears (*Ursus arctos*) were significantly more likely to be detected by track-pads, whereas elk (*Cervus elaphus*) and deer (*Odocoileus* sp.) were more likely to be detected by cameras. Crossing-event detection was affected by species, track-pad length, and number of animals using the crossing structure. At the levels of animal activity observed in our study our economic analysis indicates that cameras are more cost-effective than track-pads for study durations >1 year. Understanding the benefits and limitations of camera and track-pad methods for monitoring large mammal movement at wildlife crossing-structures will help improve the efficiency of studies designed to evaluate the effectiveness of highway mitigation measures.
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Effects of roads on wildlife are well-documented and include increased mortality and decreased landscape connectivity (Forman et al. 2003). Wildlife–vehicle collisions also constitute a major public safety concern for transportation agencies (Huijser et al. 2007). Consequently, wildlife managers and transportation planners in many jurisdictions are incorporating mitigation features into road upgrades to minimize the risk of wildlife–vehicle collisions (Spellerberg 1998, Clevenger 2005, Gagnon et al. 2007, Kleist et al. 2007).

Two common types of highway mitigation measures are wildlife-proof fencing and wildlife crossing-structures (CS). Fencing typically prevents ungulate and large carnivore access to the road right-of-way (Clevenger et al. 2001), whereas CS allow animals to safely cross the road without coming into contact with traffic (reviewed in Spellerberg 1998, Forman et al. 2003, Clevenger and Waltho 2005). Anticipated population growth and ongoing highway investments in most regions of North America, coupled with growing concern for maintaining landscape connectivity for wildlife populations, have generated increasing interest in CS as management tools (Crooks and Sanjayan 2006, Hilty et al. 2006).

Successful highway mitigation projects may be defined by a substantial reduction in wildlife–vehicle collision rates and restoration of animal movement patterns from one side of the road to the other. In the latter case, monitoring of CS is needed to determine which species are crossing the road and how often, which is especially important where issues of wildlife population persistence and connectivity are salient (Clevenger 2005, Dodd et al. 2007). In some cases, long-term monitoring (i.e., >5 yr) of CS has provided information on species preference for CS designs that shorter term studies may have missed (Clevenger and Waltho 2003). Results from long-term monitoring of CS can also provide a population-level index for some species (J. Whittington, Parks Canada, personal communication). Thus, finding reliable and cost-effective methods for monitoring CS can serve a variety of wildlife management objectives.

A review of 40 CS monitoring studies found that 62% of studies used sand-traps, sooted track-plates, or some other type of tracking material to identify species use and frequencies (A. P. Clevenger and M. Huijser, Montana State University, unpublished report). A. P. Clevenger and M. Huijser (unpublished report) also found that 50% of the studies used remotely triggered devices such as infrared-triggered cameras, counters, video cameras, or still cameras. We did not find any published research comparing relative effectiveness of these methods for use at CS.

Our goal was to compare effectiveness of track-pads with motion-activated cameras for monitoring CS use by mammals coyote-sized (*Canis latrans*) and larger. Our specific objectives were several-fold. First, we wanted to know how species-specific detection rates are biased by the method used. Second, we wanted to determine which factors associated with CS design, camera placement, and species use-patterns contributed to the likelihood of detecting a crossing event. Lastly, we developed a simple economic model to compare monitoring costs of these 2 methods.

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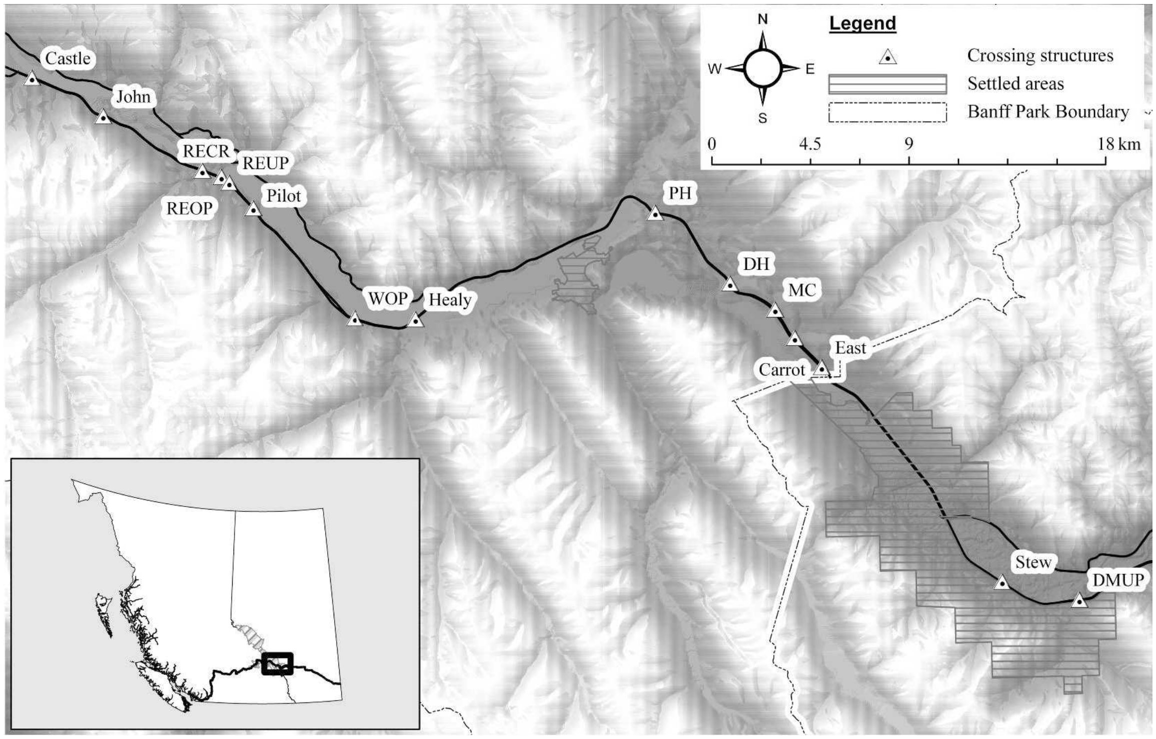

Figure 1. Map of the study area showing the locations of wildlife crossing-structures along the Trans-Canada Highway near Banff, Alberta, Canada, 29 June 2007 to 24 October 2007.

STUDY AREA

Our study was situated in the Bow River Valley along the Trans-Canada Highway (TCH) in and near Banff National Park (BNP), located approximately 120 km west of Calgary, Alberta, Canada (Fig. 1). The TCH was the major transportation corridor through the area, covering 76 km between the eastern park boundary and the western boundary at the Alberta–British Columbia border. Traffic volume was high, with an estimated average of 17,630 vehicles/day in 2007 (T. Gui, Highway Service Center, Parks Canada, unpublished data).

In the 1970s, safety issues compelled planners to upgrade the TCH within BNP from 2 to 4 lanes (twinning), beginning from the eastern boundary and working west. Large animals were excluded from the road with a 2.4-m-high fence erected on both sides of the highway, and underpasses were built to allow wildlife to cross the road. The first 27 km of highway twinning included 11 wildlife underpasses and was completed in 1988. The next 18-km section was completed in late 1997 with 11 additional wildlife underpasses and 2 wildlife overpasses. The final 30 km of twinning to the western park boundary will not be completed until 2009 and will also include fencing and several CS. There were an additional 8 km of highway fencing along the TCH outside of BNP, which was completed in 2005. This stretch included 2 wildlife underpasses.

Our current study included approximately 45 km of twinned highway at 15 of the 24 CS in the study area (Fig. 1). These 15 CS include 6 structural designs (site names in brackets): 1) 2 creek-bridge underpasses (3-m-high and 11-m-wide expanded bridges with a walkway on one side of the stream [RECR, Carrot]); 2) 1 elliptical metal culvert underpass, 4 m high × 7 m wide (Castle); 3) 1 circular metal culvert underpass with a 4-m diameter (MC); 4) 3 prefabricated concrete box underpasses, 2.5 m high × 3 m wide (Johnston, Pilot, REUP); 5) 6 open-span bridge underpasses, 16 m wide × 5 m high (PH, DH, East, Healy, Stew, DMUP); and 6) 2 50-m-wide overpasses (WOP, REOP). As part of another study that started in 2006, 2 lengths of barbed-wire, one at 75 cm from the ground and the other at 45 cm from the ground, were strung across the width of CS at all but 2 sites (DMUP and Stew) to snag carnivore hair for genetic sampling (see Long et al. 2008).

METHODS

Field Data Collection

All 24 CS in the study area were continuously monitored for large mammal use since 1996 using track-pads (Clevenger and Waltho 2000, 2005). At least one track-pad (range 2–7 pads/CS) was constructed at each end of every underpass, and each track-pad spanned the width of the underpass and was approximately 2 m long in the axis of animal movement. Track-pads on the overpasses consisted of one track-pad located at the center, spanning the width, and were approximately 4 m long in the axis of animal movement. Tracking material consisted of a dry, loamy mixture of sand, silt, and clay, 1–4 cm deep. We visited each CS every other day, and at each visit we classified the tracking medium as Good, Fair, Poor, or Too many, depending on our ability to detect tracks. A track-pad condition of Good occurred when our ability to detect tracks for all species was not adversely affected by quality of the tracking material, Fair occurred when ungulates readily showed in the tracking material but some of the carnivore species may have gone undetected, and Poor occurred when all species were difficult to detect in the track-pad due to flooding, wind, or snow. We noticed that many animals, particularly ungulate species, crossing or loitering on the track-pads reduced our confidence in accurately counting crossing events. Crossing events occurring prior to these trampling events would also likely have gone undetected by the track-pad method. A track-pad condition of Too many occurred when we could no longer confidently discern the number of individuals that passed across the track-pad. However, we still estimated the number of crossing events in these cases.

Technicians recorded species presence of wolves (*Canis lupus*), coyotes, cougars (*Puma concolor*), black bears (*Ursus americanus*), grizzly bears (*Ursus arctos*), deer (*Odocoileus* sp.), elk (*Cervus elaphus*), sheep (*Ovis canadensis*), and moose (*Alces alces*) abundance, direction of movement, and human activity at each CS check. After collecting data, technicians raked track-pads smooth to enable recording of future crossings.

In June 2007, we installed 17 infrared motion-triggered cameras (PM35M15; Reconyx™ LLP, Holmen, WI) at 15 CS. Cameras were equipped with 256-megabite to 1-gigabite-sized compact flash cards, which held up to 1,900–7,000 images, respectively, according to manufacturer's specifications. We put one camera up at each underpass and 2 cameras at each overpass to cover the full width of the 50-m-wide structures. We treated each half of each overpass as a separate site for our analyses. In most cases, we positioned cameras perpendicular to direction of animal movement, roughly 0.75 m off the ground, and we put some cameras at an oblique angle to the main direction of travel. Motion within an infrared beam triggered the camera to take 5 photos at roughly 0.1-second intervals. Cameras were equipped with an infrared light-emitting-diode flash array that allowed continuous operation throughout the day and night. We downloaded photos onto a handheld computer (Hewlett-Packard™, Palo Alto, CA; iPAQ hx2490b) each time we checked the CS, which was every other day during this study period. We then classified photos using a customized database form to record the number of individuals, species, and direction of travel.

Data Analysis

We assessed data from sites after cameras were installed (after 29 Jun 2007) and ended the study when we removed the barbed-wire hair-snagging fences (around 25 Oct 2007) to avoid introducing potential variability in detection probability after the barbed-wire fence was removed. We also excluded 51 sampling days across 10 sites where the camera malfunctioned (55% of excluded sampling days), because of data-entry errors (25%), routine track-pad maintenance (5%), safety issues (i.e., a technician encountered a grizzly bear at an underpass, 4%), and seasonal flooding of the track-pad (10%). Combined, these excluded days represent 0.2% of the total monitoring days during the study period.

Detection bias by species.—We calculated detection bias for each species for each CS check as

$$\frac{(\text{no. of detections by track} - \text{no. of detections by camera})}{(\text{no. of detections by track} + \text{no. of detections by camera})}$$

As the bias value approaches 1, species are more likely to be detected by track-pads, whereas, as bias approaches -1, species are more likely to be detected by cameras. A bias value of zero indicates that both methods detected the same number of species heading in the same direction. To determine which species detections were significantly biased by method we performed separate Wilcoxon signed-rank tests for each species, comparing the actual bias value for each crossing event with an expected bias of zero. We evaluated statistical significance at $P < 0.05$.

Over a monitoring interval, total number of each species detected, heading in one of 2 directions (i.e., N or S across the highway) at each CS check represented one unit of replication (e.g., 12 Aug, 2 deer heading N at the Healy underpass). This unit of replication covered one monitoring interval (i.e., the period of time commencing when we last raked the CS and ending when we visited it next). We calculated bias for wolf, cougar, coyote, black bear, grizzly bear, sheep, moose, elk, and deer spp., and where we detected ≥ 1 individual by either method for a given monitoring interval. We excluded records where species identification was ambiguous in the field because this would have artificially inflated the bias value. Excluded records included grizzly bear and black bear camera detections where we identified only "bear spp." on the track-pads, coyote camera detections where we identified "small canid" on the track-pad, and wolf camera detections where we identified "large canid" on the track-pad. Bias was artificially inflated in these cases because species identification was much easier using cameras when compared to track-pads.

Factors affecting detection.—To determine which factors contributed to crossing-event detections, such as the level of animal activity, camera placement, and track-pad condition, we analyzed the probability of agreement between track and camera counts for a given monitoring interval. Agreement occurred when the species, number of individuals, and direction of travel were equal for track-pad and camera records for a given monitoring interval. Here we assumed that track and camera detections were in agreement because they both detected the actual number of crossing events; however, it is possible for agreement to occur when both methods failed to detect some crossing events if the number of individuals recorded by each method is the same.

To assess factors affecting agreement between track-pad and camera detection we performed a logistic regression and defined the response variable as agreement or disagreement. Explanatory variables included location (i.e., CS), species, maximum number of individuals for that species that we detected (by camera or track, whichever was greatest) during the monitoring interval, maximum number of individuals from all species detected during the monitoring interval (by camera or track, whichever was greatest), track-pad condition (i.e., Good, Fair, Poor, Too many), and site variables. Site variables included camera height, camera angle relative to the direction of travel (i.e., oblique or right-angled), total length of tracking surfaces at each CS, and CS type (i.e., overpass, open-span underpass, round culvert, elliptical culvert, creek crossing, box culvert). We also included a binary predictor variable we called confounding species presence, which we defined as presence of another species whose tracks or appearance in the camera image could be similar to the actual species using the site. This variable indicated detection of >1 individual from any confounding species. We defined confounding species (in parentheses) for each species as follows: black bear (grizzly bear); cougar (wolves, large canid); ungulates (any other ungulate species); coyotes (dogs, wolves, small canid, large canid); grizzly bear (black bear); wolves (cougar, coyote, large canid).

To choose the best-fitting model, we used an information-theoretic approach (Burnham and Anderson 2002) with Akaike's Information Criterion corrected for small sample sizes (AIC_c). We present results for the top-performing model or models with $\Delta AIC_c < 10$. We focused our efforts on key species of interest for which there were adequate data and that we reliably recorded: wolf, cougar, coyote, black bear, grizzly bear, sheep, moose, elk, and deer spp.

Before performing the logistic regression, we excluded records from our analysis where 1) tracks were imprecisely identified (see above), 2) we could not determine direction of movement or whether the animal passed through the CS, and 3) there were no crossing events detected by either method. We performed the first 2 exclusions because the likelihood of species misidentification or directional ambiguity is low in photos compared to tracks. Furthermore, at some sites, some of the track-pads are not directly in view of the camera, so tracks detected here could have been missed by the camera if the animal did not completely pass through the CS. Including these records would artificially inflate frequency of disagreement, because camera and track-pad data will always disagree under these circumstances. We excluded records where no crossing events were detected by either method because agreement is the only possible outcome when no animals were using the site, which would artificially inflate the frequency of agreement in our analysis.

The number of animals using the CS during a monitoring interval may have affected the probability of detecting crossing events by track-pads. We addressed this issue in our field methods by including the track-pad condition category Too many when technicians felt they could no longer reliably count the number of individual tracks (see above). We estimated how many crossing events were required to create a Too many track-pad condition by simultaneously counting the number of individuals detected by the camera with the estimated number from the track-pad. For each method, we summed the total number of individuals detected at each CS check, irrespective of species or direction traveled. We used a Mann–Whitney *U*-test with the null hypothesis that the number of detections by track-pad condition was independent of detection method. We then used a Wilcoxon signed-rank test to test the null hypothesis that the number of detections was independent of method, given the same track-pad condition. For both tests, we evaluated statistical significance at $P < 0.05$. We excluded those cases with Fair or Poor track conditions to minimize the effect of non-species use factors that could have affected the number of detections. We chose only to look at CS checks with Good or Too many listed as the track-pad condition because these conditions had suitable tracking material for detecting all types of species, but there were too many crossing events to reliably estimate the number. However, a Fair or Poor track-pad condition introduced other factors into the probability of detection besides the number of animals using the site. We wanted to eliminate these factors from the analysis, so we excluded those records.

Economic models.—We devised 2 models to describe monitoring costs: cost/animal detection and cost/unit time. For each model we created 3 approaches to measuring the cost of animal detection, one each for the track-pad and camera methods separately, and a combined-methods approach. The track-pad–only method required a visit to each CS every other day to record tracks, whereas the camera-only method consisted of one visit to each site every 2 weeks to download the images and change camera batteries. The combined approach is based on our study methods, where we visited each site every other day and used both detection methods. For each of these 3 approaches we looked at study durations of 3 months, 1 year, 4 years, and 10 years. We chose these durations for practical reasons: 3 months to 4 years is the normal duration for graduate-school field studies, and 10 years is consistent with our long-term monitoring study in BNP. We created a project-cost worksheet to assist other researchers planning monitoring projects, which is available from the corresponding author.

We treated start-up costs and operational costs of monitoring separately. Start-up costs included equipment, software, and training expenses. Operational costs included technician wages and vehicle expenses such as fuel, insurance, and maintenance. The track-pad model start-up costs included costs for a handheld computer and software to enter and store data, a rake, and 16 hours of technician training. We did not include track-pad construction costs in our calculations, though other studies may require this expense. In our study, these costs were included when the structures were first built and tracking soil was trucked into the sites. The camera-only model required the same handheld computer and software as the track-pad–only model, but with only 8 hours of technician training, and additional equipment expenses for cameras, memory cards, batteries, and battery chargers. Operational costs for the track-pad model were based on a 100-km circuit to check 17 sites over 8 hours every other day. The camera-only approach, however, required one check of the 17 sites every 2 weeks. We assumed the number of animal crossings to have little impact on the time required for a technician to

Table 1. Number of large-mammal-species crossing events detected by track-pads and cameras at wildlife crossing-structures along the Trans-Canada Highway, Alberta, Canada, 29 June 2007 to 24 October 2007.

Species	Total track	Total camera	Ratio of total track:total camera detections
Unknown bear spp.	5	2	2.50
Bike	16	6	2.67
Black bear	42	44	0.95
Cougar	39	41	0.95
Coyote	140	74	1.89
Deer spp.	2,235	3,060	0.73
Domestic dog	0	1	
Elk	551	716	0.77
Grizzly bear	56	47	1.19
Horse	5	1	5.00
Human	26	165	0.16
Large canid	3	0	
Moose	13	11	1.18
Sheep	116	106	1.09
Small canid	8	2	4.00
Wolf	150	154	0.97

visit a CS under the track-pad–only method. On the other hand, the number of crossings influenced the camera model because we assumed that 2 minutes was required for a technician to classify and record each crossing event. The combined approach, involving both track-pad and camera monitoring, also used these start-up and operational costs with 24 hours of technician training.

For the first model, cost/animal detection, we calculated costs separately for carnivores and ungulates and also for both species groups combined. For each species group, we extrapolated the mean daily number of crossing events that we found during the current study period to cover 365 days, though we recognize that the level of animal activity at each CS changes within and between years. We summarized costs for each quarter year (3 months) and spread the one-time costs over the full length of the study up until the quarter under calculation.

Our second model, cost/unit time, was based on per-quarter operating expenses. We considered a hypothetical range of animal activity, from 0 to 2,000 crossing events/CS/quarter. Across this range, we assumed that frequency of track-pad checks would be such that ≤ 6 animals would cross a particular CS before the next check. We chose this number based on our experience in the field and it reflects a threshold value of crossing events where additional crossing events become difficult to detect (but see results below regarding the Too many track-pad condition). Thus, for example, 2 visits/day were required when number of animals/CS/quarter exceeded 1,000 in our model. Finally, we considered 4 study durations (3 months, 1 yr, 4 yr, and 10 yr) to observe the effect of spreading out start-up costs over greater lengths of time.

RESULTS

We detected ≥ 1 individual using a CS for 78% of 917 CS checks from 29 June 2007 to 24 October 2007. Overall, track-pads detected 3,405 crossing events and cameras detected 4,430 crossing events (Table 1). Human detections (including hikers, bikers, and horseback riders) were 2.65 times more likely to occur by camera than track-pad, which was likely an artifact of Parks Canada signage near the CS entrances instructing people to stay off the track-pad.

Table 2. Detection bias by cameras and track-pad methods for monitoring large mammal movements at wildlife crossing-structures along the Trans-Canada Highway, Alberta, Canada, 29 June 2007 to 24 October 2007.

Species	n[a]	$\bar{x}$ bias[b]	SE bias	Z[c]	P[c]
Black bear	46	−0.046	0.089	−0.537	0.591
Cougar	44	−0.046	0.086	−0.534	0.594
Coyote	124	0.457	0.060	−6.384	≤0.001
Deer spp.	1,222	−0.140	0.019	−7.133	≤0.001
Elk	378	−0.135	0.034	−3.840	≤0.001
Grizzly bear	46	0.224	0.085	−2.527	0.012
Moose	15	0.133	0.165	−0.816	0.414
Sheep	24	0.222	0.199	−1.058	0.290
Wolf	133	0.056	0.068	−0.866	0.386

[a] No. of site visits where we detected the species.
[b] Bias increased as we detected more crossing events by track-pads than by cameras.
[c] Results of the Wilcoxon Rank Sums test, which tests the null hypothesis that bias = 0.

Detection of black bears, cougars, deer, and elk was biased toward the camera method, but only with deer and elk being significantly ($P < 0.05$) so (Table 2). Coyotes, grizzly bears, wolves, sheep, and moose were more likely to be detected by track-pads, with only coyotes and grizzly bears being significantly more likely.

When >1 animal was detected by either method, we found that 32% of crossing events were in agreement between both methods. The best-performing model to predict agreement between camera and track-pad crossing-event detections included track-pad length, total number of individuals detected from the same species during the monitoring interval, total number of individuals detected from any species during the monitoring interval, species, and track-pad condition (Table 3). All other models evaluated had a $\Delta AIC_c > 10$ compared to this model so we only present results of the best-performing model. Total number of crossing events (from the same and all species) between 2 CS checks inversely affected probability of agreement. Total track-pad length increased agreement, but other site variables such as camera placement (ht, angle) and CS design did not help predict agreement between methods. Odds ratios indicated that a track-pad condition of Fair was 218%, 104%, and 42% less likely to predict agreement than a condition of Good, Poor, and Too many, respectively. Only cougars were more likely (117%) to be in agreement between the 2 methods than black bears, whereas coyote (−75%), deer (−54%), elk (−36%), grizzly bear (−24%), moose (−5%), sheep (−100%), and wolves (−71%) were less likely.

Track-pad conditions were reliable, with 83.9% of checks classified as Good, 4.6% as Fair, 6.5% as Poor, and 5.0% as Too many (Table 4). Track-pad condition deteriorated to a Too many condition after approximately 18 camera-detected passages (Table 5). We tended to underestimate the number of crossing events when recording track-pad use. Mean number of detections by camera for all species

Table 3. Coefficient estimates from the best-performing model to predict agreement between track-pad and camera detections of large mammal movement through wildlife crossing-structures along the Trans-Canada Highway, Alberta, Canada, 29 June 2007 to 24 October 2007.

Term	B[a]	SE	P
Intercept	0.316	0.540	0.559
Track-pad condition			
Good	1.156	0.372	0.002
Poor	0.715	0.455	0.116
Too many	0.350	0.497	0.481
Fair[b]	0.00	0.00	na[c]
Total track-pad length	0.048	0.015	0.002
Total crossing events/check, all species	−0.094	0.021	<0.001
Crossing events/check, same species	−0.572	0.061	<0.001
Species			
Cougar	0.775	0.559	0.166
Coyote	−1.393	0.408	0.001
Deer	−0.778	0.371	0.036
Elk	−0.453	0.376	0.228
Grizzly bear	−0.270	0.477	0.572
Moose	−0.055	0.647	0.932
Sheep	−15.011	426.247	0.972
Wolf	−1.251	0.422	0.003
Black bear[d]	0.00	0.00	na

[a] Coeff. values increased with probability of agreement between cameras and track-pads.
[b] Reference category for track-pad condition.
[c] na indicates not applicable.
[d] Reference category for species.

combined was 19% more than track-pads under tracking conditions rated Good and increased to 68% more than track-pads when under track-pad condition was Too many.

Short-term costs of using remote cameras were US$3–45 greater/crossing event than track-pad monitoring depending on the species of interest; however, for studies >1 year in duration, it was always cheaper to use cameras-only than track-pads or cameras and track-pads simultaneously at the levels of animal activity we observed (Fig. 2). Cost of focusing the monitoring program on carnivores remained the highest because we detected them less frequently at the CS than ungulates (Fig. 3). For instance, the cost ratio of detecting carnivores to herbivores using cameras-only was 10:1 when study durations were ≤1 year and 6:1 for study durations ≥4 years. When using a hypothetical range of animal activity, track-pads were the most economical monitoring option when studies were ≤4 years and when animal activity resulted in <100 crossing events/3 months. For example, for a 4-month study period and 200 animal passages, it would cost US$7,552 to monitor by track-pad only and US$22,375 to monitor by cameras-only. For monitoring periods >4 years or with ≥1,000 crossing events/month we found the camera-only method was the most economical.

Table 4. Track-pad condition of various wildlife crossing-structure designs encountered during monitoring along the Trans-Canada Highway, Alberta, Canada, 29 June 2007 to 24 October 2007.

Crossing-structure design	No. of sites[a]	Track-pad condition (% of total visits) Good	Fair	Poor
Creek bridge	2	94	4	2
Large culvert (4 × 7 m)	1	100	0	0
Open-span bridge	6	96	4	0
Overpass	2	71	8	21
Small culvert (2-m round and box culverts)	4	99	1	0

[a] We visited each site 144 times.

Table 5. Mean number of large-mammal crossing events detected/visit using track-pads and cameras while monitoring wildlife crossing-structures along the Trans-Canada Highway, Alberta, Canada, 29 June 2007 to 24 October 2007.

	Detection method			
	Track		Camera	
Track-pad condition	$\bar{x}$	SE	$\bar{x}$	SE
Good (n = 742)[a]	3.66 AB[b]	0.14	4.35 BD	0.27
Too many (n = 32)[a]	10.81 AC	1.13	18.16 CD	1.80

[a] Sample size is total no. of monitoring visits made to all wildlife crossing-structures where we detected at ≥1 animal by either method.
[b] Test statistics for A ($Z = -7.210$) and D ($Z = -8.342$) are significant for the Mann–Whitney U test at $P < 0.001$. Test statistics for B ($Z = -3.618$) and C ($Z = -3.724$) are significant for the Wilcoxon signed-rank test at $P < 0.001$.

DISCUSSION

Cameras and track-pads offer complimentary advantages and limitations for monitoring large mammal movement at wildlife crossing-structures along highways. We found species-specific detection bias for these 2 methods and found several factors that can be used to more efficiently design studies to detect animal movement.

Track-pad monitoring offered some key study design and species-specific advantages over camera-based monitoring. Lower start-up costs of track-pad–based monitoring make this method more cost-effective in the short-term and track-pads are also more reliable than cameras at detecting coyote and grizzly bear crossing events. Anecdotal evidence from the photo images suggests that ungulates, black bears, and cougars tend to walk more slowly through the CS than do coyotes. The greater detection rate of coyotes by track-pads could be explained by the small size of coyotes and their fast traveling speed, which may exceed the sensitivities of the motion sensor on the camera. However, this hypothesis does not explain why moose and sheep detections tend to be biased towards track-pads, because their size and speed should readily lend themselves to camera detection. One possibility is that this result was caused by technician error, in which tracks identified as sheep and moose in the field were actually made by deer and elk, respectively. In this case, it appears that the track-pads detected species that the cameras missed when in fact the track-pad records were actually misidentified crossing events that the camera correctly detected. We have no explanation for the significant bias towards track-pad detection in grizzly bears.

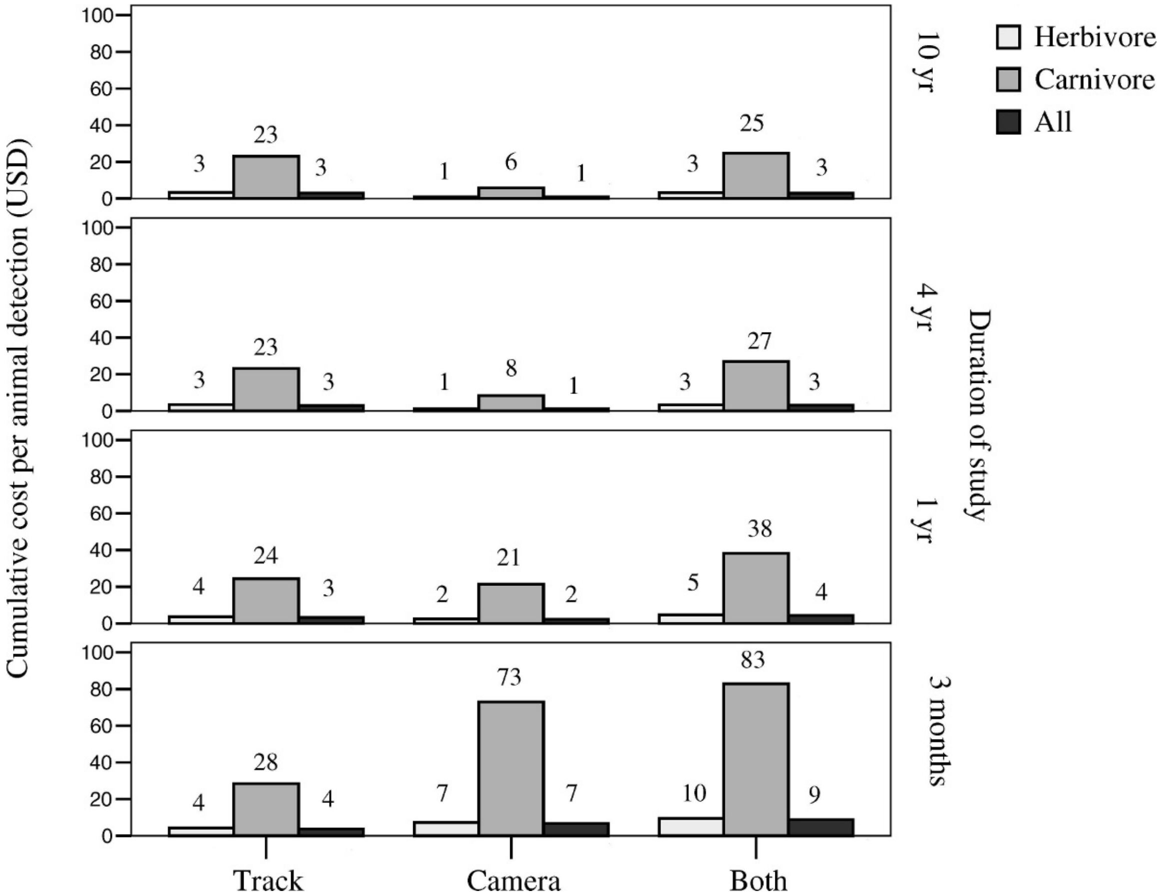

Figure 2. Estimated cost of monitoring wildlife crossing-structures/animal detection, using estimated study costs and mean number of large-mammal camera detections we encountered/month on the Trans-Canada Highway, Alberta, Canada, 29 June 2007 to 24 October 2007: US$43.36 herbivores; US$6.48 carnivores; US$49.84 for both species groups. Herbivore species include deer, elk, sheep, and moose, and carnivore species include black bear, cougar, coyote, grizzly bear, and wolf.

Besides higher long-term costs (Figs. 2 and 3), track-pads have 2 important limitations relative to camera-based monitoring of CS: 1) lower confidence in species identification, and 2) degradation of data quality during the monitoring interval. The tracks of some species in our study area were difficult to distinguish, whereas camera images can provide an accurate estimate of CS passages made by these species. We hypothesized above that track misidentification was the reason why track-pads appeared to detect more sheep and moose crossing events than did cameras. Additionally, mule deer and whitetail deer tracks were almost impossible to tell apart using track-pads. Given that deer species constitute >65% of crossing events we recorded (Table 1), it is indeed a major limitation of our data set that we cannot distinguish passage rates between these 2 species. The issue of species misidentification may become even more important when rare species use the CS alongside common species with similar looking tracks. In our study area, for example, wolverine (*Gulo gulo*), lynx (*Lynx canadensis*), and mountain goat (*Oreamnos americanus*) tracks could be easily classified as more common species such as wolves, cougars, or deer, respectively. In situations where these rare species are also legally designated as threatened or endangered, it is worthwhile to incorporate methods of animal detection that consistently minimize errors in species identification (Foster and Humphrey 1995, Kelly et al. 2008).

The other important limitation of track-pads is that data quality degrades as track-pad conditions worsen from both environmental and animal-use factors (Foresman and Pearson 1998). The effect of environmental variables on track-pad condition depends on the design of the structure, with track-pad quality at the exposed overpasses more dependent on weather conditions than at underpasses (Table 4). Animal activity at the CS also deteriorates the track-pad condition, leading us to underestimate the number of passages by almost half when approximately 10 crossing events occurred over a 2-day period (Table 5). Issues of species identification and data quality in track-pad monitoring can be addressed through camera-based methods.

Advantages of camera-based monitoring include more reliable species identification, more affordable long-term operating costs, and less sensitivity to weather conditions, CS design, and level of animal activity. Cameras can also provide additional data on the timing of the crossing event, group size, and sometimes the sex and age of individuals (Olsson et al. 2008). Remote cameras have been used in other studies to differentiate individuals based on coat patterns (Kelly et al. 2008, Long et al. 2008), though

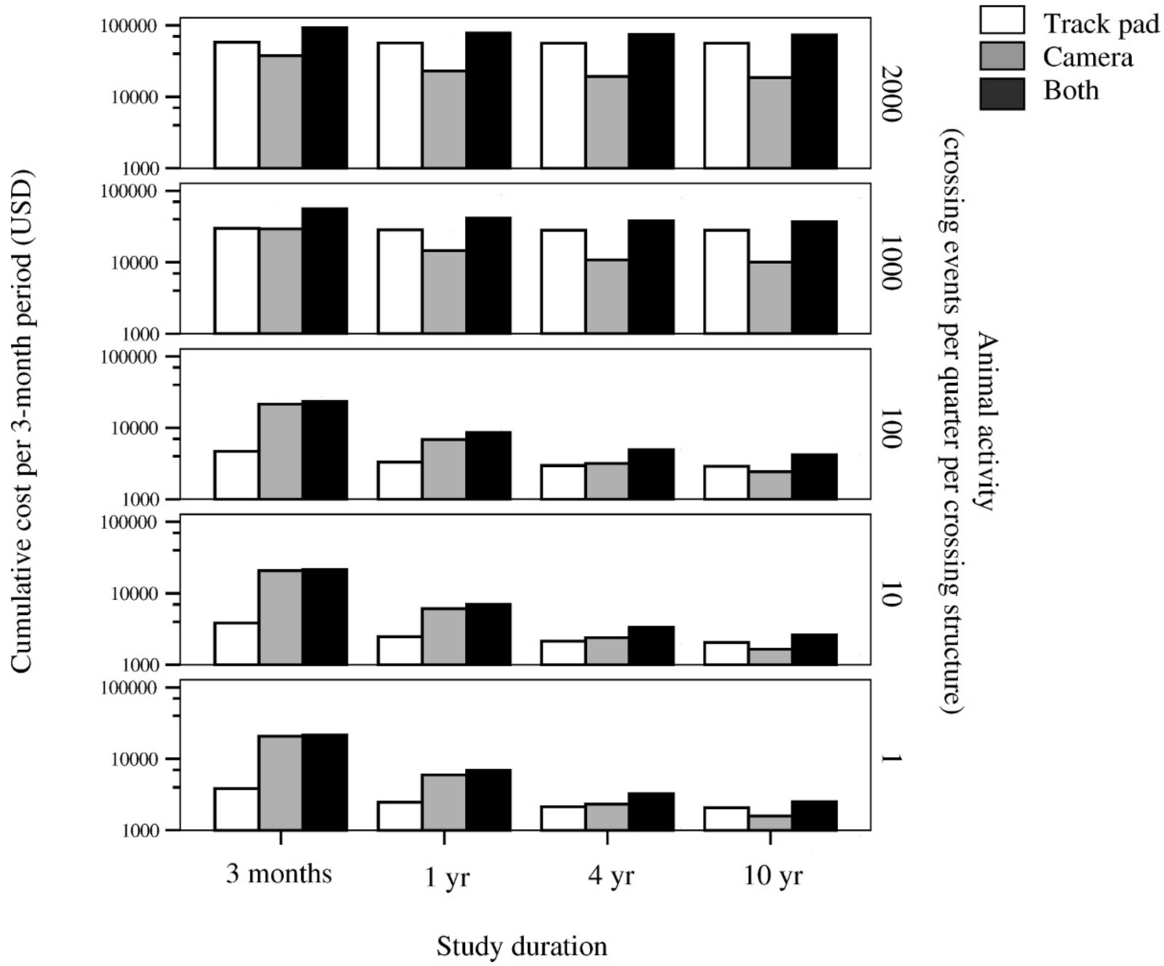

Figure 3. Estimated costs of monitoring wildlife crossing-structures given varying levels of animal activity encountered at each site and over different durations of monitoring on the Trans-Canada Highway, Alberta, Canada, 29 June 2007 to 24 October 2007. We present costs on a log scale.

conspecific coat patterns are too similar among the large mammals in our study to reliably use this technique for individual identification. While performing a species occupancy study, Foresman and Pearson (1998) found that cameras outperformed tracking due to higher detection rates, greater confidence in species identification, more reliable performance under varying weather conditions, less frequent field visits required, and greater ease of implementation. We agree with these findings but, unlike Foresman and Pearson (1998), our study also shows that cameras are less expensive than tracking. With the cost of remote cameras decreasing (A. T. Ford, Montana State University, personal communication) and the cost of fuel increasing, our economic models indicate that, in the near future, camera-based methods could become more affordable than track-pad methods for studies <1 year in duration.

Our results shed light on design considerations for CS monitoring studies. By using the logistic formula (Hosmer and Lemeshow 1989) with the coefficients from the best-fitting model to predict probability of agreement (Table 3), we can determine the relative importance of factors that contribute to crossing-event detection. For example, setting track-pad condition as Good, species as Deer, crossing events/monitoring interval = 1 (for both the same species and for all other species), and varying the track-pad length from 2 m to 10 m, we increase probability of agreement from 0.53 to 0.62. On the other hand, holding track-pad length constant at 2 m, and varying number of crossing events/monitoring interval (simultaneously for the same and for all other species) from 1 to 8, we reduce probability of agreement from 0.53 to 0.13. These results, combined with absence of other site variables in our best-performing model, suggest that animal activity is a more sensitive consideration in designing a CS monitoring plan than is camera placement or track-pad design. Reducing the number of crossing events/monitoring interval requires more frequent visits to a given site. However, human presence at CS increases disturbance to wildlife and may affect movement across the highway. For example, Clevenger and Waltho (2000) found that human activity at several crossing structures consistently had a negative effect on animal passage rates. An additional advantage of camera monitoring is that the duration of the monitoring interval could be increased without jeopardizing reliability of detecting crossing events.

Our field methods provide us with information on which species used the crossings and how often. Cameras also

Table 6. Benefits and limitations of cameras and track-pad methods for monitoring wildlife crossing-structures along the Trans-Canada Highway, Alberta, Canada, 29 June 2007 to 24 October 2007.

Issue	Track-pads	Cameras	Recommended method to address issue
Detections of coyotes and grizzly bears	Significantly higher probability of detection	Significantly lower probability of detection	Track-pads
Detections of elk and deer	Significantly lower probability of detection	Significantly higher probability of detection	Cameras
Detections of black bears, cougars, wolf, sheep, and moose	Work slightly better for wolves, sheep, and moose	Work slightly better for black bears and cougars	Either method
Monitoring interval	2–7 days	>2 weeks	Cameras
Disturbance to wildlife	Decreases inversely to duration of monitoring interval	Camera flash may disturb wildlife at night	Cameras
Species identification	Limited by species groups and track-pad condition	High confidence	Cameras
Temporal resolution of crossing events	Increases with no. of visits to the site	Does not depend on the no. of visits to the site	Cameras
Start-up costs	Cheaper	More expensive	Track-pads
Operational costs	More expensive	Cheaper	Cameras
Maintenance	Higher (at least once/yr)	Lower	Cameras
Weather dependency	Wind, snow, and rain negatively affect track-pad conditions	Condensation or frost can cover the lens	Cameras for overpasses, track-pads for underpasses
Security	Low risk of theft and vandalism	Higher risk of theft and vandalism	Track-pads

provided us with some information about gender, group size, age, and timing of crossing events. Both track-pads and cameras, however, share some important limitations when it comes to evaluating effectiveness of CS. For example, these methods cannot differentiate among individuals and can only estimate animal behavior within or near the CS from a limited area of observation (e.g., track-pad length or camera field of view), and we cannot use these methods directly to determine if highway mitigation measures are contributing to population persistence. Additional methods are available to monitor wildlife use of CS that can address these issues. Individual identification at CS has been used with capture–mark–recapture (McDonald and St. Clair 2004, Olsson et al. 2008), genetic sampling (A. P. Clevenger and M. Sawaya, Montana State University, unpublished data) and passive integrated transponder tags (Boarman et al. 1998). Video surveillance (Gagnon et al. 2007, Kleist et al. 2007) has been used to document individual responses to the CS and traffic.

MANAGEMENT IMPLICATIONS

Our analysis suggests that camera-based monitoring is more cost-effective in the long term and more efficiently detects crossing events for most large mammal species in our study area. Cameras are particularly more effective than track-pads at locations where animal activity is expected to be high. Tracking remains a viable means of monitoring CS (see Olsson et al. 2008), however, and the best choice of either of these 2 methods depends on the logistical constraints and objectives of the study (Table 6). If a long-term monitoring plan is being considered using track-pad–based methods, it is also worth considering using multiple detection methods at CS under a robust study design (Nichols et al. 2008), especially because the long-term costs of a combined approach in our study are similar to a track-pad–only approach (Fig. 2). Although cameras appear to be the best overall choice for monitoring CS and are increasingly being used in a variety of wildlife monitoring studies (Rowcliffe and Carbone 2008), there is further need to evaluate their effectiveness at CS relative to other methods using marked individuals (e.g., Cutler and Swann 1999, Long et al. 2007, Vanak and Gompper 2007, Olsson et al. 2008).

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