



Wildlife Responses to Non-Motorized Recreation in the Southern Canadian Rockies: A Multi-Scale Analysis near Fernie, BC

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1 Title: **Wildlife Responses to Non-Motorized Recreation in the Southern Canadian Rockies:**
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20 **Data availability**

21 The code and data to reproduce this analysis is deposited at the following github:

22 https://github.com/ctlamb/MtFernie_RecreationEcology

23 The photos and species classifications from the Fernie Trail Network data are publicly accessible

24 at the following links (each year of data is its own link):

25 <https://portal.wildtrax.ca/home/camera-deployments.html?sensorId=CAM&projectId=998>

26 <https://portal.wildtrax.ca/home/camera-deployments.html?sensorId=CAM&projectId=1401>

27 <https://portal.wildtrax.ca/home/camera-deployments.html?sensorId=CAM&projectId=1971>

28 <https://portal.wildtrax.ca/home/camera-deployments.html?sensorId=CAM&projectId=2626>

29

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40 Abstract

41 Human outdoor recreation is expanding across natural landscapes, yet its effects on wildlife
42 remain poorly understood across spatial and temporal scales and across different contexts. We
43 assessed the responses of large mammals to non-motorized recreation near Fernie, British
44 Columbia, using a multi-scale observational approach combining data from 66 camera traps and
45 GPS telemetry from 21 grizzly bears (*Ursus arctos*). We evaluated (1) how wildlife detections
46 varied by trail type, relative to the broader landscape, and with varying levels of recreational
47 users, and (2) whether animals shifted activity to avoid peak human use, and (3) how collared
48 grizzly bear movement responded to recreation compared to other anthropogenic features. Trail
49 type, surrounding landscape, and recreational pressure significantly influenced detection
50 probabilities, but responses varied by species and scales. Elk (*Cervus canadensis*) showed the
51 strongest avoidance, with reduced presence on recreation trails (odds ratio ≈ 0.037 , $p \approx 0.01$) and
52 a marked shift toward low-use periods ($\Delta\text{overlap} = -0.24$). In contrast, moose (*Alces alces*) and
53 mule deer (*Odocoileus hemionus*) were more frequently detected on or near recreation trails.
54 Grizzly bears consistently avoided areas adjacent to recreation trails in GPS movement data and
55 camera detections but were detected on recreation trails more than nearby wildlife trails
56 suggesting when they do move through the trail network they do so on recreation trails. These
57 findings highlight species- and scale-dependent behavioural responses, with effects ranging from
58 strong (elk), to moderate (grizzly bears), to minimal (black bears, moose, mule deer, red fox, and
59 white-tailed deer). Our results suggest that concentrating recreation near existing developed areas
60 and during mid-day should minimize impacts on wildlife while providing important access to
61 recreation for people. Maintaining low-use zones elsewhere will be important for more sensitive
62 species. While observational studies like ours are valuable for identifying patterns and informing

63 management of rapidly changing pressures, stronger inference through experimental designs is
64 encouraged to clarify causal relationships between recreation and wildlife behavior and further
65 elucidate species- and context- dependent relationships.

66

67 **Introduction**

68 Humans have long shaped the distribution and abundance of wildlife through habitat alteration
69 and direct mortality. Road networks fragment habitat and cause vehicle collisions (Forman and
70 Alexander 1998), human settlement and persecution has reduced or eliminated species from
71 large portions of their former ranges (Laliberte and Ripple 2004). While these negative effects
72 are well documented and intensifying in many regions, it is also true that people and wildlife
73 have coexisted on Earth for millennia. Multiple examples exist where ecosystems co-evolved
74 with human interaction and have suffered when human use has been excluded, as has been the
75 case with the exclusion of cultural and prescribed fire from dry montane forests in North
76 America during the 20th century (Greene 2021). Even under contemporary pressures, there
77 remain landscapes—some densely populated—where large mammal communities persist with
78 remarkable continuity (Laliberte and Ripple 2004). This paradox underscores a central challenge
79 in conservation biology: understanding the conditions under which wildlife can persist and even
80 thrive in contemporary human-dominated environments.

81 Just as wildlife depend on access to natural habitats, humans increasingly seek those
82 same landscapes for health, well-being, and recreation. Time spent in nature has been linked to
83 improved physical and mental health, enhanced cognitive function, and greater social cohesion

84 (Bratman et al. 2019). Outdoor recreation offers the dual benefits of time in nature paired with
85 cardiovascular exercise (Thomsen et al. 2018). As participation in outdoor recreation grows, so
86 too does the spatial extent of recreational use—particularly in mountainous and forested regions.
87 This expansion raises pressing questions about how human presence influences wildlife, and
88 how these landscapes can be stewarded to sustain both biodiversity and public access. Land
89 managers, recreation planners, and policymakers are increasingly seeking science-based
90 guidance to help anticipate, mitigate, or avoid unintended impacts on sensitive species (Miller et
91 al. 2020, Jordan et al. 2025).

92 Recreation ecology—the study of recreational impacts on ecological systems—has
93 expanded rapidly to meet this need (Monz et al. 2013). Yet its findings remain mixed. Some
94 studies report strong negative effects of recreation on wildlife, such as spatial displacement,
95 increased energy expenditure, reduced reproductive success, or elevated mortality risk
96 (Wiedmann and Bleich 2014, Thompson et al. 2024, Urhan et al. 2025). Others document
97 minimal or even positive responses, including behavioral habituation (Miller et al. 2020,
98 Granados et al. 2023) or the use of human-modified areas as refuges for prey from predators or
99 hunting pressure (Berger 2007). These variable responses tend to depend on species' sensitivity,
100 landscape context, and the type, timing, and intensity of recreation (Naidoo and Burton 2020,
101 Prockop et al. 2022). This heterogeneity of outcomes poses a challenge for managers: the best
102 available science is often context-dependent and difficult to generalize without appropriate
103 consideration of species, landscape, activity type, and scale.

104 Among the most informative studies are those that employ experimental or quasi-
105 experimental designs, such as before–after–control–impact (BACI) frameworks or manipulative

106 trail closures. For example, (Miller et al. 2020) conducted a BACI study around a new unpaved
107 recreational trail being built in an Appalachian protected area, focusing on responses from white-
108 tailed deer, coyotes, raccoons, and gray squirrels. Their results showed that overall species
109 decreased use of the area during trail building but returned to baseline detection levels once
110 construction was complete and humans were using the trail, albeit at low rates (1.4 visitors per
111 day). Notably, control sites helped decouple population fluctuations from experimental effects
112 that would have obscured results in even a traditional before-after experiment. Contrary to
113 Millers results, Wiedmann and Bleich (2014) assessed bighorn sheep responses to a hiking trail
114 built in western North Dakota, USA that had high rates of use. Although not stated in the paper,
115 in 2016 the trail apparently saw >15,000 users a year, or >40 people per day. They document
116 displacement, lower recruitment, population decline, and eventual abandonment of lambing areas
117 for one subpopulation of bighorn sheep. However, three other subpopulations of sheep were
118 exposed to the trail at lower intensities and with more consistent human use, and these
119 populations showed no negative effects from the trail and increased in size. Experimental
120 perturbations of elk and mule deer by recreationists at the Starkey Experimental Forest suggested
121 recreationist displaced elk by >500 meters, reduced the time elk fed or rested, and increased the
122 time they were travelling (Wisdom et al. 2018, 2018). Recreation effects on elk were greatest for
123 ATV riding, moderate from bikes, hikers, and horseback riders. Similar experiments on mule
124 deer at Starkey Experimental Forest did not produce strong effects (Wisdom 2005). Finally,
125 (Costello et al. 2013) assessed GPS collared black bear responses to the development of a non-
126 motorized trail alongside an existing road. At least 100 people were using the trail per day but
127 there was no detectable change in bear home range or frequency of crossing the corridor. Bears
128 did alter their 3rd order selection near the corridor and shifted to more nocturnal behaviour. Even

129 strong inference from experimental studies suggest recreational effects can and will vary by
130 recreational type, intensity, predictability and wildlife species.

131 Such context dependent responses to recreation are perhaps something that wildlife
132 managers will have to accept, and thus the more information that can be generated on how these
133 different contexts scale up to impact wildlife behaviour and demography at local and broader
134 scales will allow for better evidence-based management. Importantly, experimental approaches
135 can isolate causal effects but are logistically and ethically constrained, especially in high-use or
136 multi-jurisdictional areas. As a result, well-designed observational studies remain an important
137 part of knowledge generation, particularly when paired with complementary data sources such as
138 telemetry or high-resolution camera monitoring.

139 Scale is also critical to recreation ecology inquiry. Johnson's (1980) hierarchical
140 framework of habitat selection emphasizes that animals respond to their environment at multiple
141 levels: the placement of home ranges within the landscape (second-order selection), the use of
142 habitats within those home ranges (third order), and fine-scale behavioral decisions (fourth
143 order). Recreational activity can influence wildlife at all these scales. Animals may avoid regions
144 with high recreation altogether (Wiedmann and Bleich 2014), reduce use of areas near trails and
145 infrastructure within their home range (Whittington et al. 2022, Thompson et al. 2024), or shift
146 activity to less disturbed times of day (Gaynor et al. 2018, Lamb et al. 2020). Accurately
147 capturing such responses requires models and datasets that are sensitive to variation in both
148 space and time.

149 In this study, we examine how a community of large mammals responds to outdoor
150 recreation in the southern Canadian Rockies near Fernie, British Columbia. We addressed four

151 core questions: (1) Intensity of use: How do wildlife detections vary in areas of intense
152 recreational use relative to the surrounding landscape and how do different levels of recreational
153 use on trails influence detections? (2) Diel patterns: For animals present in the trail network, do
154 they adjust the timing of their trail use to minimize overlap with recreational users and how does
155 this compare to behaviour observed across the landscape? (3) Grizzly bear movement: How do
156 GPS-collared grizzly bears modify their movement and habitat selection in relation to trail
157 proximity and recreation intensity? (4) Near encounters: how common are close encounters in
158 space and time between humans and potentially dangerous animals such as bear or moose on
159 recreation trails? We hypothesized that if recreation was having strong and consistent negative
160 effects that wildlife would be detected at lower rates in areas near trails due to animals avoiding
161 the areas with high human disturbance. Within the trail network we hypothesized that wildlife
162 would avoid trails used by recreationist compared to nearby wildlife trails with low human use,
163 and that when using recreation trails, they would prefer to use recreation trails with lower
164 recreational use. We hypothesized that wildlife would temporally avoid the peak times of day
165 people are active on the trails and during these times and would avoid those times less in areas
166 with fewer people. We hypothesized that collared grizzly bears would strongly avoid the trail
167 network, and this avoidance would be similar in magnitude to other high impact disturbances
168 such as towns and the highway. Finally, we hypothesized that the overall avoidance of the
169 recreationist would mean there were few near encounters between recreationists and potentially
170 dangerous wildlife. To answer these questions, we combined multi-year camera-trap monitoring
171 integrated step selection analysis of grizzly bear telemetry. This multi-stream approach allowed
172 us to assess patterns of avoidance, co-use, and scale-dependent sensitivity to recreation activity.

173

174 **Methods**175 *Study Area*

176 We conducted our study in the forested mountain landscape surrounding Fernie, British
177 Columbia (49.5°N, 115.1°W), a city of 6,320 residents as of the 2021 Census . Situated in the
178 Elk Valley of southeastern British Columbia, Fernie lies along the Elk River and is encircled by
179 the Rocky Mountains, including the Lizard Range and Three Sisters peaks (Figure 1). The region
180 encompasses a broad elevation gradient (900–2,400 m) and features diverse forest types,
181 including montane and subalpine coniferous stands dominated by Douglas-fir (*Pseudotsuga*
182 *menziesii*), lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmannii*), and
183 subalpine fir (*Abies lasiocarpa*). Riparian zones along the Elk River and its tributaries support
184 black cottonwood (*Populus trichocarpa*) communities.

185 Fernie is accessible via Highway 3 (Crowsnest Highway), a major east-west
186 transportation corridor traversing southern British Columbia and connecting to Alberta through
187 the Crowsnest Pass . The area supports a diverse assemblage of large mammals, including
188 grizzly bears (*Ursus arctos*), black bears (*U. americanus*), cougars (*Puma concolor*), wolves
189 (*Canis lupus*), elk (*Cervus canadensis*), and mule and white-tailed deer (*Odocoileus spp.*). A
190 dense, year-round network of recreational trails—used by hikers, bikers, backcountry skiers, and
191 motorized users—overlays this habitat, primarily on provincial Crown land but also on private
192 land accessible to the public.

193

194 *Camera Traps*

195 We deployed remote cameras (Reconyx Hyperfire 2) throughout the recreational (Rec) trail
196 network on Mount Fernie and Mount Proctor (hereafter collectively called Mount Fernie trail
197 network) (Figure 1). Cameras were set on a tree 1.5 meters above the ground and 6-10 meters
198 from the trail. Any vegetation that would interfere with detection on the trail was removed each
199 year in the spring or summer.

200 We monitored human and wildlife use on two types of trails, 1) single and double track
201 bike and hiking trails (together called Recreation trails, n=18), and 2) adjacent wildlife trails
202 within 500 meters of trails (n=10). Cameras were programmed to take 5 photos at each detection
203 on high sensitivity, with <1 second (rapid-fire setting) between images. No delay between
204 subsequent detections were set, essentially meaning the camera took as many photos as fast as it
205 could while there was detectable movement in its' view. A timelapse photo was set to be taken at
206 12:00 pm daily to denote the period the camera was operating. The cameras were checked 2-10
207 times a year and were present year-round from May 2021- November 2024.

208 We uploaded images to WildTrax (<https://wildtrax.ca/>), a cloud-based camera trap data
209 management platform. The MegaDetector software (Beery et al. 2019) is automatically run
210 within WildTrax to remove high likelihood empty photos as well as humans and vehicles,
211 increasing the efficiency of downstream image processing (Fennell et al. 2022). A team of image
212 taggers from the Alberta Biodiversity Monitoring Institute manually verified species tags in each
213 image and classified images without species tags from the MegaDetector. For each image the
214 number of each wildlife species present in the image was recorded. We did not count the number
215 of humans present in each image due to the volume of photos, and rather just tagged to the type
216 of human use- bike, vehicle, off-road vehicle, heavy machinery, or human (typically a hiker or

217 runner). Initially we classified domestic dogs along with hikers and bikers on the trails. Dogs
218 were present at high rates, and we didn't expect that there would be sufficient variation in dog
219 absence or presence with recreationists to assess dog effects, thus we stopped tagging dogs in
220 2022 to reduce costs and do not conduct any analyses on domestic dogs. Off leash dogs were
221 common.

222 In addition to the camera traps specifically deployed for this project, we also used
223 cameras from neighbouring projects near Fernie to gain a broader landscape perspective (Figure
224 1). These cameras were dispersed through the Elk and adjacent river valleys as well as high
225 elevation areas. While these cameras were deployed on a variety of trail types, we only used the
226 cameras deployed on wildlife trails. We broke these landscape-level cameras into two groups.
227 The "landscape-valley" group was within 25 km of Fernie and in similar habitats to the Fernie
228 recreation cameras ($n=21$), which were typically Interior Cedar Hemlock or Montane Spruce
229 zones. The landscape-valley cameras were in areas that also had highways, railways, towns, and
230 resource roads but less recreational use than the Fernie trail network and thus provided a
231 comparison with insight into the additive effect of the trail network on wildlife detections and
232 behaviour. The second group, "landscape-remote", were in more remote and higher elevation
233 habitats than the Fernie trail network ($n=17$). Because the habitat of the landscape-remote
234 cameras was not as comparable with the Fernie trail network we used these cameras for temporal
235 (diel) comparisons only but not intensity of use. All cameras were Reconyx, although a variety
236 of Reconyx models were used (HP2X, Hyperfire PC600-900). We included the camera model in
237 our models to account for detectability differences. Details on these landscape-level camera
238 projects can be found in the following publications (Granados et al. 2023, Lamb 2025a, 2025b,
239 Lamb et al. 2025), Figure 1).

240

241 *Camera Statistical Analysis*

242 From the classified images, we created several datasets for the following analyses. We subset the
243 camera data to the period between May 1 and October 31 each year to focus on the snow-free
244 season, when wildlife were consistently present across the landscape. This period also
245 corresponded with peak non-motorized recreational activity on the Fernie trail network. During
246 the winter months many migratory ungulates left the area and bears were hibernating (Lamb et
247 al. 2022, Poole et al. 2024). Recreation use was low in winter on most trails except those
248 groomed for winter biking, walking, or cross-country skiing. We considered an alpha level of
249 0.10 for statistical analysis of the camera due to small sample sizes.

250 *Intensity of use*—We generated a detection dataset by collapsing consecutive photos of the same
251 species into single detection events if separated by less than ten minutes. This approach likely
252 underestimates the true number of recreationists detected as many individuals or groups may
253 pass in 10-minute window but aligns with the tagging protocol of the landscape-level cameras
254 allowing for comparison among projects. These detections were compiled for each species at
255 each camera. We assessed how average monthly detection rates varied by location (Recreation
256 trails and wildlife trails in the Fernie trail network and the Landscape-valley cameras outside the
257 Fernie trail network) using generalized linear mixed models. To account for the abundance of
258 months with no detections, we used a hurdle-model approach where we first modelled presence-
259 absence using a binomial model with logit link for each species per month and then a second
260 model where animals were detected using a truncated Poisson distribution to model the detection
261 rate (relative abundance). For each model we included random intercepts for camera model,

262 month, year, and camera ID. We also assessed if additional environmental variables were
263 appropriate to include to remove environmental variation between the camera projects that could
264 interfere with our comparisons. For each species we compared whether inclusion of indices of
265 habitat productivity (annual precipitation or summer enhanced vegetation index) improved the fit
266 of data to the model via Akaike's Information Criteria (AIC, Akaike (1973)). In cases where
267 these covariates improved model fit, we included the covariates in their final model models.

268 Within the Fernie trail network, we assessed how wildlife detection rates were influenced
269 by the number of recreational users on the recreation trails. We conducted this analysis at a
270 weekly interval to detect finer-scale responses of wildlife to changing recreation pressure. To
271 account for finer differences between trail locations we included measures of canopy cover,
272 slope, summer enhanced vegetation index, and distance to a building for each camera. We used
273 the hurdle model structure as above to model presence and then relative abundance based on the
274 number of recreational users on the trails. We included random effects for week of the year, year,
275 and camera ID. No random effect for camera model was included because the cameras were all
276 the same model in this analysis.

277 *Diel patterns*—In addition to comparing detection rates across space, we analyzed temporal
278 variation in response to human recreation by summarizing daily diel overlap between people and
279 wildlife across trail types. We assessed diel patterns using detection histograms and calculated
280 coefficients of temporal overlap (Δ) to quantify behavioral displacement of wildlife from people
281 on recreation trails, adjacent wildlife trails, and the wildlife trails across the broader landscape.
282 People were primarily detected on recreational trails and thus we compared the use of wildlife

283 during this period of high human use on the recreation trails to assess if animals not facing this
284 same level of human use still avoid these times or not.

285 *Near encounters*—To quantify how often large mammals were detected soon before or after
286 recreationists, we paired every biker and hiker detection on single-track trails with all detections
287 of black bears, grizzly bears, or moose at the same camera. We selected these animals as
288 they are the primary species that can be dangerous to people and were frequently detected in the
289 trail network. We then kept only the closest-in-time wildlife detection for each species and
290 recreation event. We calculated the time difference in minutes and summarized how often
291 wildlife detections occurred within 30 minutes and within 5 minutes of people. We visualized
292 these “near encounters” by species and recreation type.

293

294 *Collared Grizzly Bears*

295 Grizzly bears were collared throughout the Elk Valley between 2016–2024 as part of a study to
296 assess population demography (Lamb et al. 2023). Although the study goal was not to assess
297 recreational impacts on bear behaviour, we are able to leverage these data as part of our multi-
298 lines of inference approach given the abundance of grizzly bear telemetry around Fernie. Full
299 details on the grizzly bear capture and handling and relevant permits are summarized in (Lamb et
300 al. 2023). Briefly, the bears we considered here were collared with Vectronics Vertex Lite GPS
301 collars programmed to take locations every 2 hours during the active season for grizzly bears
302 (April to December). The data was transmitted via Iridium satellite. We collared all age and sex
303 classes except animals <2 years of age due to challenges fitting collars to these rapidly growing

304 young bears. For this analysis we used location data for bears with at least 50 locations within 10
305 km of Fernie between May 1-October 31 across years.

306 *Grizzly Bear Integrated Step Selection Analysis*

307 We used integrated step selection analysis (iSSA) to evaluate how large mammals respond to
308 human recreation and habitat features in the Fernie region of British Columbia (Avgar et al.
309 2016). Step selection functions were implemented using conditional Poisson regression with
310 random effects, which is mathematically equivalent to conditional logistic regression but enables
311 more flexible estimation of random slopes and intercepts using generalized linear mixed models
312 (GLMMs) (Muff et al. 2020).

313 For each GPS-collared animal, observed steps were paired with a set of ten random
314 available steps drawn from the empirical step length and turn angle distribution, forming
315 matched strata of one “used” and ten “available” steps. We then fit iSSA models using the
316 glmmTMB package (v1.1.7) in R, with a binary response variable (where 1 = used step and 0 =
317 available), family = poisson, and a random intercept for each stratum to condition the analysis
318 within each matched set.

319 The fixed effect’s structure included habitat covariates (e.g., land cover type, elevation,
320 summer greenness [EVI]), topographic complexity (TRI), and several measures of anthropogenic
321 influence, including distance to trail, highway, and rural development, as well as semipermeable
322 barrier effects. Movement covariates included step length (log-transformed), turn angle (cosine),
323 and their interaction (e.g., cos_ta:log_sl_km) to capture behavioral state transitions. We also

324 included habitat-by-movement interactions (e.g., `cos_ta:dist_to_trail`) to allow for context-
325 dependent movement decisions.

326 To account for variation in selection across individuals and seasons, we included random
327 slopes by individual ($(0 + \text{covariate} | \text{id})$) for key habitat, movement, and barrier variables, and a
328 random slope for elevation by month to account for seasonal effects ($(0 + \text{elevation_end} |$
329 $\text{month})$). All continuous covariates were standardized prior to modeling to facilitate convergence
330 and comparability of coefficients.

331 We used a candidate model approach to evaluate how outdoor recreation and
332 environmental covariates influenced step selection by wildlife. We began with a core set of
333 ecological and movement covariates and iteratively added disturbance and barrier terms to
334 construct biologically plausible models. Each candidate model was evaluated using AIC and the
335 top model was selected based on parsimony and fit.

336 To assess model stability and performance, we examined predicted values to ensure no
337 extreme or implausible outputs and checked for convergence warnings. Due to the structure of
338 iSSA data—particularly the large number of strata and design-imposed zeros—we did not use
339 residual simulation tools such as DHARMA, which are known to perform poorly under these
340 conditions.

341

342 **Results**

343 *Camera Traps*

344 Cameras operated in the Fernie trail network for 13, 698 trap nights between May 1, 2021, and
 345 October 31, 2024, and captured 1,739,387 images. After removing empty images and classifying
 346 unique detections (images 10 minutes apart) there were 98,499 detections. Of these detections,
 347 88,558 were of people, 43 of domestic species, and 9,451 were of wildlife (Table 1). Mountain
 348 bikers were the most detected recreational group on the cameras. White-tailed and mule deer
 349 were the most detected wildlife. Several species were detected at low rates (<30 detections) such
 350 as bobcats, badgers, wolverine, and a mountain goat and were not used in subsequent analyses
 351 due to their rarity. We focus our analyses on 7 large/medium mammal species with > 30
 352 detections each (white-tailed deer, mule deer, elk, red fox, moose, black bear, and grizzly bear).

353

354 *Table 1. Summary of detections by species at Fernie Trail Network cameras between May and*
 355 *October each year between 2021-2024*

Group	Species	Sites	Detections	Hit rate per 100 days
Human	bike	19	73346	535.5
Human	human	28	14666	107.1
Human	all terrain vehicle	8	286	2.1
Human	vehicle	5	242	1.8
Human	heavy equipment	2	18	0.1
Wild	white-tailed deer	28	3611	32.6
Wild	mule deer	27	2008	17.9
Wild	elk	27	1382	13.4
Wild	red fox	22	908	6.7

Wild	moose	26	670	5.7
Wild	black bear	28	464	3.8
Wild	deer	24	141	1.1
Wild	grizzly bear	20	101	1
Wild	snowshoe hare	7	85	0.6
Wild	gray wolf	11	22	0.2
Wild	cougar	9	14	0.1
Wild	bird	9	13	0.1
Wild	coyote	8	10	0.1
Wild	porcupine	6	7	0.1

356

357 *Camera Statistical Analysis*

358 *Intensity of use*— Across species, trail type and its' surrounding habitat influenced detection
 359 probabilities and relative abundance, but effects varied by species and by model component
 360 (presence vs. abundance). Trail contrasts were assessed both between the Mt. Fernie trail
 361 network and the broader valley, and within the trail network (wildlife vs. recreation trails, Figure
 362 2).

363 Humans and bikers were overwhelmingly detected on recreation trails. Presence and
 364 abundance (given presence) were significantly higher in the Mt. Fernie trail network compared to
 365 Landscape-valley sites (human presence Odds Ratio (OR) >120, $p < 0.001$; abundance ratio >8,
 366 $p < 0.001$, although bike model struggled with convergence due to near zero bikes detected at

367 Landscape-valley sites). Within the trail network, detections were strongly concentrated on
368 recreation trails (presence OR>55, p < 0.001; abundance ratio >626, p < 0.001).

369 Black bears presence was higher within the trail network overall compared to Landscape-
370 valley sites ($OR \approx 3.6$, $p \approx 0.022$) and showed significantly higher presence on wildlife trails
371 within the trail network compared to Landscape-valley sites ($OR \approx 4.7$, $p \approx 0.016$). Black bear
372 abundance did not differ significantly across contexts when present. Elk occurred more
373 frequently in Landscape-valley sites than in the Mt. Fernie trail network ($OR \approx 26.7$, $p \approx 0.013$).
374 Within the trail network, they were more likely to occur on wildlife trails than Recreation trails
375 ($OR \approx 2.6$, $p \approx 0.065$), consistent with the near-zero detections on recreation trails. Grizzly bears
376 were detected infrequently, but trail type affected their probability of occurrence. Abundance
377 was lower on the Mt Fernie trail network than Landscape-valley sites (abundance ratio ≈ 0.45 , p
378 ≈ 0.06), but presence appeared unaffected. Within the Mt Fernie trail network, Grizzly bear
379 presence was higher on recreation trails than wildlife trails ($OR \approx 4.7$, $p \approx 0.001$).

380 Moose showed the opposite pattern. Both presence and abundance were significantly
381 higher in the trail network compared to Landscape-valley sites (presence $OR \approx 59.9$, $p < 0.001$;
382 abundance ratio ≈ 3.2 , $p \approx 0.014$). Moose were most often detected on recreation trails, but
383 differences between recreation and wildlife trails within the trail network were not significant.
384 Mule deer followed a similar trend to moose. Presence and relative abundance was higher on
385 recreation trails than wildlife trails within the Mt Fernie trail network (presence $OR \approx 3.2$, $p <$
386 0.015 ; abundance ratio >1.8 , $p \approx 0.07$). Landscape-level differences in mule deer detections
387 between the Mt Fernie trail network and Landscape-valley sites were not notable.

388 Red foxes were significantly more likely to occur in the Mt Fernie trail network than in
389 the Landscape-valley sites (presence OR ≈ 16.4 , $p < 0.001$) and were more abundant on
390 recreation trails than on wildlife trails (abundance ratio ≈ 3.7 , $p \approx 0.005$), leading to the highest
391 expected detections on recreation trails. White-tailed deer showed somewhat higher detection
392 rates at Landscape-valley sites than the Mt Fernie trail, but none of the presence or abundance
393 contrasts reached statistical significance. Cougars and gray wolves were rarely detected, and
394 models generally did not converge for these species. We did not consider either species in
395 subsequent analyses.

396 Species varied in their responses to local recreation activity on single-track trails, but the
397 strength and direction of effects differed by species and model component (presence vs.
398 abundance, Figure 3). Elk showed the strongest evidence of recreation avoidance: both the
399 probability of occurrence ($\beta \approx -0.37$, $p \approx 0.002$) and expected abundance ($\beta \approx -0.15$, $p \approx 0.038$)
400 declined significantly with higher recreation use — a stronger effect than any local habitat
401 variable in the model.

402 In contrast, mule deer and moose showed positive associations with recreation activity.
403 Mule deer were more frequently detected in areas with greater recreation use, with positive
404 effects on both presence ($\beta \approx 0.25$, $p \approx 0.069$) and relative abundance ($\beta \approx 0.14$, $p \approx 0.036$),
405 although these effects were moderate in size. Moose also showed a significant increase in
406 relative abundance with higher recreation levels ($\beta \approx +0.32$, $p \approx 0.009$), but presence was not
407 significantly affected ($\beta \approx +0.11$, $p = 0.48$).

408 Red fox, black bear, white-tailed deer, and grizzly bear showed no clear relationship with
409 local recreation levels. For these species, both presence and abundance estimates were small and

410 statistically non-significant ($p > 0.1$), indicating little to no consistent response to trail use
411 intensity.

412 *Diel patterns*— Hikers and bikers were active almost entirely during daylight hours on single-
413 track trails, with detections peaking from about 9 AM to 8 PM. All wildlife species showed
414 strongly crepuscular or nocturnal activity overall, with lower detections during these core
415 human-use periods (Figure 4).

416 The overlap estimates reflect how closely each wildlife species' daily activity on
417 recreation trails, wildlife trails, landscape-valley, and landscape-remote coincides with the peak
418 periods of recreation use on recreation trails, hereafter called the recreation period (Figure 5). In
419 this analysis we incorporate the Landscape-remote cameras, which capture animal behaviour in
420 higher elevation areas with much lower human pressure than the other areas and perhaps serve as
421 a comparison for behavior that is less impacted by people. Black bears had moderately lower diel
422 overlap with recreation periods on recreation trails (mean ≈ 0.62) than on adjacent wildlife trails
423 (0.74 ; $\Delta = -0.13$, $p < 0.10$). However, overlap did not differ significantly between recreation
424 trails and landscape-valley or landscape-remote sites. Elk exhibited clear diel avoidance: overlap
425 on recreation trails (0.28) was significantly lower than on adjacent wildlife trails (0.40),
426 landscape-valley sites (0.31), and especially landscape-remote sites (0.51). The greatest contrast
427 was between recreation trails and landscape-remote sites ($\Delta \approx -0.24$, $p < 0.10$), indicating strong
428 temporal shifts away from human-dominated periods on busy trails. Grizzly bears showed
429 moderate diel differences, with significantly lower overlap on recreation trails (0.44) than in
430 landscape-remote areas (0.62 ; $\Delta \approx -0.15$, $p < 0.10$). Overlap on recreation trails vs. landscape-

431 valley sites was slightly higher ($\Delta \approx 0.12$) but not statistically significant, and no estimate was
432 available for wildlife trails due to too few detections.

433 Moose showed minimal diel variation across contexts. Overlap estimates ranged from
434 0.43 (recreation trail) to 0.50 (landscape-remote), with only a small difference between
435 recreation trails and remote sites ($\Delta \approx -0.07, p < 0.10$), suggesting modest temporal avoidance of
436 peak human use. Mule deer had broadly consistent overlap across locations but showed
437 significantly lower overlap at landscape-remote sites (0.44) compared to recreation trails (0.51; Δ
438 $\approx -0.09, p < 0.10$). Slight differences from recreation to wildlife trails ($\Delta \approx -0.03$) or landscape-
439 valley ($\Delta \approx -0.01$) were not significant.

440 Red foxes exhibited the strongest diel shift: overlap was much lower on recreation trails
441 (0.18) than on wildlife trails (0.41; $\Delta \approx -0.25, p < 0.10$) and valley sites (0.41; $\Delta \approx -0.23, p <$
442 0.10), consistent with strong temporal avoidance of human activity in high-use areas.
443 Comparisons with landscape-remote sites were not possible due to too few detections. White-
444 tailed deer showed slightly lower diel overlap in landscape-valley and remote contexts ($\approx 0.40-$
445 0.44) compared to recreation trails (0.53), with significantly higher overlap on recreation trails
446 vs. landscape-valley ($\Delta \approx 0.13, p < 0.10$) and vs. landscape-remote sites ($\Delta \approx 0.08, p < 0.10$).
447 This pattern suggests a tolerance of daytime human activity.

448 *Near encounters*—Across all recreation trail detections, only a small fraction of recreation events
449 were associated with close-in-time wildlife detections. For black bears and moose, about 0.1% of
450 recreation events had a wildlife detection within 30 minutes (149 and 148 cases respectively),
451 and around 0.02% fell within just 5 minutes. Grizzly bears showed even lower overlap, with only
452 0.015% of recreation events within 30 minutes (19 cases) and fewer than 1 in 1000 within 5

453 minutes (1 case). Histograms show that most close calls clustered within 5–30 minutes, with no
454 strong bias toward bikers or hikers for any species (Figure 6).

455

456 *Collared Grizzly Bears*

457 After sub-setting to the focal area around Fernie and the desired seasonal window we retained
458 19,489 GPS collar locations from 21 grizzly bears between June 2017 and October 2024. An
459 average of 928 locations per bear were collected within the focal area, which ranged from 61-
460 3,012 locations across all 21 bears.

461 *Grizzly Bear Integrated Step Selection Analysis*

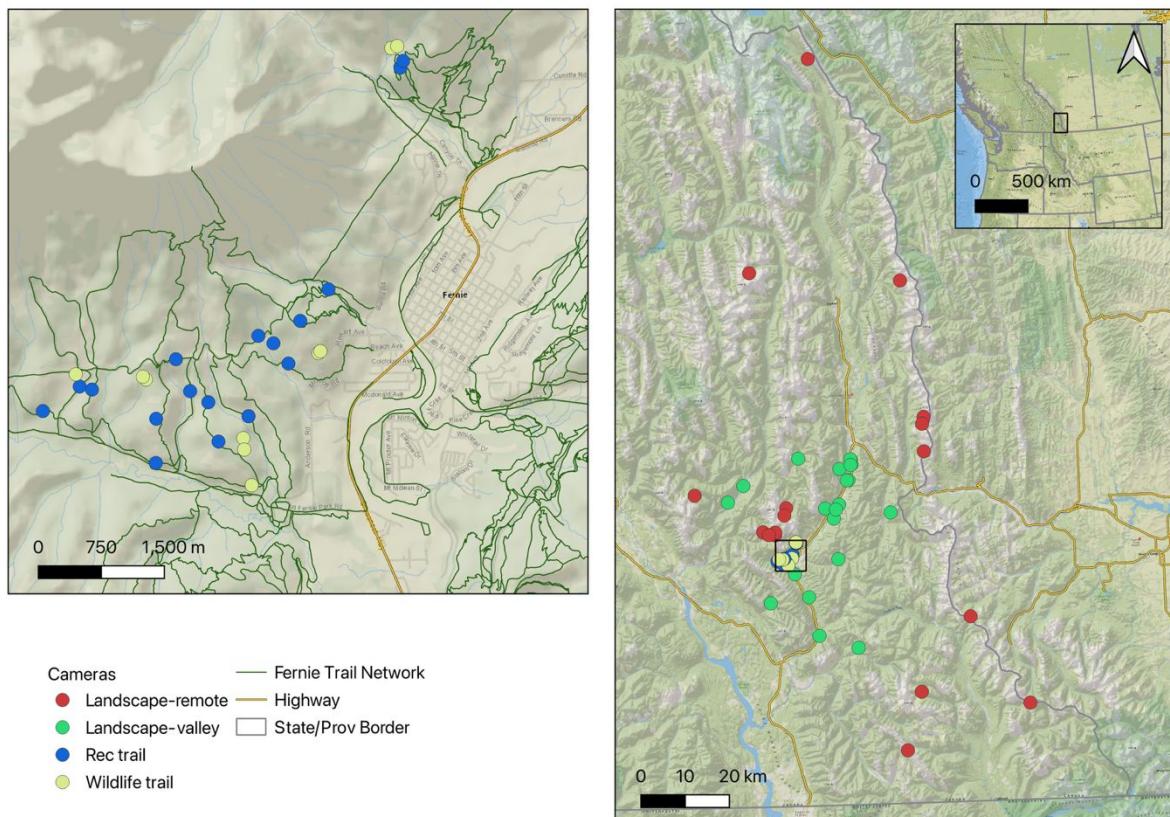
462 A suite of candidate iSSA models was compared using AIC to evaluate drivers of wildlife
463 movement. The best-supported model included trail distance, town distance, and highway effects
464 (AIC = 394,212), outperforming all alternatives by ≥ 34 AIC units. This suggests that the
465 combined influence of multiple anthropogenic features best explains movement behavior, with
466 trails emerging as particularly influential (Figure 7).

467 Among fixed effects, animals selected areas with higher summer greenness (EVI $\beta = 0.44, p <$
468 0.001) and avoided steep elevation gains ($\Delta\text{elev } \beta = -0.37, p < 0.001$). Distance to trails
469 significantly increased selection ($\beta = 0.088, p = 0.016$), indicating avoidance of trail-adjacent
470 areas. Crossing trails further reduced selection ($\beta = -0.23, p < 0.001$), an effect of smaller
471 magnitude to barrier effects from highways ($\beta = -0.50$) and rivers ($\beta = -0.68$). Trail-related
472 avoidance was notable but generally weaker than town and highway effects. Step-trail

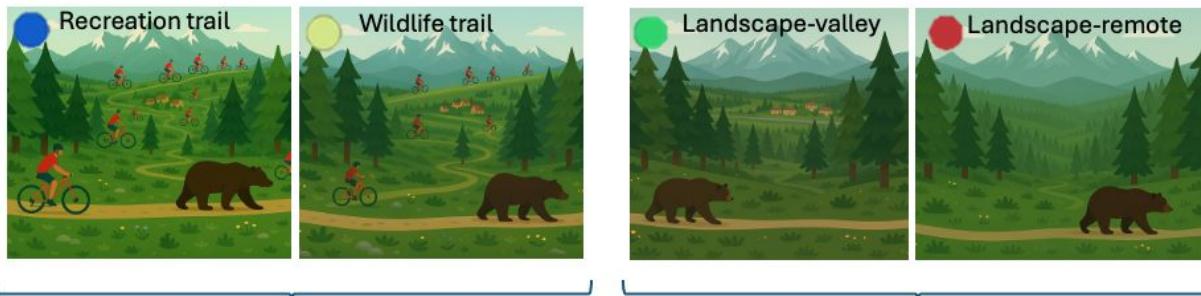
473 interactions revealed that animals took longer steps when closer to trails ($\beta = -0.044, p < 0.001$),
474 suggesting faster movement near recreation infrastructure. Random slopes revealed substantial
475 individual variation, particularly for barrier responses.

476

For Review Only



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478

Fernie Trail Network

Across Landscape

479 *Figure 1. Map of study area near Fernie, BC, Canada in the southern Canadian Rockies. The*
 480 *Fernie trail network was assessed west and north of Fernie BC on the slopes of Mount Fernie*
 481 *and Mount Proctor with cameras on wildlife trails and recreation trails. Landscape-level*
 482 *comparisons across these habitat contexts were made with ancillary data from neighboring*
 483 *camera projects where landscape-valley were in similar habitats and a multi-use landscape to*

484 *the Fernie trail network cameras but with less overall non-motorized recreation pressure.*

485 *Landscape-remote were on wildlife trails in areas with lower levels of human pressures*

486 *compared to the other cameras but were also in different habitats (often higher elevation) and*

487 *not thus intensity of use at these cameras were not as directly comparable to other cameras.*

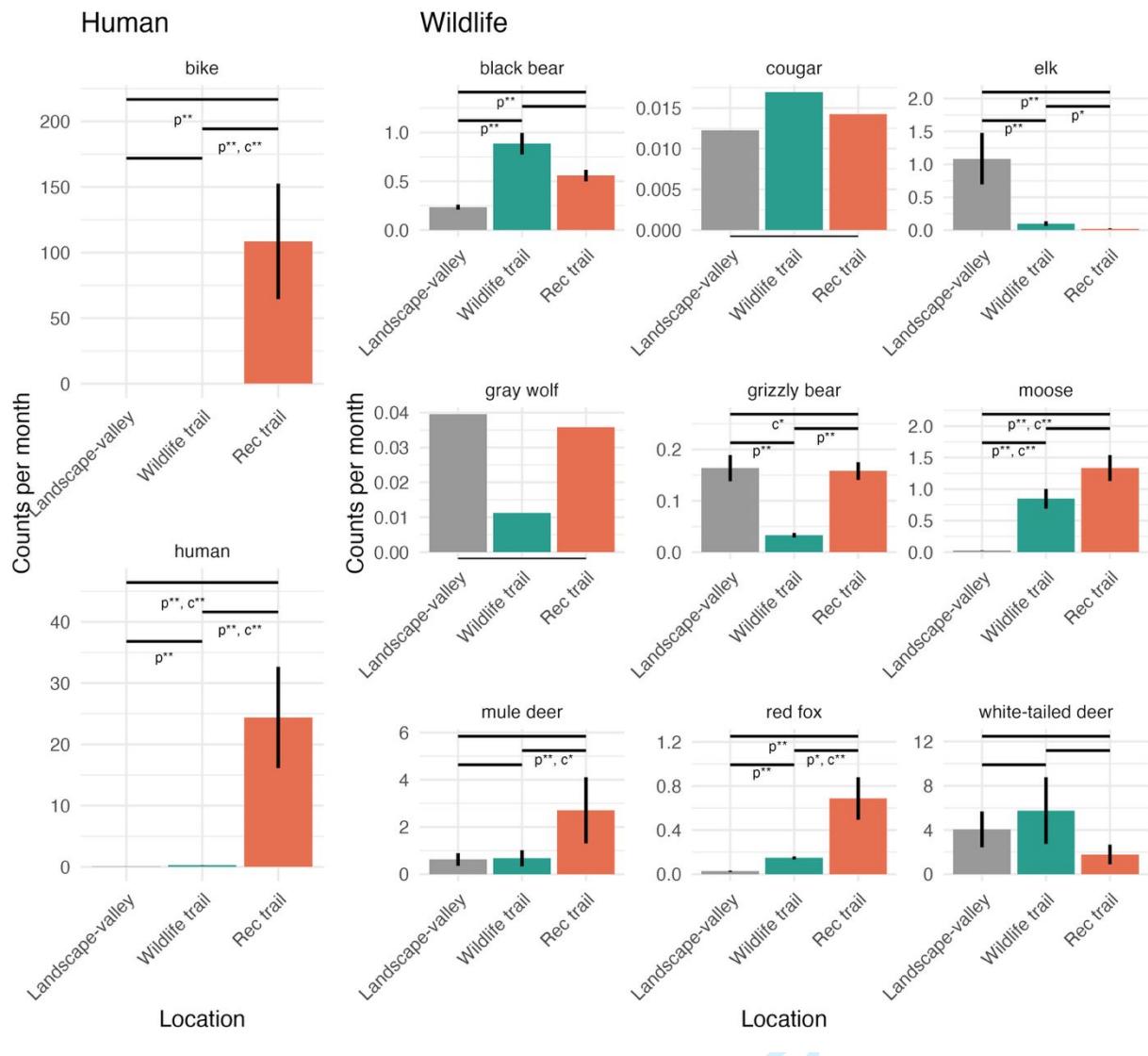
488 *Landscape-remote cameras were also on wildlife trails and used as a baseline for diel patterns*

489 *in wilder areas.*

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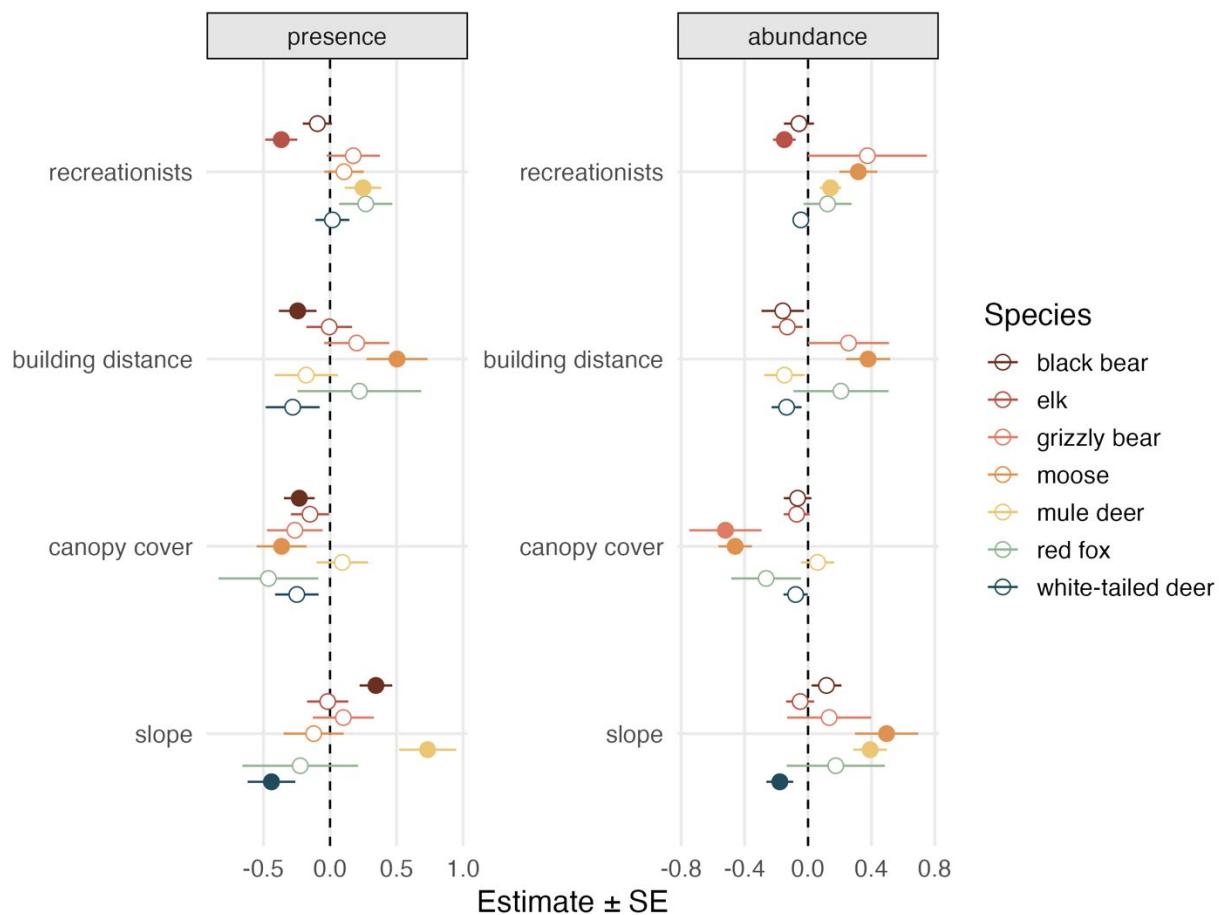


492

493 *Figure 2. Intensity of use (monthly detection rate) assessments for human and wildlife groups*
 494 *across three zones. Results are predictions from a GLMM, and statistical significance shown as*
 495 **for $p < 0.1$ and **for $p < 0.05$ for presence (p) and relative abundance counts (c) under the*
 496 *applicable bar. Horizontal Bars indicate comparison between groups. The horizontal bar*
 497 *spanning the full width is a combined comparison between landscape-valley and the Mt Fernie*
 498 *trail network (i.e., wildlife and recreation trails pooled). Cougar and gray wolf did not have*
 499 *sufficient detections for model convergence and were excluded from subsequent analyses.*

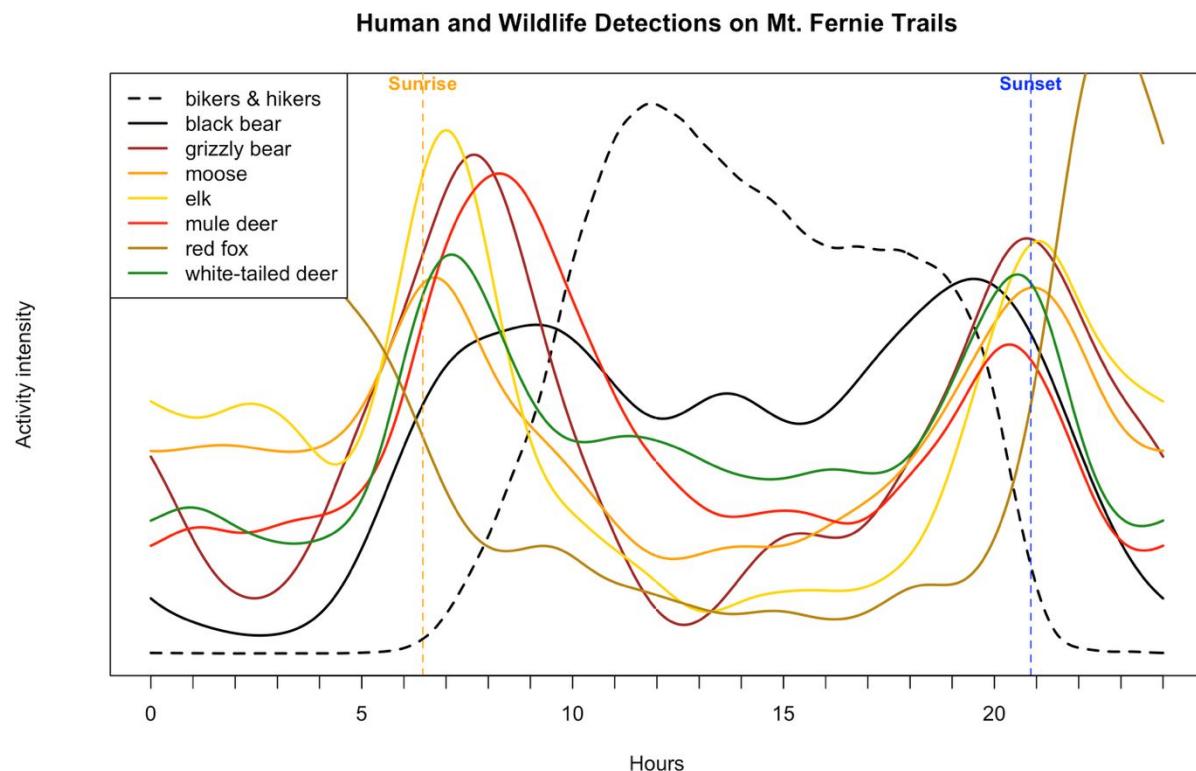


500



501

502 *Figure 3. Influence of the number of recreationists on wildlife detections by species on*
 503 *recreation trails in the Fernie trail network. Ancillary habitat variables included to control for*
 504 *additional variation and compare magnitude of response. Filled dots signify statistical*
 505 *significance at $p < 0.1$.*



506

507 *Figure 4. Diel patterns of wildlife and human recreation on recreation trails in the Fernie trail*
508 *network.*

509

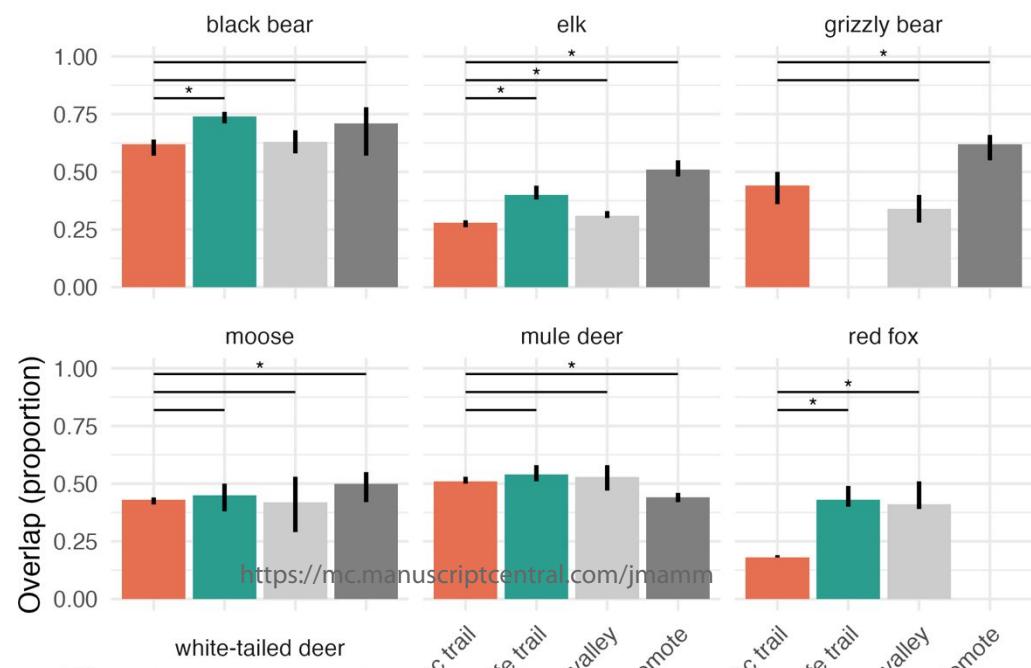
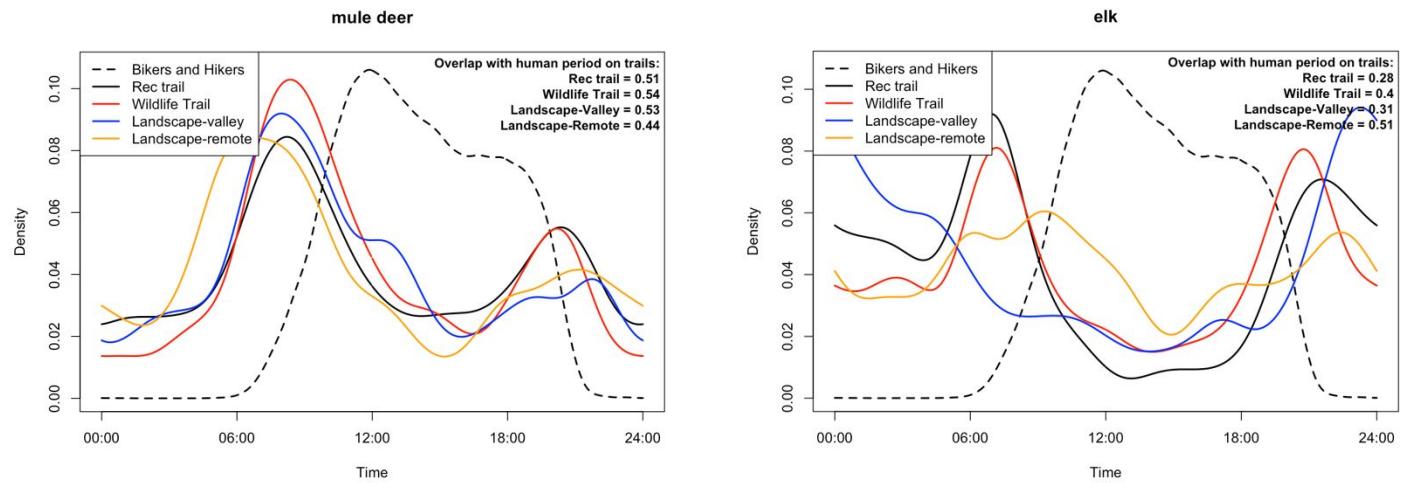
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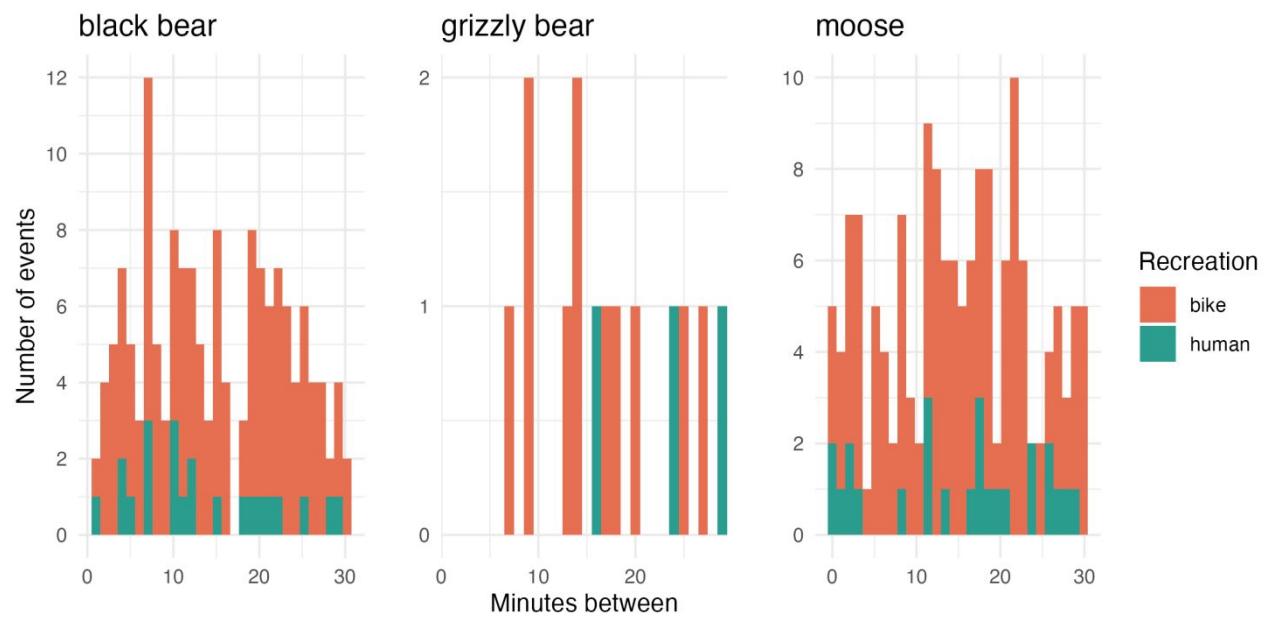
516 *Figure 5. top left) Comparison of recreation, wildlife, and larger landscape diel patterns for*
 517 *mule deer which show little diel changes across habitat context, top right) Comparison of*
 518 *recreation, wildlife, and larger landscape diel patterns for elk that show more daytime activity in*
 519 *remote areas, bottom) average overlap with peak recreation time from recreation trails between*
 520 *trail types for all species and areas.*

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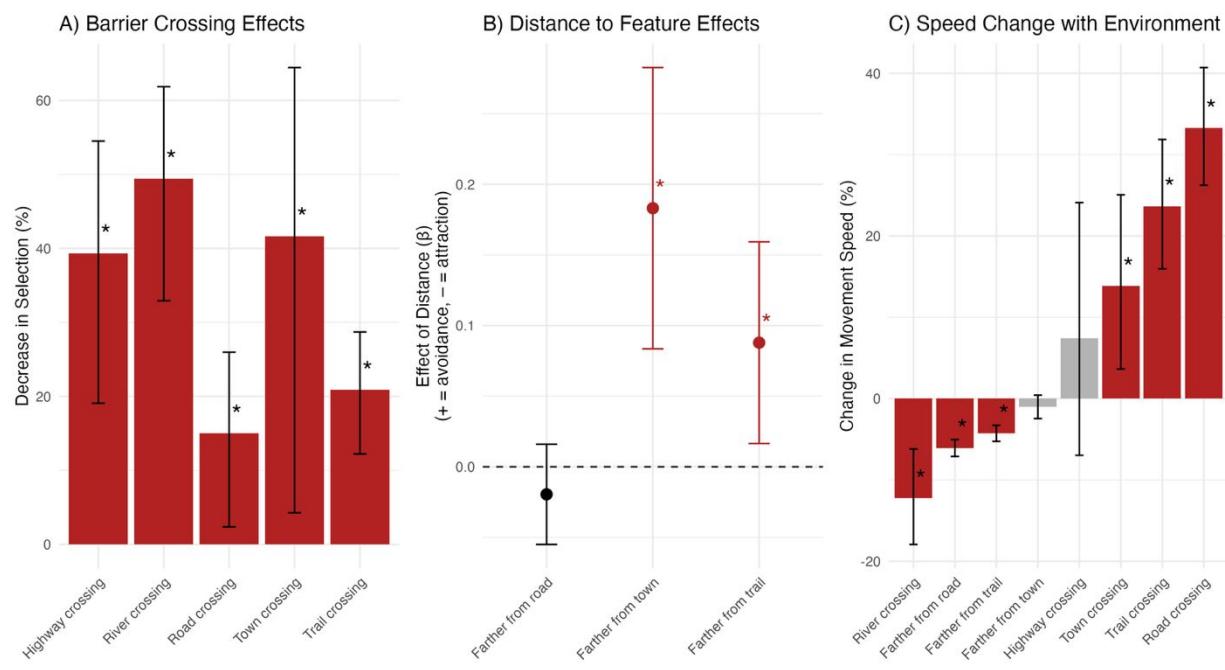


525

526 *Figure 6. Near encounters between recreationists and three species of wildlife that can be*
 527 *dangerous to people. top) Example sequence showing bikers detected 2 minutes before and 5*

528 minutes after a black bear on a single-track trail, and bottom) histogram of minutes between
 529 recreationists and select wildlife species between 2021-2024.

530



531

532 *Figure 7. Integrated step selection results for grizzly bears near Fernie, BC. Response to human*
 533 *features shown A)decrease in selection for crossing various human features, B) effect of*
 534 *distance to human features. Note highway not included here due to covariance with distance to*
 535 *town, and C) change in movement speed in various contexts.*

536

537

538

539

540 *Table 2. Summary of recreation effects across scales and species.*

Selection Order		3rd		4th	
Species	Response to trail network at landscape scale	Fine scale use of trails vs nearby wildlife trail	Use of single-track trails with increasing recreational pressure	diel patterns on trails when people are active	Overall effect
Black bear	selection	neutral	neutral	avoidance	Landscape selection, avoidance/coexistence
Elk	avoidance	avoidance	avoidance	avoidance	Landscape avoidance
Grizzly bear	avoidance	selection	neutral	avoidance	Landscape avoidance
Moose	selection	neutral	selection	avoidance	Landscape selection, avoidance
Mule deer	selection	neutral	selection	neutral	Landscape selection, avoidance
Red fox	selection	selection	neutral	avoidance	Landscape selection, avoidance
White-tailed deer	neutral	neutral	neutral	selection	Landscape neutral, fine scale selection

541

542

543 **Discussion**

544 Our study revealed that large mammal responses to non-motorized recreation in the Southern
 545 Canadian Rockies varied considerably among species, spatial scales, and behavioral metrics. Elk
 546 and grizzly bears showed avoidance of recreation at landscape and trail scales, whereas black
 547 bear, moose, mule deer, white-tailed deer, and red fox exhibited tolerance or behavioral
 548 adaptations such as diel shifts in activity. The goal of our study was to add to the growing body
 549 of literature on wildlife responses to recreational pressure and provide wildlife managers with
 550 locally relevant information to inform decisions, given previous research documented substantial
 551 species and context-specific responses to recreation (e.g., (Naidoo and Burton 2020, Miller et al.
 552 2020, Prock et al. 2022, Granados et al. 2023, Jordan et al. 2025)).

553 Overall, our hypothesis of strong and negative responses to recreation across species was
 554 rejected. Instead, and perhaps inconvenient for management, we observed variable and scale-

dependent responses in several species. Elk, for example, exhibited avoidance of recreational areas at both broad (third order) and fine (fourth order) scales, suggesting that recreation may displace individuals from otherwise suitable habitat. Grizzly bears showed moderate landscape-scale avoidance of trail networks in GPS and camera data but appeared to select for recreational trails rather than wildlife trails as travel corridors when moving through the trail network. In contrast, red foxes did not show strong spatial avoidance but shifted their activity patterns to avoid humans temporally. It is likely that landscape-scale avoidance may be more indicative of demographic consequences such as reduced abundance due to loss of habitat, whereas diel behavioral shifts may reflect a more flexible, potentially less costly strategy of coexistence.

The variation in responses among species likely reflects both intrinsic traits, such as body size, trophic position, and anti-predator strategies, and extrinsic factors including recreation intensity, trail design, and predictability of human presence. Conceptual frameworks such as the “landscape of fear” (Brown et al. 1999), “risk-disturbance hypothesis” (Frid and Dill 2002), and the “human shield hypothesis” (Berger 2007) have been proposed to explain these patterns. The landscape of fear framework suggests that animals perceive and respond to spatial variation in predation risk, often avoiding areas they associate with danger—even if those areas contain valuable resources (Brown et al. 1999). Building on this, the risk-disturbance hypothesis posits that wildlife treat human disturbance as a form of predation risk, leading to anti-predator behaviors such as avoidance, increased vigilance, or altered activity patterns in areas used by people (Frid and Dill 2002). Because some wildlife avoid people, the human shield hypothesis proposes that some prey species may benefit from human presence by using areas near people as refuges from natural predators, who themselves avoid humans (Berger 2007). Empirical results provide mixed support for these hypotheses in explaining the variation among species and scales

578 in response to recreation. Multi-species analyses often show some species had positive responses
579 to recreation (Naidoo and Burton 2020, Prockro et al. 2022, Fennell et al. 2023, Granados et al.
580 2023), suggesting the risk-disturbance hypothesis does not explain recreation effects as whole.
581 Support for the landscape of fear and human shield also remain mixed with cases of predator and
582 prey selecting for recreation trails (Granados et al. 2023), but others showing some support for
583 avoidance of recreation trails by large predators and selection by prey (Prockro et al. 2022,
584 Fennell et al. 2023).

585 Our findings provide additional insights. Prey species showed mixed responses to
586 recreation with clear avoidance by elk and selection by mule deer and moose, suggesting that
587 there is not widespread support for the landscape of fear or risk-disturbance hypotheses. We had
588 limited data to fully assess the human shield hypothesis, however the one large predator, grizzly
589 bear, that we had sufficient data for did appear to avoid the area due to recreation pressure.
590 Limited data on cougar and wolves reduced our ability to assess the response of the full large
591 predator community but the anectodical evidence we had showed cougars detected at similar
592 levels within the trail network compared to the surrounding landscape and perhaps some
593 avoidance by wolves. Regardless, because the primary prey of these large carnivores did not
594 show consistent selection or avoidance of the area and thus the human shield hypothesis is not an
595 explanation for the responses of all species in the Fernie trail network.

596 The response of elk to recreation was among the most consistent and negative of all
597 species in our study. Elk were significantly less likely to occur within the trail network compared
598 to the broader landscape, and within the trail network, they were less likely to use trails than
599 adjacent off-trail areas. When using recreation trails, elk were more likely to use trails with fewer

600 recreational users—the only species with this response. These multiple lines of evidence suggest
601 that recreation may displace elk from otherwise suitable habitat, consistent with other studies
602 showing elk sensitivity to human activity (e.g., Prock et al. 2024, Jordan et al. 2025). Elk
603 avoided daytime periods on recreation trails more than they do in remote areas and wildlife trails
604 within the Fernie trail network. However, elk generally had low use of daytime periods on
605 recreational trails, wildlife trails, and the landscape-valley cameras compared to landscape-
606 remote cameras suggesting the avoidance of daytime on the recreation trails may not solely be
607 due to recreation effects and may be a response to additional human pressures such as towns,
608 roads, or hunting pressure. Overall the strong response of elk to recreation in our study and
609 others seems to juxtapose with concurrent observations of elk becoming a nuisance in human-
610 dominated areas such as agricultural fields and even in towns (Wilmers and Levi 2013, Guthrie
611 2020, Rutherford et al. 2025r). Resolving this juxtaposition was not a focus of our study but
612 clearly demonstrates the multiple competing pressures that elk are responding to in a multi-use
613 landscape. In the case of agricultural conflicts, the reduced prevalence of hunters and predators
614 on working ranches paired with productive forage results in dense congregations of elk. Clearly
615 human presence thus does not always produce negative responses in elk, and when human
616 presence also provides productive habitat and mortality reduction elk can be found in great
617 numbers. There are other examples where elk congregate near people and disturbance such as
618 open pit coal mines in the Elk Valley where hunters and predators are likely fewer and patches of
619 reclaimed areas can temporarily provide nutrient dense food (Poole et al. 2024). Indeed elk do
620 appear to show a functional response in selection for human footprint that depends on the level
621 of human footprint they are continually exposed to suggesting habituation and synanthropy
622 (Gaynor et al. 2025). Elk likely avoid recreation trails because the trade-off of being disturbed by

623 recreationists is not offset by benefits such as better forage and there is not sufficient predator or
624 hunter avoidance of these areas. One prediction from this would be that if recreational use was
625 more intense in the Fernie trail network and as a result predators avoided the area more, and
626 forage was increased through habitat restoration, then elk may have reduced or positive
627 responses. Such a prediction would require testing, and such increased recreational intensity
628 would continue to come with trade-offs for other species and recreationist.

629 Grizzly bears displayed a complex response to non-motorized recreation. At a broad
630 scale, GPS data indicated moderate avoidance of the Mt. Fernie trail network relative to the
631 surrounding valley landscape. Within the network, however, camera data showed grizzly bears
632 were more likely to use recreation trails than adjacent wildlife trails, but overall, the use of the
633 trails within the Mt Fernie network (wildlife and recreation trails) was lower than the
634 surrounding landscape. This apparent selection for recreation trails compared to wildlife trails
635 within the trail network may reflect efficient travel along predictable corridors, which is
636 consistent with the step selection analysis that shows bears moving faster when using the trail
637 network. The overall low detection rates within the trail network and moderate avoidance of
638 high-use zones suggest that trail use by grizzly bears is limited to periods or areas with lower
639 human activity. This dual pattern of broad-scale avoidance and localized, functional trail use is
640 consistent with a risk-management strategy in which bears minimize overlap with people while
641 exploiting the linear features for movement when safe to do so. Similar to elk, grizzly bears were
642 more nocturnal within the Fernie trail network and landscape-valley trails than the landscape-
643 remote cameras suggesting human effects beyond just recreation are causing bears to alter their
644 behaviour. The iSSA analysis provides important context of bears' response to other competing
645 human pressures. While bears avoided the trail network, they more strongly avoided settled areas

646 such as the area around the town of Fernie, thus the effects detected from cameras within the
647 Fernie trail network must be considered with cumulative effects of additional pressures of the
648 town, highway, and roads in mind. Bears avoided crossing the recreation trails and resource
649 roads, but not nearly as much as they avoided crossing the town, or highway.

650 From a management perspective, our results indicated that non-motorized recreation can
651 influence wildlife habitat use and behavior, but effects were species- and context-specific. It is
652 our perspective that overall, the behavioural effects of recreation were moderate to low for the
653 species we considered, especially considering the currently compact footprint of the trail network
654 relative to the surrounding landscape. Of the species considered, elk and grizzly bear were the
655 primary species that showed negative effects, with elk showing the most consistent and strong
656 responses. Mitigating the negative effects to elk and grizzly bear could be accomplished by
657 concentrating recreation in high-use, predictable areas such as those around existing towns. Such
658 an approach reduces the spatial extent of disturbance because the towns themselves already have
659 a buffer of impacts around them and provides low use refugia for more sensitive species in the
660 areas outside the concentrated recreation areas. Seasonal or spatial closures may be warranted in
661 areas that overlap with key habitats or during vulnerable periods such as bighorn sheep lambing
662 areas or bear dens. To protect the nocturnal and crepuscular periods that wildlife often begin to
663 use as pressure increases during the day it is recommended to concentrate recreation pressure
664 during the daylight hours between 10 am and 7 pm. The very low rate of near encounters
665 between recreationists and wildlife, particularly large carnivores, suggests that current patterns of
666 recreation do not pose a high risk of conflict, though proactive measures such as signage,
667 concentrating use during the day, and education remain important. The animals within the Fernie
668 trail network are often avoiding human recreation at some scale, likely to reduce any negative

669 effects on themselves, so seeing as the animals are doing what they can to coexist with recreation
670 it's important for recreationists to do what they can to coexist with wildlife.

671 While it is well documented that time in nature is good for people, the effects of
672 recreation on wildlife continues to be an evolving area of research that struggles to find
673 consistently strong effects across contexts and species. There is also substantial variation in the
674 perspectives of the public and recreationists on the effects of recreation on wildlife, which ranges
675 from benign to substantial impacts. Recreationists commonly perceive any negative
676 environmental impacts as the fault of other recreation types and rarely their preferred type of
677 recreation (i.e., hikers blame mountain bikers and horseback riders, and vice versa, (Taylor and
678 Knight 2003)). In a landscape of murky results, polarized stakeholders, and increasing
679 recreational pressure, landscape managers are clearly left in a challenging position. Some of the
680 challenge in finding consistent effects of recreation may be a result of layers of ecological
681 complexity that result in true context-dependency or could be a result of generally small true
682 effect sizes and confounding variables creating variable results. Our study relied on
683 observational data, which limits our ability to infer causality. Although we used a multi-scale
684 design and integrated data from camera traps and GPS telemetry, confounding factors such as
685 habitat quality, habituation, topography, and detectability can never be perfectly accounted for.
686 As noted by others (e.g., Jordan et al. 2025), stronger inference requires experimental
687 approaches, such as Before-After-Control-Impact (BACI) designs, temporary trail closures, or
688 controlled recreation manipulations. While such studies present logistical and ethical challenges,
689 they are critical for establishing causal links between recreation and wildlife responses and for
690 identifying thresholds of acceptable use. We encourage land managers, trail alliances, and
691 researchers to collaborate to set up BACI experiments prior to new trails being built. Such an

692 experiment would ideally have multiple years of before and after data and include measurements
693 directly on the trail and nearby within the buffer of potential recreation effects (100-500 m).
694 Such an approach would provide strong evidence of the effect of recreation on wildlife.
695 Replicating these experiments across gradients of recreation disturbance such as new trails
696 within existing networks and those within a less disturbed landscape, as well as across differing
697 recreation use volumes would eventually provide the critical information to assess the context-
698 dependent nature of recreation.

699 In conclusion, non-motorized recreation influences wildlife behavior and space use in
700 complex, scale-dependent ways. Some species demonstrate behavioral plasticity that may
701 facilitate coexistence, while others appear more sensitive to human presence and may be
702 displaced from preferred habitats. Managing recreation to maintain predictable use patterns,
703 minimize trail proliferation, and retain undisturbed refugia will be essential to support diverse
704 wildlife communities in multi-use landscapes. Future experimental and demographic studies will
705 further help quantify the long-term impacts of recreation and to inform adaptive management
706 strategies.

707

708

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716

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