Understanding the Effects of Human Recreation on Wildlife from Fieldwork to Management Decisions

Marcela Inés Todd Zaragoza

A thesis
submitted in partial fulfillment of the
requirements for the degree of

Master of Science

University of Washington
2025

Committee:
Beth Gardner
Andrea S. Thorpe
Alex McInturff

Program Authorized to Offer Degree:
School of Environmental and Forest Sciences

University of Washington

Abstract

Understanding the Effects of Human Recreation on Wildlife from Fieldwork to Management Decisions

Marcela Inés Todd Zaragoza

Chair of the Supervisory Committee:

Beth Gardner

School of Environmental and Forest Sciences

Interest in outdoor recreation is increasing across natural landscapes, benefiting people and communities, but posing challenges for wildlife and land managers. This thesis examines recreation and wildlife management through field-based research on wildlife responses to recreation and an exploration of how scientific research informs management decisions. In Chapter 1, we examined the impacts of recreation on wildlife using camera trap data from 113 stations across eight Washington State Parks in the wildland-urban interface (WUI) — critical ecological zones where recreation-wildlife dynamics remain understudied. Using dynamic occupancy models and temporal activity analyses, we found that recreation influences species detection probabilities and activity patterns. Raccoons, bobcats, and cougars were more likely to be detected at stations with high recreation, while black bears, elk, black-tailed deer, and coyotes had higher detection probabilities at stations with low recreation. Temporal shifts were evident among coyotes and deer, which had significant differences in their activity patterns, showing increased diurnal activity in off-trail areas. To understand how field-based studies inform recreation and wildlife management, Chapter 2 examines the role of science in decision-making. We conducted semi-structured interviews with 14 land managers from local, state, and federal agencies in Washington, using thematic analysis grounded in the Theory of Planned Behavior. While managers expressed positive attitudes toward science-based decision-making, structural constraints, resource limitations, and communication gaps were barriers to research integration. In contrast, partnerships and accessible science were key facilitators, with tribal and local community pressures shaping management priorities. As outdoor recreation expands, maintaining spatial and temporal refuges for wildlife and strengthening the integration of science into management decisions will be essential for balancing wildlife conservation with sustainable recreation access.

Table of Contents

Chapter 1: Human Recreation Influences Detection and Activity Patterns of Mammals in the Wildland-Urban Interface

ABSTRACT

The growing demand for outdoor recreation has resulted in the increasing potential for human activity to displace wildlife in natural environments. While most recreation research has focused on large contiguous landscapes, transitional zones like wildland–urban interface (WUI) are critical ecological areas where natural landscapes interface with urban development. These zones support biodiversity in fragmented landscapes but face growing pressures from expanding urbanization and increasing recreation, underscoring the need to better understand recreation–wildlife dynamics. In this chapter, we studied the impacts of non-consumptive recreation on the spatial and temporal activity patterns of 7 mammal species across 8 Washington State Parks in the WUI. We analyzed camera trap data from 113 camera stations collected between summer 2021 and fall 2024, paired with environmental and recreation covariates, using dynamic occupancy models and temporal activity analyses we found recreation affected both detection probabilities and temporal activity patterns. Raccoons, bobcats, and cougars had higher detection probabilities in areas with high recreation activity while black bears, elk, black-tailed deer, and coyotes had higher detection probabilities in areas with low recreation activity. Colonization and extinction probabilities varied by season for deer, coyotes, and bobcats, highlighting shifts in habitat use over time. Trail width and distance to focal point also played a role in detection probability for most species. Temporal shifts were evident for most species and most strongly seen in coyotes and deer, which showed significant increased diurnal activity in off-trail areas. Our results suggest that most species prefer areas with lower recreation and alter their temporal

patterns to minimize overlap with human activity. As WUI recreation areas continue growing in popularity, maintaining spatial and temporal refuges for wildlife will be crucial for supporting biodiversity while ensuring sustainable recreation access.

INTRODUCTION

Participation in outdoor recreation has increased dramatically in the past several years. Non-consumptive recreational activities, such as hiking, mountain biking, and equestrian trail use, can play a vital role in harnessing public support of public lands (Zaradic et al., 2009) and in connecting people with cultural and natural resources (Cooper et al., 2015; Nelson and Bailey, 2021). While these recreational activities may be perceived as harmless to wildlife, increasing evidence indicates they can negatively impact wildlife species, causing behavioral responses (Arlettaz et al., 2007; Naylor et al., 2009), changes in spatial or temporal habitat use (George and Crooks, 2006), and, at a population level, declines in abundance, occupancy, or density (Banks and Bryant, 2007). However, these effects are highly context-dependent and influenced by a variety of factors including type of recreation activity and intensity, species' sensitivity to human disturbance, and habitat characteristics (Knight and Cole, 1991; Larson et al., 2016).

A review of 274 studies on the impacts of recreation on wildlife found that 93% reported at least one impact of recreation on wildlife, with 59% of those impacts being negative (Larson et al., 2016). Wildlife in natural areas respond to human activity using three strategies: behavioral, spatial, or temporal shifts. Behaviorally, wildlife may become more vigilant in areas with humans. The presence of humans can cause species to perceive an increased risk of predation, leading to a reduction in fitness-related behaviors such as foraging or reduced caring for young as they navigate a trade-off associated with anti-predator behaviors (Frid and Dill, 2002; Belotti et al., 2018). Species can also modify their movement patterns to avoid or seek human use areas. Some may favor areas with lower levels of human use over those with high recreational use or avoid areas within certain distances of trails, even in areas where human activity is low (Rogala et al., 2011; Sytsma et al., 2022). Temporally, species may either align their activity patterns with human presence or shift their patterns to avoid periods of peak human activity (Gaynor et al., 2018).

Species respond differently to recreation depending on their ecological traits and sensitivity to anthropogenic factors. Temporal avoidance of humans is common across many species, while spatial avoidance is usually observed for bigger-sized species and larger groups of animals (Stankowich and Blumstein 2005; Hennings 2017). For example, larger carnivores like cougars (*Puma concolor)* are more sensitive to fragmentation, as they have large space requirements, and have been shown to avoid recreational areas (Hennings 2017). Cougars and bobcats (*Lynx rufus)* also have a high sensitivity to urbanization due to their solitary nature and carnivorous diet, requiring natural habitats (Crooks 2002; Ordeñana et al., 2010). In contrast, generalist species like coyotes (*Canis latrans*) and raccoons (*Procyon lotor*) show increased occupancy near urban areas, due to their efficiency at exploiting anthropogenic food sources and their tolerance of urban developments (Hadidian et al., 2010; Ordeñana et al., 2010; Reilly et al., 2017). Despite these differences in spatial patterns, all four species have shown shifts towards more nocturnal activity to avoid direct human interaction (Ordeñana et al., 2010; Wang et al., 2015; Reilly et al., 2017). Similarly, in areas of both low and high human use, black bears (*Ursus americanus)* have shifted their temporal activity patterns to avoid peak human activity (Sytsma et al., 2022).

Meanwhile, black-tailed deer (*Odocoileus hemionus hemionus*) may benefit areas with human activity can serve as a protective effect from predators, known as the “human shield effect” (Berger, 2007). This can cause an “attraction” to human areas, either spatially or temporally. To accurately understand human impacts on wildlife species, it is important to consider the type of human disturbance and the species’ sensitivity through a multi-disturbance and multi-species approach.

The effects of human disturbance on wildlife species are influenced by the frequency, timing, type, and predictability of the disturbance (Lewis et al., 2021). Recreation impacts can vary depending on season. For example, disturbances during the non-breeding season could affect foraging and survival while disturbances during the breeding season could affect productivity (Knight and Cole, 1991). Recreation dynamics are important considerations for the level of disturbance they present to wildlife. Trail-based recreation is more predictable, and less alarming to wildlife, compared to off trail recreation (Hennings, 2017). Hikers with dogs are more disturbing to wildlife compared to hikers and equestrians without dogs, while mountain bikers tend to be more alarming due to their noise, speed, and unpredictability (Hennings 2017; Naidoo and Burton, 2020). Understanding the different impacts of recreation types and timing on wildlife is important for balancing recreation access and conserving wildlife.

Research on recreation impacts on wildlife has largely focused on extensive protected areas (e.g., national parks or forests; Belotti et al., 2018; Procko et al., 2022; Granados et al., 2023) or, alternatively, on urbanized environments (e.g., Lewis et al.,2015; Poisson et al., 2023). There remains a critical need to investigate these dynamics in the wildland-urban interface (WUI), transitional zones where urban features, such as houses or other infrastructure, intersect with wildland habitats like forests that have minimal human development. Increased development in WUI areas leads to habitat loss and degradation, putting native species and ecosystems at risk (Bar-Massada et al., 2014). Due to their accessibility, WUI areas are characterized by high levels of non-consumptive recreational activities that are widespread and present year-round (Stein, 2005).

As urbanization expands, WUI areas experience rapid changes, including growing housing development, encroachment of infrastructure into natural habitats, and increased recreational pressures (Rasker and Hansen, 2000; Radeloff et al., 2005; Seto et al., 2017). Unlike large, contiguous protected areas, many WUI landscapes consist of habitat "islands" surrounded by human development with fragmentation and reduced connectivity (Jenerette et al., 2022). The combination of urbanization and recreation poses unique threats to wildlife in the WUI, demanding a better understanding of their responses to human activities. While some species can do well in highly urbanized environments, others with specific habitat requirements or high sensitivity to human disturbance require refugia to escape the high human densities characteristic of urban landscapes (DeStefano and DeGraaf, 2003).

WUI habitats can serve as critical refugia and movement corridors for species displaced by urbanization (Jenerette et al., 2022). Remnant habitat strips and revegetated landscapes have been found to provide important linkages for native species (Bolger et al., 2001). The small size of WUI habitats and their proximity to human activity make them especially vulnerable to cumulative stressors like habitat loss and degradation, increased human-wildlife conflict, and increased recreation (Bar-Massada et al., 2014). Nevertheless, by facilitating species movement, these habitats provide essential linkages between urban and wildland areas, reinforcing their ecological importance.

As development in the WUI expands, recreational use is also expected to increase, making effective management crucial to minimizing its impact on wildlife (Seto et al., 2017). Management strategies must balance the growing demand for outdoor recreation with the need to preserve ecological integrity. Given the rapid changes occurring in WUI landscapes, proactive planning and targeted management will be essential to minimize the negative impacts of human activity on wildlife (Kellner et al., 2017). Understanding how outdoor recreation influences wildlife in these dynamic landscapes is essential for guiding management strategies that sustain both biodiversity and recreation access.

Here, we asked two key questions: 1) How does human activity in WUI recreational areas influence the spatial patterns of wildlife? And 2) How do varying levels of human activity affect the temporal activity patterns of wildlife? To address these questions, we used occupancy models and temporal activity analyses fit to camera trapping data for 7 medium- to large-sized mammals across 8 western Washington state parks. We hypothesized that felids (i.e., cougars and bobcats) would be negatively impacted by human recreation, exhibiting behavioral avoidance in response to increased recreational activity due to human-derived risk (Moss et al., 2015). We predicted that spatially, felids would avoid sites with higher levels of human use. We also predicted that, temporally, felids would adjust their activity patterns to avoid periods of human activity, with stronger adjustments observed in areas of high human activity compared to areas of low human activity. We hypothesized that generalists like coyotes would be associated with human recreation as they may be more tolerant of human disturbance and efficient at exploiting human food sources (Devictor et al., 2008; Hadidian et al., 2010). Specifically, we predicted that occupancy probability would be less influenced by human recreation and temporally, generalists would exhibit more nocturnal behavior in areas of high human use. Lastly, we hypothesized that ungulates would exhibit spatial and temporal alignment with humans, due to the "human-shield effect", potentially using areas with higher human activity as a refuge from predators (Berger, 2007). Specifically, we predicted that ungulates would show higher occupancy in areas with high levels of human activity and that temporally, they might align their activity patterns with human presence.

METHODS

Study area

We used systematic camera trapping from 2021 to 2024, to study the effects of human outdoor recreation on black-tailed deer, black bear, bobcat, cougar, coyote, raccoon, and elk (*Cervus canadensis*). Our study area included eight state parks: Beacon Rock, Fort Ebey, Deception Pass, Larrabee, Moran, Olallie, Squak Mountain, and Wallace Falls (Figure 1). Six of the eight parks are located within 100 miles from Seattle and receive a high number of visitors annually. These parks have experienced a dramatic increase in the levels of recreation in the past six years, shifts in the patterns of recreational activity, and higher volumes of endurance running and cycling events, including larger events and events spanning multiple days and nights. These parks receive thousands to millions of non-consumptive, non-motorized recreational visits annually, including activities such as hiking, dog walking, mountain biking, and equestrian trail use. Motorized use on park trails is restricted to park personnel and hunting is not permitted. Our study parks were selected based on their extensive trail networks and relatively high numbers of permits for special recreational activities. These special recreational activities include a variety of long-distance races, night races, and other trail running and mountain biking events placing large groups of participants on trails in addition to the daily recreational activities present throughout the parks.

Our study parks were situated within the WUI, with most parks having urban development (e.g., neighborhoods) near one or several sections of the park. All parks were located near cities or towns ranging in size from 1,300 to 95,000 people, with the furthest city being 3 miles away from the main entrance of Beacon Rock. The study parks range in size from 261 hectares at Fort Ebey to 2,126 hectares at Moran, encompassing diverse forested ecosystems. These were characterized by a variety of habitats, including North Pacific Maritime Dry-Mesic Douglas-fir–western hemlock forests, North Pacific Dry Douglas-fir-(Madrone) forests and woodlands, North Pacific Lowland Riparian forests and shrublands near pasture edges, North Pacific Maritime Mesic-Wet Douglas-fir–western hemlock forests, and harvested forest-shrub regeneration areas (Washington State Parks and Recreation Commission, 2025).

Camera trap sampling design

We deployed cameras at 119 locations across our study area between March 2021 and August 2023. Most cameras were placed on trails that varied from single-track trails to closed administrative roads. In March 2021, Washington State Parks personnel deployed 40 cameras in four parks (Beacon Rock, Fort Ebey, Larrabee, and Moran). Trails within each of the four parks were stratified by habitat significance and relative recreational use. Habitat significance was determined using a model of habitat value developed by Washington State Parks that integrates seven different metrics of habitat characteristics and conditions. Relative recreational use was determined using Strava Heatmaps. These heatmaps were created from public user data uploaded to Strava, an internet service for tracking physical exercise based on GPS data, mostly used for cycling, running, and swimming (Strava Inc., 2019). Relative trail use levels were also informed through interviews with local park staff. Cameras were distributed through the parks in areas of relatively low and high habitat significance and relatively low, medium, and high recreational activity.

In August 2022, we expanded the study to include four additional parks (Deception Pass, Olallie, Squak Mountain, and Wallace Falls). We overlaid 500 x 500 m grids over all eight parks using ArcGIS (ESRI, 2022). The grid size was determined to ensure adequate grid cells were available to stratify ten camera sites at all parks. Trails within each grid cell were classified into low, medium, or high usage categories using Strava Heatmaps. The classification was done manually, relying on the color intensity of the heatmap. Red colors indicated high trail usage, purple medium usage, and blue low usage. We randomly sampled three low, medium, and high-use grids at each park. We also selected an "overnight" activity grid that included areas adjacent to campgrounds, neighborhoods, or heavily used day areas where we expected human presence to occur at night (e.g., outside of normal park hours). This grid category was not randomly selected due to the low number of suitable grids for camera deployment. We applied this same sampling strategy to the parks where cameras had been placed in summer 2021, which resulted in moving one to three cameras in each of the parks.

We navigated to each randomly selected grid and found a suitable tree to attach a Reconyx Hyperfire Pro 2 camera (Reconyx, Holmen, WI, USA) in the direction of the trail. Cameras were set at approximately 2.5 m in height to avoid theft. To maximize the detection of medium- and large-bodied wildlife species, we crawled in front of the camera during setup and adjusted the camera angle accordingly to capture wildlife species and humans. To account for differences in camera deployment between 2021 and 2022, we measured the distance from the camera lens to the focal point. These distances were included in our modeling to address the potential impacts of focal point distance on detectability and bias (Miller et al., 2017). Other site and habitat data were recorded at each camera station, and relevant covariates are included in the final covariate table (Table 1). The minimum distance between cameras was 250 m.

In August 2023, we deployed three off-trail cameras facing a game trail at each park. These off-trail cameras were intended to represent areas with very minimal to no direct human disturbances. Following Procko et al. (2022), we aimed to deploy these off-trail cameras 250 m away from established trails or roads; however, due to the trail networks, our actual distances ranged from 70 – 335 meters, with an average of 219 m. The shortest distance was at Fort Ebey, while the longest was at Moran, where we searched for active game trails at shorter distances but only found clear signs, such as fresh scat and ground markings, at a greater distance. Due to steep terrain, we were only able to deploy two off-trail cameras at Larrabee and one of the off-trail cameras at Wallace Falls malfunctioned immediately after deployment.

A total of 113 cameras were active throughout the study period, with 91 placed on-trail and 22 off-trail. Most cameras were active for at least one year. Cameras deployed in 2021 operated for up to three years, those deployed in 2022 for up to two years, and those deployed in 2023 for one year (Appendix A). Periods of camera inactivity occurred due to malfunctions (3 cameras), theft (4 cameras), vandalism (2 cameras), or memory saturation. All cameras were checked at least yearly, with cameras on heavily used trails checked more frequently to ensure batteries and memory cards were running properly. Final camera collection occurred in November 2024.

Data processing

All photos were processed through MegaDetector, a Microsoft machine-learning algorithm that detects animals, people, and vehicles in camera trap images (Beery et al., 2019). These recognitions were then used to blur all photos containing humans to ensure privacy protection (WildCo, 2021). All photos were then reviewed using Timelapse2 (Greenberg et al., 2019). Trained technicians identified species for all images containing wildlife and domestic animals, and classified photos of humans into the following categories: hikers, hikers with dogs, mountain bikers, mountain bikers with dogs, horseback riders, and vehicles. Approximately two-thirds of the photo sets were tagged to a finer level of detail, differentiating between hikers and runners, and identifying the age and sex of ungulates. This fine detail of human activity tagging was used for summarizing trail types, but not used for these analyses. After initial photo tagging was complete, the team lead performed a quality check to ensure tagging integrity, including correct wildlife species identification and counts, and proper human activity recording. Data were then imported to R (version 4.4.2; R Core Team, 2021) for data cleaning and statistical analyses.

Occupancy analysis

We evaluated species' spatial activity patterns using a dynamic occupancy modeling framework allowing us to account for imperfect detection and model occupancy throughout the four study years. With this framework, we estimated occupancy probability (the probability of a species occupying or using a site) and detection probability (the probability of detecting a species given it occupies a site; MacKenzie et al., 2004). We also modeled colonization (the probability of an unoccupied site becoming occupied) and extinction rates (the probability of an occupied site becoming unoccupied), allowing both parameters to vary seasonally to account for potential seasonal influences. Each camera station was considered a ‘site’, but likely not independent of one another due to their proximity, so we assumed occupancy probability is more representative of use probability. We defined independent detections of wildlife as images of the same species taken at least 30 minutes apart at a site. We generated 7-day detection histories for wildlife species with the camtrapR package (version 2.3.0; Niedballa et al., 2016) in R (R Core Team, 2021).

We fit dynamic occupancy models to estimate occupancy, detection, colonization, and extinction probabilities for each focal species at each camera site across the entire study period. This resulted in 13 primary periods with each primary period representing a season from summer 2021 to fall 2024. We excluded the first summer primary period (i.e., summer 2021) due to a low number of detections and variable start dates. The models for black-tailed deer, coyote, cougar, and raccoon included 12 primary periods (fall 2021 through summer 2024). For the bobcat, black bear, and elk models, we also excluded the first fall (fall 2021) due to a low number of detections (maximum of 2), and for black bears, we removed all winter primary periods due to hibernation. Each primary period was divided into equal secondary periods of 13 weeks.

We fit a combination of environmental and recreation-related covariates for occupancy, detection, colonization, and extinction (Table 1). Elevation, trail width, and distance to the focal point were collected at each camera site using GAIA GPS for elevation, measuring the trail width at the camera's viewpoint, and measuring the distance from the camera lens to the center of the viewpoint. The overnight category was assigned if the trail near the camera was located close to a neighborhood, campground, or heavily used day area, which was determined prior to deployment. We calculated distance to water by measuring the shortest distance between camera sites and flowline features using the 'National Hydrography Dataset Flowlines' data from the State of Washington Geospatial Open Data Portal, which represents a network of surface water features like streams, rivers, and canals. The 'tree' covariate was calculated using the National Land Cover Database (NLCD) 2021 USFS Tree Canopy Cover data, which provides percent tree canopy estimates for each 30-meter pixel across the conterminous U.S. These data were associated with camera coordinates to obtain tree canopy measures at each site. The ‘season’ covariate for colonization and extinction estimates was based on the previously mentioned seasonal ranges.

We calculated weekly human detections by considering independent detections separated by at least one minute. Relative recreation use was determined based on the median of total independent human detections across all cameras and parks for the entire study period. Stations were categorized as "high" or "low" based on whether the total number of human detections for each station was above or below the overall human detections median. We also calculated a trail class covariate to indicate whether a trail was 'single' use (hiking only), 'multi' use (hiking and other activities), or 'game' (off-trail). This classification was based on the proportion of independent human detections for each activity type. Trails were defined as 'multi' use if they had any horseback riders or if bikers made up at least 1.8% of all hiker detections, a threshold determined from observational data to distinguish between trails with occasional bikers and those that were truly multi-use. This resulted in a distribution of 22 off-trail cameras, 62 multi-use, and 29 single-use.

We tested for collinearity among numeric covariates using the variance inflation factor (VIF) and found no significant correlation between covariates (VIF < 2). Weekly human detections and relative recreation use were not included in the same model as they represent two measures of recreation that differ in their scale but are based on weekly human detections. We ran all possible model combinations and evaluated all combinations of covariates for occupancy, colonization, extinction, and detection, selecting top models based on AICc values. Models within 2 delta AICc were considered competitive. We also used a robust p-value threshold of 0.1 to determine covariate statistical significance. To ensure robustness, we assessed model fit, standard errors (SE), and 95% confidence intervals (CIs) and excluded models with high SEs for parameter estimates. The final model selected for each species was parsimonious, effectively explaining the observed variation without overfitting.

Activity analysis

We evaluated seasonal temporal activity patterns of wildlife species (Ridout and Linkie, 2009). using the Overlap package (version 0.3.9) in R (R Core Team, 2021). We estimated activity curves for each species using kernel density estimators to quantify detection density over a 24-hour cycle. To account for seasonal variations in day length, we converted the clock time of each detection to sun time by scaling the time of day to sunrise and sunset (Nouvellet et al., 2012; Meredith and Ridout, 2017). Detections of the same species were considered independent if they were separated by more than 1 minute (Peral et al., 2022).

Seasonal ranges were determined based on wildlife species biological considerations, such as mating and breeding, that may influence behavioral patterns. These were categorized as summer (June 16 – September 15), fall (September 16 – December 15), winter (December 16 – March 15), and spring (March 16 – June 15). For each species and season, we calculated the coefficient of overlapping (Δ) using kernel density estimates (Meredith and Ridout, 2017) to determine differences in activity patterns between high- and low-use, high use and off-trail, and low- and off-trail use. We initially looked at activity patterns per season for each species, but there were not enough detections for all species and seasons per human activity level (i.e., high, low, and off-trail; minimum $n = 30$). For species that did have enough detections for more than one season (deer, elk, bobcat, and coyotes), we looked at seasonal activity patterns and did not find shifts in activity from one season to the next. We moved forward combining detections for all seasons for each species. The Δ1 estimator was used for species with fewer than 50 detections and the Δ4 estimator was used for species with 50 or more detections. The coefficient of overlapping (Δ) ranges from 0 (complete separation of activity) to 1 (complete overlap of activity); therefore, lower overlap values indicate temporal activity differences. 95% confidence intervals for overlap coefficients were generated using 10,000 smoothed bootstrap samples. If confidence intervals between groups did not overlap with zero, we considered this to be a significant result.

Strava camera stratification

In addition to the activity and occupancy analyses, we used Poisson linear mixed models to assess the validity of using Strava data to stratify cameras based on relative recreation use and to evaluate the applicability of Strava Heatmaps as a recreation management tool. We assumed that the number of human images captured by a camera represents relative trail use. Based on this assumption, we expected trails with higher apparent use on Strava (more intense map colors) to reflect both individuals who upload tracking data to generate Strava heatmaps and casual users who do not. If this pattern holds, Strava Heatmaps would be a reliable predictor of relative trail use.

To test this assumption, we analyzed data from a one-week period in 2022 (September 27–October 3), during which 64 cameras were active. We processed the images through MegaDetector, selected those classified as "person," and used Poisson linear mixed models to examine human counts as a function of Strava classification. We incorporated modeled Strava categories (low, medium, and high), camera settings to account for cameras with a 'quiet period' setting, and included a random intercept for the park in which the camera was deployed. Of the 64 cameras, 23 were classified as low-use, 20 as medium-use, and 21 as high-use. Statistical significance was assessed using a p-value threshold of 0.05.

Table 1. Covariates for occupancy, colonization, extinction, and detection fit in dynamic occupancy models. Covariates marked with the (+) symbol indicate those directly related to recreation activities.

Covariate	Definition	Range
Occupancy (ψ)		
Elevation	Elevation at each site (ft)	16 – 3760
Nearest water source	Linear distance to water flow (m)	0.3 – 1242.4
Tree	Percent tree canopy cover	6.5 – 82.9
Human counts+	Total human counts at each site over the study period	31 – 46105
Trail class+	Indicator of hiking only trail or hiking and other recreational use trail at each site	Single, Multi, Game
Overnight+	Near a campground, neighborhood, or heavily used day area	Y, N
Colonization (γ)		
Season	Time of year influencing the probability of an unoccupied site becoming occupied	Fall, Spring, Summer, Winter
Extinction (ε)		
Season	Time of year influencing the probability of an occupied site becoming unoccupied	Fall, Summer, Spring, Winter
Detection (p)		
Trail width	Width of trail in the camera's viewpoint (m)	0.16 – 7.2
Distance to focal	Distance from camera lens to center of camera viewpoint (m)	2.2 – 15.1
Weekly detections+	Weekly human detections at each site	0 – 1990
Park	Study parks: Beacon Rock, Fort Ebey, Deception Pass, Larrabee, Moran, Olallie, Squak Mountain, Wallace Falls	BCRO, FTEB, DEPA, LARR, MORA, OLAL, SQMT, WAFA
Relative Recreation use+	Below or above the median total human detections	Low, High
Trail class+	Indicator of hiking only trail or hiking and other recreational use trail at each site	Single, Multi, Game

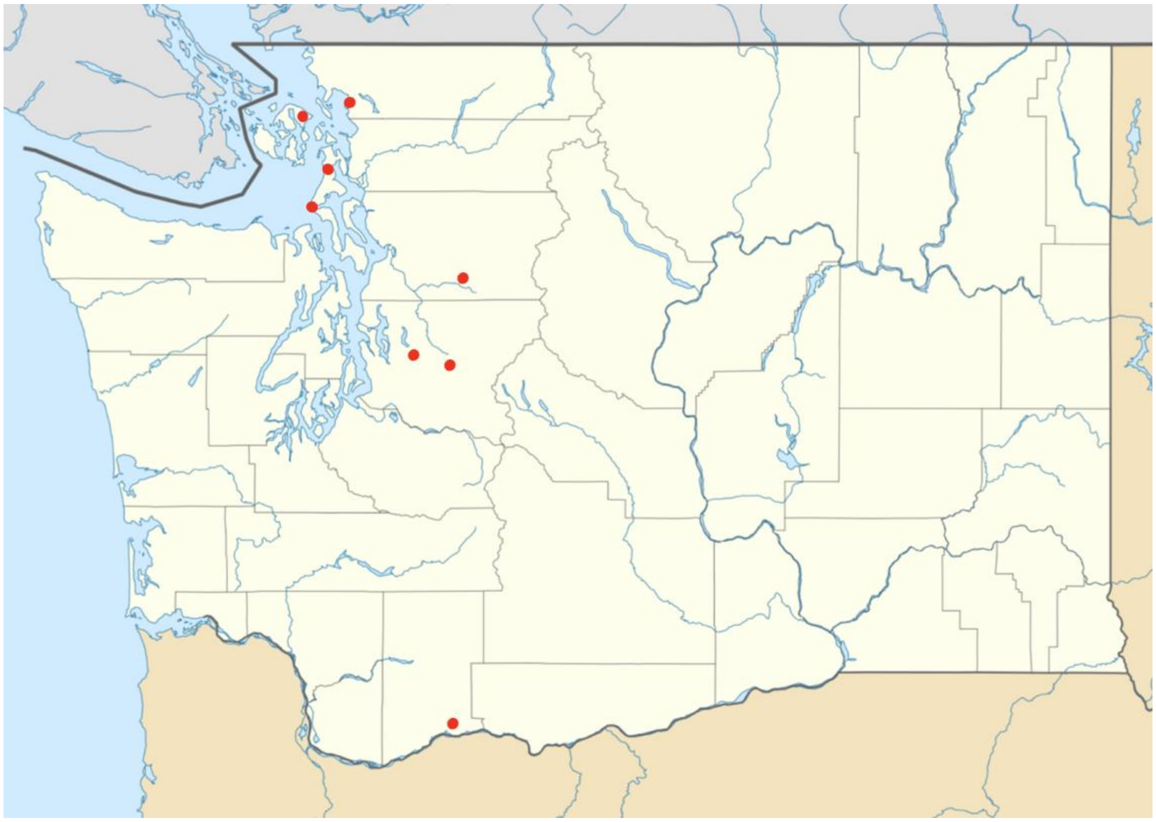


Figure 1. Map of study parks in Washington State, with study parks overlaid in red. Original map created by Alexrk2. (2009). USA Washington location map [Map]. Wikimedia Commons. [https://en.wikipedia.org/wiki/File:USA_Washington_location_map.svg]

RESULTS

We collected a total of 5,680,275 images and classified 3,357,695 from 54,244 camera trap days. These data contributed to 7,797 station-weeks used in modeling. Survey effort, as measured by camera trap days varied by recreation level, with 9,219 days for off-trail cameras, 15,386 for low use, and 29,639 for high use. We detected 20 different species across our study sites (Appendix B). We focused on the 7 species that had more than 150 detections at 10 or more sites. This ensured enough detections to analyze spatial activity patterns in response to recreational activities throughout the study sites. These included, in order of most to least 30 minute-independent detections, black-tailed deer (*n* = 8803), coyote (*n* = 1935), bobcat (*n*= 403), raccoon (*n* = 323), elk (*n* = 266), black bear (*n = 185*), and cougar (*n* = 180). Deer were the most widely distributed of these wildlife species, detected at 108 of the 113 sites (96%), while elk were the least distributed, detected at 33 sites (29%; Appendix C). Although we did not include this information in analyses, we examined the counts of all offspring for each park (Appendix D), the counts of the seven most detected species per year (Appendix E), and for the image sets tagged to a finer level (59% of image sets), we included a summary of ungulate age and sex classifications per year (Appendix F).

We also collected 664,504 independent detections of humans with a 1-minute threshold (Appendix G). Most of the detected human activities were of hikers (*n* = 476,395), detected at 100 sites (88%). Domestic animals (Appendix H) were detected alongside humans most of the time, either preceding or following a human detection. Dogs were the most detected domestic animal (*n* = 94,558).

Human activity varied across the study period, with higher detections during summer months and lower detections in winter, reflecting typical seasonal recreation patterns and weekly variation in counts (Appendices I and J). To further understand these patterns, we calculated seasonal human pressure and found that human activity peaked in fall 2023 and was lowest in winter 2021 (Appendix K). In general, summer had the highest average human activity, while winter had the lowest.

Occupancy analysis

Average estimated occupancy probabilities ranged from 0.04 for elk to 0.86 for deer, based on the top selected model (Tables 2 and 3). Contrary to our expectations, we found that no covariates were included in initial occupancy in the top models for all species, except for coyotes for which distance to the nearest water flow had a negative significant relationship with occupancy probability (-1.69 ± 0.83).

Detection probability was significantly influenced by several variables including measures of human recreation. We found that sites classified as low recreation use had higher detection probabilities for deer (0.27 ± 0.06), coyotes (0.28 ± 0.08), and black bears (0.57 ± 0.22). Similarly, we found that lower weekly human detections resulted in higher detection probabilities for elk (-1.75± 0.31). In contrast, we found that low recreation use areas had lower detection probabilities for cougars (-0.32 ± 0.25) and higher weekly human detections were positively associated with detection probability for bobcats (0.18 ± 0.08) and raccoons (0.004± 0.0007).

Trail width had a negative effect on detection for deer (-0.18 ± 0.036) and raccoons (-0.49 ± 0.20), and a positive effect for cougars (0.26 ± 0.07) and bobcats (0.184 ± 0.03). Distance to the focal point (i.e., the distance from the camera lens to the main target of the camera) showed a significant negative relationship with detection probabilities for deer (-0.15 ± 0.04), coyotes (-0.14 ± 0.04), and raccoons (-0.28 ± 0.16) which means that detection increased when the trail was closer to the camera for the smaller bodied species. For elk, the largest bodied species of our focal species, there was a significant positive relationship (0.37 ± 0.10) indicating that detection probability was higher for elk when the camera was positioned further from the trail.

Season was a significant predictor of colonization and extinction probabilities for certain species (Table 2). Bobcats exhibited a lower colonization probability in spring compared to fall, while deer had a higher colonization probability in spring, summer, and winter relative to fall. Extinction probabilities for deer varied seasonally, with lower probabilities in winter, spring, and summer compared to fall. For coyotes, extinction probabilities were higher in spring and winter but lower in summer relative to fall.

Activity analysis

We collected a total of 13,127 wildlife detections with a 1-minute threshold for our focal species. Deer (*n* = 11,443), coyotes (*n* = 2,078), elk (*n* = 532), and black bears (*n* = 203) had more than 30 detections for off-trail locations (Figure 2), while bobcats (*n* = 407), cougars (*n* = 164), and raccoons (*n* = 336) did not and thus we restricted inference to only low- and high- use sites (Figure 3). High-use and low-use sites were categorized based on the median of total independent human detections across all cameras while off-trail sites were simply categorized as off-trail. All species exhibited some differences in activity patterns between off-trail, low-use, and high-use sites, indicated by a lack of complete overlap (maximum Dhat observed = 0.95 for raccoons). Estimates of temporal activity overlap between low- and high- use trails ranged from 0.59 – 0.95, between low-use and off-trail locations from 0.66 – 0.88, and between high- and off-trail locations from 0.50 – 0.81 (Table 4). All species exhibited temporal separation from human activity, with less separation at off-trail sites and greater separation at high-use sites. Human activity across all sites was diurnal and peaked at midday.

Deer exhibited significant activity shifts between high-use and off-trail sites (Dhat = 0.81 [0.79, 0.83]; Figure 4). This shift was statistically significant compared to the overlap between low-use and high-use trails (Dhat = 0.90 [0.89, 0.92]) and low-use and off-trail sites (Dhat = 0.88 [0.86, 0.91]), as indicated by the non-overlapping 95% confidence intervals. Deer activity was predominantly crepuscular across low-use, high-use, and off-trail sites. However, higher activity densities were observed in off-trail sites compared to the other two types, with increased midday activity at off-trail sites, followed by low-use and high-use sites (Figures 2 and 3). Coyotes displayed a unique pattern, with a strong midday activity peak at off-trail sites and nocturnal peaks at low-use and high-use sites. The activity difference between high-use and off-trail sites (Dhat = 0.51 [0.44, 0.62]) was significant compared to the overlap between low-use and high-use sites (Dhat = 0.84 [0.81, 0.88]). This highlights a distinct temporal shift in deer and coyote activity depending on trail type.

None of the other five species exhibited significant differences in activity levels across trail types. However, a general pattern emerged as species tended to be more active at night and dawn on low-use and high-use trails but showed increased midday activity at off-trail sites (Figures 2 and 3). Bobcats, cougars, and raccoons showed a similar pattern, despite game site comparisons not being possible. At low-use sites, daytime activity densities were generally higher than at high-use sites. Cougars (Dhat = 0.71 [0.59, 0.83]) exhibited some increased midday activity at low-use sites compared to high-use sites (Figure 3).

Black bears exhibited higher activity density at off-trail sites. The overlap in activity patterns between low-use and high-use sites was relatively high (Dhat = 0.86 [0.70, 0.91]), indicating similar temporal activity across these areas. However, overlap decreased when comparing low-use with off-trail sites (Dhat = 0.82 [0.65, 0.88]) and was lowest between high-use and off-trail sites (Dhat = 0.75 [0.61, 0.86]). This pattern suggests that while black bears maintained similar activity patterns across low- and high-use areas, their temporal overlap with human activity decreased at off-trail locations.

Elk also exhibited shifts in activity patterns, with increased dawn activity at low-use sites and more midday activity at off-trail sites. Notably, the overlap between high-use and off-trail sites was among the lowest observed (Dhat = 0.50 [0.38, 0.63]), suggesting a strong shift in elk activity in response to human presence in these areas.

Strava camera stratification

We found that the low, medium, and high use classifications we had manually assigned to each camera station were statistically different ($p < 0.05$) and corresponded to the average number of images of people captured by the cameras for each classification. For the selected week, the predicted number of images was 192, 309, and 986 for low, medium, and high use, respectively, representing a gradient of increasing human detections from low to high use areas.

Table 2. Species-specific dynamic occupancy model results for deer, coyotes, and bobcats across 113 camera stations in western Washington State Parks from summer 2021 to fall 2024. Estimates for occupancy (ψ), colonization (γ), extinction (ε), and detection probability (p) are provided with 95% confidence intervals. Each species' top model was selected using AICc model selection. Negative values indicate a decrease in probability associated with a given predictor, while positive values indicate an increase.

Parameter	Deer Estimate (95% CI)	Coyote Estimate (95% CI)	Bobcat Estimate (95% CI)
ψ (Occupancy, Intercept)	1.85 (0.88, 2.82)	-0.74 (-1.61, 0.14)	-0.90 (-1.60, -0.21)
ψ (Rec Level Low)	-	-	-
ψ (Nearest Water)	-	-1.60 (-3.23, 0.04)	-
γ (Colonization, Intercept)	-2.15 (-3.63, -0.68)	-1.67 (-2.01, -1.32)	-2.04 (-2.76, -1.31)
γ (Season: Spring)	2.09 (0.39, 3.78)	-	-1.81 (-4.04, 0.43)
γ (Season: Summer)	1.8 (-0.20, 3.81)	-	-8.05 (-72.44, 56.34)
γ (Season: Winter)	1.92 (0.33, 3.52)	-	-0.21 (-1.35, 0.94)
ε (Extinction, Intercept)	-1.26 (-1.68, -0.84)	-2.96 (-4.23, -1.68)	-1.80 (-2.35, -1.24)
ε (Season: Spring)	-1.3 (-2.20, -0.40)	1.73 (0.30, 3.17)	-
ε (Season: Summer)	-1.3 (-2.34, -0.26)	-0.35 (-4.27, 3.56)	-
ε (Season: Winter)	-2 (-3.18, -0.83)	1.46 (0.05, 2.88)	-
p (Detection, Intercept)	-0.09 (-0.17, -0.02)	-0.89 (-0.99, -0.79)	-1.62 (-1.78, -1.47)
p (Trail Width)	-0.18 (-0.25, -0.11)	-	0.18 (0.12, 0.25)
p (Weekly Detections)	-	-	0.18 (0.02, 0.33)
p (Distance to Focal)	-0.15 (-0.22, -0.08)	-0.14 (-0.21, -0.06)	-
p (Rec Level Low)	0.27 (0.16, 0.38)	0.28 (0.12, 0.43)	-

Table 3. Species-specific dynamic occupancy model results for raccoon, black bear, elk, and cougar across 113 camera stations in western Washington State Parks from summer 2021 to fall 2024. Estimates for occupancy (ψ), colonization (γ), extinction (ε), and detection probability (p) are provided with 95% confidence intervals. Each species' top model was selected using AICc model selection. Negative values indicate a decrease in probability associated with a given predictor, while positive values indicate an increase.

Parameter	**Raccoon Estimate (95% CI)**	**Black Bear Estimate (95% CI)**	**Elk Estimate (95% CI)**	**Cougar Estimate (95% CI)**
ψ (Occupancy, Intercept)	-1.39 (-2.29, -0.49)	-1.65 (-2.68, -0.62)	-3.04 (-4.87, -1.21)	-1.34 (-2.30, -0.37)
γ (Colonization, Intercept)	-2.16 (-2.57, -1.74)	-2.58 (-3.16, -2.00)	-3.33 (-3.88, -2.77)	-2.54 (-3.11, -1.97)
ε (Extinction, Intercept)	-0.87 (-1.46, -0.27)	-1.27 (-2.01, -0.52)	-1.71 (-2.68, -0.74)	-1.33 (-2.30, -0.36)
p (Detection, Intercept)	-2.46 (-2.77, -2.16)	-2.16 (-2.51, -1.80)	-1.96 (-2.26, -1.66)	-2.39 (-2.72, -2.06)
p (Trail Width)	-0.49 (-0.89, -0.09)	-	-	0.26 (0.12, 0.39)
p (Weekly Detections)	0.003 (0.002, 0.01)	-	-1.75 (-2.37, -1.14)	-
p (Distance to Focal)	-0.28 (-0.59, 0.02)	-	0.37 (0.17, 0.57)	-
p (Rec Level Low)	-	0.57 (0.13, 1.01)	-	-0.32 (-0.82, 0.18)

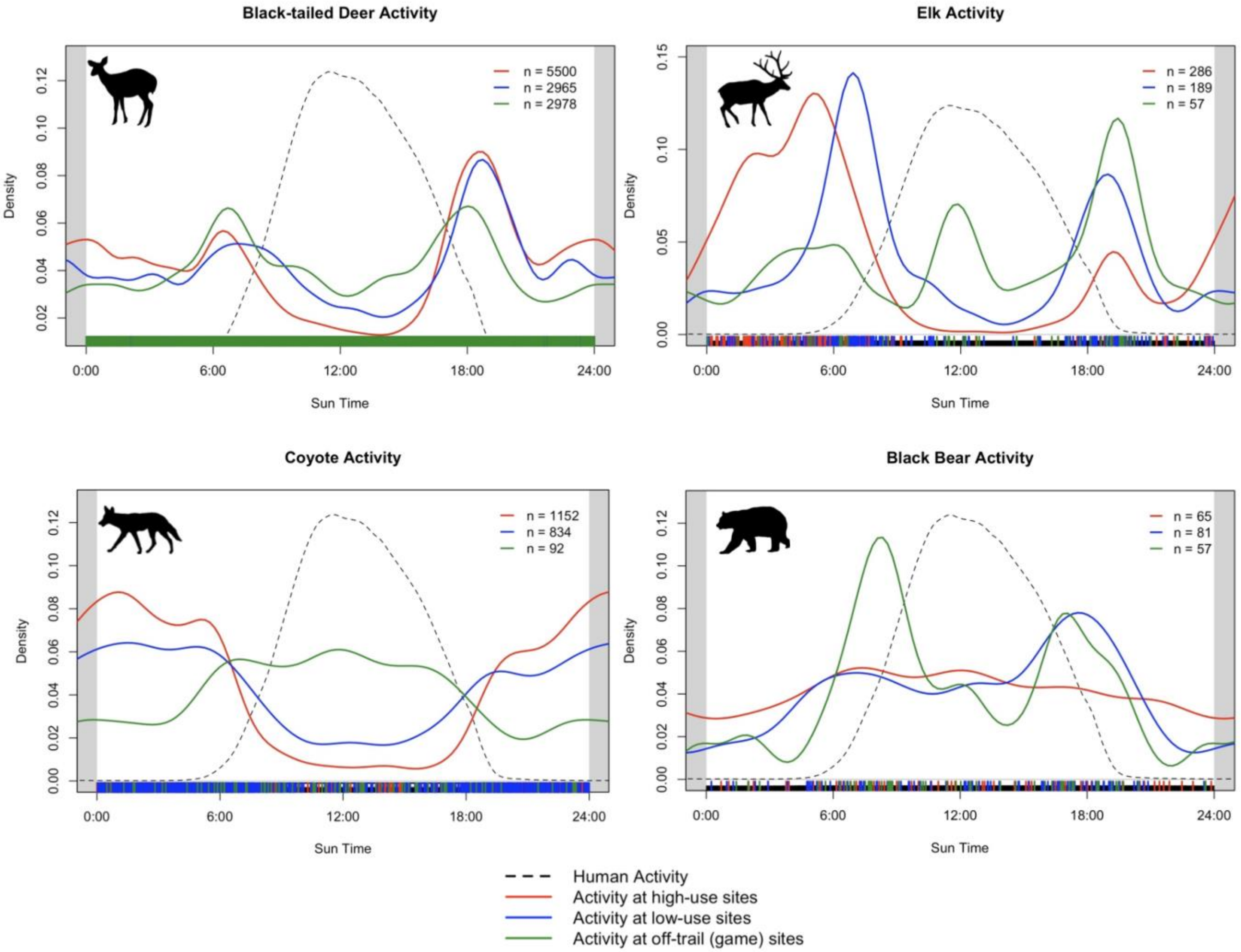


Figure 2. Activity patterns for deer, elk, coyotes, and black bears across all seasons in high human-use trails (red solid line), low human-use trails (blue solid line), and off-trail sites (green solid line; none or minimal human use) calculated using camera trap detection data from 113 sites from summer 2021 to fall 2024 in western Washington State Parks. Human activity from all sites is shown with the dotted black line.

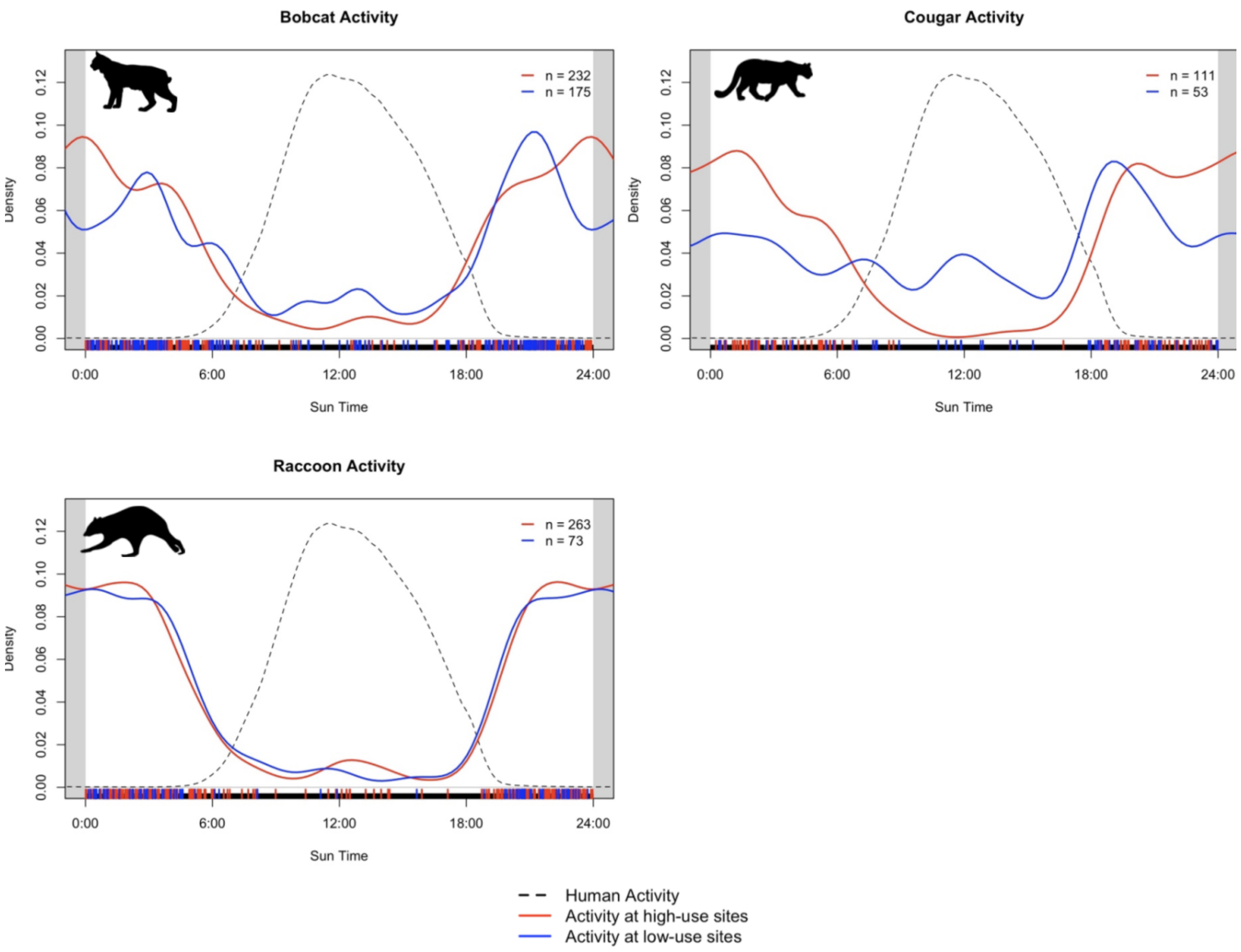


Figure 3. Activity patterns of bobcats, cougars, and raccoons across all seasons in low human-use areas (blue solid line) and high human-use areas (red solid line) calculated using camera trap detection data from 113 sites from summer 2021 to fall 2024 in western Washington State Parks. Human activity from all sites is shown with the dotted black line.

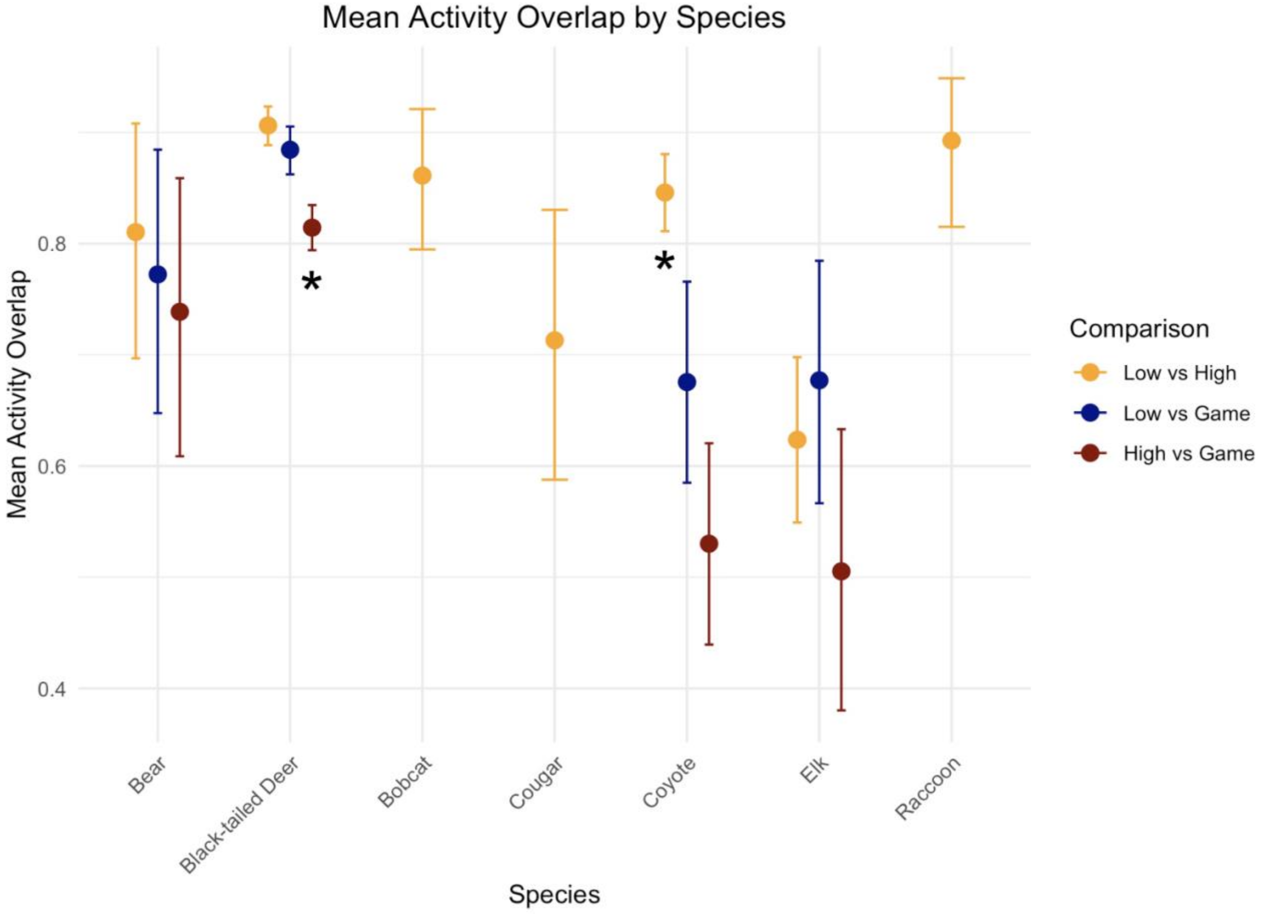


Figure 4. Activity pattern overlaps calculated using camera trap detection data from 113 sites from western Washington State Parks from summer 2021 to fall 2024. Circles represent mean overlap between low- and high-human use sites (yellow), low- and off-trail sites (blue), and high-use and off-trail sites (red) and lines indicate standard errors. Comparisons with statistically significant differences (95% confidence intervals that don't overlap with zero) in their activity patterns between one or two groups are marked with an asterisk.

Table 4. Activity overlap results across 113 camera stations in western Washington State Parks from summer 2021 to fall 2024. Detection independence for each species was determined using a 1-minute threshold. Dhat values range from 0 (no overlap) to 1 (complete overlap). Bolded estimates indicate significant differences in overlap for at least one comparison within a given species.

Species	Comparison	Dhat value (95% Confidence Interval)	Mean overlap	SD overlap
Deer	Low vs High	0.90 (0.89, 0.92)	0.91	0.01
	Low vs Off-trail	0.88 (0.86, 0.91)	0.88	0.01
	High vs Off-trail	**0.81 (0.79, 0.83)**	**0.81**	**0.01**
Cougar	Low vs High	0.71 (0.59, 0.83)	0.71	0.06
Bobcat	Low vs High	0.85 (0.79, 0.92)	0.86	0.03
Bear	Low vs High	0.86 (0.70, 0.91)	0.81	0.05
	Low vs Off-trail	0.82 (0.65, 0.88)	0.77	0.06
	High vs Off-trail	0.75 (0.61, 0.86)	0.74	0.06
Raccoon	Low vs High	0.95 (0.82, 0.95)	0.89	0.03
Elk	Low vs High	0.59 (0.55, 0.70)	0.62	0.04
	Low vs Off-trail	0.68 (0.57, 0.78)	0.68	0.06
	High vs Off-trail	0.50 (0.38, 0.63)	0.50	0.06
Coyote	Low vs High	0.84 (0.81, 0.88)	0.85	0.02
	Low vs Off-trail	0.66 (0.58, 0.77)	0.68	0.05
	High vs Off-trail	**0.51 (0.44, 0.62)**	**0.53**	**0.05**

DISCUSSION

Our research adds to a growing body of knowledge on wildlife responses to recreation across the WUI. Previous research has shown that wildland habitat adjacent to urban areas can effectively support carnivores, mesocarnivores, and ungulates (Wang et al., 2015; Lewis et al., 2015; Soccorsi and LaPoint 2023). We documented 22 species using the eight state parks and for the seven focal species in the study, we found that they exhibited behavioral shifts in response to human recreation though they were not always consistent with our hypotheses. We found no evidence of human recreation affecting occupancy of any species in our study. On the other hand, we found changes in detection probability related to human recreation measures for all seven species and notable temporal shifts in wildlife activity for some species. For example, coyotes and deer had significant differences in activity patterns between off-trail and high-use trails, indicating that these species altered their activity patterns in the parks in response to varying levels of human presence. Our findings highlight the importance of understanding species-specific responses to human recreation in the WUI and the implications for management.

FELID RESPONSES TO RECREATION

We did not find support for our spatial predictions that felids would avoid sites with high human use. Contrary to our expectations, cougar detection was lower in areas of overall low recreation and higher in areas with high recreation use. Similarly, bobcat detection was positively associated with weekly human detections, a short-term and fluctuating recreation activity measure. Bobcats tend to avoid areas with intense human activity (Lewis et al., 2017; Procko et al., 2022) and cougars avoid trails during seasonal peaks in human activity periods (Morrison et al., 2014). A possible explanation for our results is that carnivores are known to prefer well-defined human recreation trails as travel corridors (Karanth et al., 2010; Kays et al., 2017). In areas with fewer natural movement corridors, bobcats and cougars could be utilizing trails regardless of human activity levels, while avoiding direct encounters with humans through nocturnal activity. Cougar and bobcat actively were largely nocturnal in our study area and appeared even more so in more heavily used human areas (Figure 3). Consistent with these results, we found that trail width had a positive effect on detection for cougars and bobcats, indicating that as trail width increases, detection increases for both species. Wider trails are typically more heavily used human trails that tend to cut across larger sections of the park creating wildlife travel corridors. In the WUI, movement may already be restricted as these are habitats situated in fragmented landscapes, thus trails as movement corridors could represent more important habitat selections over recreational activity. This further supports previous research in the WUI indicating that these habitats are crucial movement corridors and important drivers of connectivity in fragmented landscapes (Jenerette et al., 2022).

GENERALIST RESPONSES TO RECREATION

Coyotes

We found partial support for our hypothesis that generalist species, such as coyotes, black bears, and raccoons, would show less spatial response to human recreation and more temporal changes. Coyotes have displayed spatial displacement in sites with high levels of human recreation (George and Crooks, 2006; Reed and Merenlender, 2011) as well as shifts in their temporal activity in response to human presence (Wang et al., 2015; Reilly et al., 2017). We did not find a difference in coyote occupancy in relation to human recreation, but we did find that detection probability was higher in areas of low recreation. These results suggest that coyotes are using low recreation areas more or are more active in those areas, indicating that while coyotes may be tolerant of human activity, they may be exhibiting spatial responses to recreation pressures. In the absence of human disturbance, coyote activity has been shown to be crepuscular or diurnal and exhibit shifts towards more nocturnal activity patterns when there is human disturbance (Kitchen et al., 2000; Wang et al., 2015). Here, we observed that coyote activity was predominantly nocturnal in both low- and high-human-use areas, but diurnal in off-trail locations, suggesting more natural activity patterns in areas without direct human disturbance. This shift in diel activity patterns is consistent with studies showing that coyotes adapt their temporal behavior to persist in fragmented landscapes and avoid human contact (Tigas et al., 2002; Rasmussen and Macdonald, 2012) and supports our temporal prediction of increased nocturnal activity in areas of high human activity.

Raccoons

Raccoon occupancy did not vary with human recreation measures, but we did find that detection probabilities increased with increasing weekly human detections. This indicates that raccoons are using areas with higher human presence, possibly due to the availability of anthropogenic food sources (Prange et al., 2003). Raccoons are known to be highly adaptable species that can use a variety of resources across landscapes (Prange et al., 2003). Their ability to thrive in human-dominated landscapes, including in urban and recreational areas (Ordeñana et al., 2010), likely contributes to this behavior. We also found that raccoon activity was nocturnal and human use on trails did not change their daily activity patterns. Raccoons have small home ranges and an ability to navigate fragmented landscapes and utilize small habitat patches to successfully navigate different levels of human activity (Lewis et al., 2021). These results fully support our hypothesis that generalist species would be associated with human recreation as they have adaptations allowing them to tolerate human disturbance.

Black bears

Black bears had higher detection probabilities in areas of low recreation use consistent with other studies reporting black bear avoidance of high trail use (Kasworm and Manley, 1990; Erb et al., 2012). While past research has shown that bears are more diurnal in areas with low recreation and shift to nocturnal activity in areas with high recreation (Kaczensky et al., 2006; Hubbard et al., 2022), we observed black bear activity was primarily crepuscular. In off-trail locations, black bear activity showed a much higher density in the early morning compared to activity at low- and high-use sites, indicating some temporal shifts occurring as a response to different levels of human disturbance. However, these differences were not statistically significant, limiting our ability to draw strong conclusions. Consistent with Hubbard et al. (2022), our results suggest that black bears in the WUI are not strongly shifting their diel activity patterns in response to human recreation.

UNGULATE RESPONSES TO RECREATION

We hypothesized that ungulates would exhibit spatial and temporal alignment with humans, due to the “human-shield effect,” using areas with human activity as a refuge from predators that avoid human activities (Berger, 2007). We did not find support for this hypothesis as both black-tailed deer and elk exhibited decreased detection probabilities with higher measures of human activity as well as lower temporal overlap with humans in areas of high recreation. This indicates that rather than seeking humans for refuge, they are exhibiting spatial and temporal separation from human activity.

Black-tailed deer

Black-tailed deer were the most detected and widely distributed species in our study area, present at 82% of camera sites. Previous research in urban nature reserves has shown that deer primarily respond to recreation through temporal shifts rather than spatial avoidance (George and Crooks, 2006; Reilly et al., 2017). We found that deer had higher detection probabilities in areas of low recreation use, which can indicate they are using those areas more. This could be an indicator of shifts in their spatial use of areas, though they occupied areas of both higher and lower recreation use equally.

Previous research found that black-tailed deer became more nocturnal in areas of high recreation to avoid humans but maintain use of these areas, but our findings did not support this (Lewis et al., 2021). Instead, activity peaked at dawn and dusk, consistent with natural crepuscular patterns, but there were significant differences in activity between off-trail locations and both low- and high-use trails. This aligns with George and Crooks (2006), who found lower probabilities of detecting deer during the day in areas with higher recreational activity. Our findings indicate that deer in our study sites are responding to different levels of recreation both spatially and temporally, with increased diurnal activity in off-trail areas likely reflecting a strategy to access resources while minimizing direct encounters with humans (Coppes et al., 2017).

Deer diurnal activity in off-trail areas aligns with the activity patterns we observed in coyotes, suggesting that both species are modifying their behavior in response to human recreation, a pattern observed in other studies (e.g., Coppes et al., 2017; Gaynor et al., 2018). This shared use of off-trail areas during the day may indicate a shift to avoid high-recreation areas. While coyotes are generally more nocturnal with increased human presence, their increased daytime activity in off-trail areas could indicate a greater tolerance for these environments compared to larger carnivores, such as cougars. However, we did not have enough off-trail detections to fully assess this dynamic. The use of off-trail locations may indicate behavioral flexibility in mesopredators, allowing them to exploit ecological opportunities in human-altered landscapes, while more sensitive carnivores may be displaced (Gulsby et al., 2018). Understanding how recreation influences these interactions is important for understanding shifts in predator-prey dynamics and managing for multiple species in the WUI.

Elk

Elk were our least widespread species being detected only in 3 parks and had the lowest initial occupancy probability of all species. Despite our hypothesis that elk may use humans as a shield, studies have shown that elk reduce their probability of site use with increasing levels of human recreation (Rogala et al., 2011). We found elk detection decreased with increasing human weekly detections, indicating that elk may be using or moving around those areas less.

Elk in our study had crepuscular activity patterns with higher daytime activity in off-trail locations. While these differences across trail classifications were not significant, elk displayed the lowest overlap in activity between high-use and off-trail locations out of all the species, suggesting shifts in activity in response to recreation. Procko et al. (2024) found that elk in the Cascade Mountain Range of Washington shifted to strictly crepuscular or nocturnal behavior when human recreation detections exceeded nine per day, further supporting this finding that increased recreation can create strong shifts in elk activity patterns. These results suggest elk may tolerate humans up to a certain threshold, and be displaced afterwards, highlighting the importance of considering both spatial and temporal factors into management. Limiting human activity in key elk habitats, especially during peak elk activity periods may help reduce displacement and minimize disturbance.

Other factors

Overall, we found little to no impact from most environmental factors on occupancy probabilities, except for coyote occupancy decreased as a function of distance to the nearest water flow. While coyotes are known to navigate human-developed landscapes and exploit anthropogenic water sources, which may be present in urban areas near the WUI, (Gese et al., 2012), our findings suggest that natural water sources still play an important role in their distribution. We expected environmental factors would explain some variation in occupancy as they would describe important habitat features, but overall, many of our sites were in similar forest habitats and at similar elevations. For some species with larger home ranges, such as cougars and black bears, multiple camera locations could be contained within one home range making it harder to detect variation in occupancy patterns.

We observed seasonal variation in occupancy for bobcats, deer, and coyotes. For deer, colonization probability (probability of an unoccupied site becoming occupied) was higher in all seasons compared to fall while extinction probability (probability of an occupied site becoming unoccupied) was lower in all seasons compared to fall. This suggests deer were more likely to occupy new sites and less likely to leave existing ones throughout the year, except in fall. We would have expected that deer might use state parks as a refuge during the fall when hunting season occurs, as hunting is not allowed within parks.

Changes in seasonal occupancy for coyotes and bobcats may reflect seasonal shifts in resource availability, competition, or human activity that influence site use. Previous studies have found season-specific variation within mammal communities as a result of shifting predator-prey interactions as well as fluctuations in human activity patterns (Lewis et al., 2021; Poisson et al., 2023). Further examining these seasonal variations could provide additional insights into how species respond to recreation pressure across different times of the year, especially in the WUI areas where recreation levels fluctuate based on the season.

LIMITATIONS

Interpreting the meaning of recreation factors influencing detection probability is less clear than occupancy probability. While factors such as camera height, trail width, distance to focal point, and habitat openness influence the likelihood of a camera triggering, variation in detection probability can also be driven by biological factors, including changes in abundance (Royle and Nichols, 2003, Royle et al., 2005) or shifts in animal movement and behavior (Rogala et al., 2011; Belotti et al., 2018). We interpreted recreation covariates that influenced detection probability as indicators of changes in site use or movement patterns of individuals as a response to human activity. However, several confounding factors may complicate this interpretation. Some high-use recreation areas may overlap with high-quality habitats, attracting wildlife despite human presence, or be located near natural features such as favorable foraging areas that wildlife may select independent of recreation. Further research is needed to disentangle the contribution of these factors we did not consider, particularly by considering additional habitat and landscape variables.

Although our study demonstrated that our focal wildlife species are influenced by human recreation spatially and temporally, there are several considerations when interpreting our results. First, there could be age-, sex-, or season-specific differences in ungulate responses to recreation that could be important for fully understanding recreation impacts that we didn't analyze (Gulsby et al., 2018). For example, younger individuals or females with offspring may be more risk-adverse and avoid high-use recreation areas, while males may be less sensitive to human disturbance (Gulsby et al., 2018). Considering these characteristics could further reveal how recreation affects different demographic groups within ungulate populations. Second, when comparing wildlife activity, we assumed that wildlife occurring either on-trail or off-trail exhibited "natural" activity patterns. However, wildlife could be influenced by additional human factors such as noise levels, group sizes, and lagged effect, among others, that we did not consider. Third, there were differences in camera setup between the first and second years of the study. Crawl tests during camera setup to ensure proper camera angling that would capture animals were not conducted during the first year. We found that detection probability decreased with increasing distance to the focal point for deer, coyotes, and raccoons. While recommendations for camera placement distance vary, Rowcliffe et al. (2011) suggest positioning cameras within 8 meters from the detection zone for visitor-focused studies. In our study, camera distances ranged widely from 2.2 to 15.1 meters. For cameras placed farther away, we believe camera angle may have influenced detection probabilities, an aspect not accounted for in our models.

MANAGEMENT IMPLICATIONS

Our study highlights that Strava Heatmaps can serve as an important tool for managers who may not have access to resource-intensive measures, such as camera trapping, to identify areas of low recreation within parks. Strava Heatmaps are an accessible and accurate tool for measuring different levels of recreational trail use that can be used to manage landscapes with extensive recreation networks. Heatmaps are updated monthly and can provide information for understanding relative recreation trends throughout the seasons. Marion et al. (2024) discuss methodology for extracting Strava information for more in-depth analysis, but our preliminary results indicate that the Heatmaps can serve as a publicly available tool that may only require visualization to utilize.

Our findings can help inform strategies to reduce recreation impacts on wildlife in the WUI. Our results indicate that even species that we thought to be highly adapted to people showed preference for areas with less recreation and temporal separation from areas of high human activity. For example, black-tailed deer demonstrated shifts in activity, favoring areas with lower levels of recreation and diurnal patterns in off-trail locations, but crepuscular activity in on-trail locations. Similarly, black bears showed spatial preferences for areas with less recreation. Areas with minimal or low recreation are serving as spatial refuges within these highly used parks. Preserving areas with minimal recreation in these already fragmented systems can allow spatial separation from humans for wildlife that may be using these areas during the day or night (Reed and Merenlender 2008; Stankowich 2008; Larson et al., 2019).

In areas where recreation is widespread, it is crucial to preserve crepuscular and nocturnal periods free from human disturbance, as wildlife rely on these times for their natural behaviors. This may involve limiting and enforcing recreational activities to daytime hours. To maintain both ecological integrity and recreational opportunities in the WUI, managers of parks and public lands must carefully consider species-sensitivities to human disturbance and strike a balance between recreation and wildlife conservation.

Chapter 2: Integrating Science into Recreation and Wildlife Management: Insights from Washington Land Managers

ABSTRACT

Interest in outdoor recreation has grown in recent years, benefiting people but posing challenges for wildlife. While scientific research has advanced our understanding of the recreation impacts on wildlife and the value of science-based management, there remains a gap in our understanding in how research is integrated into management decisions involving recreation and wildlife. This chapter examines the factors shaping the science-practice gap in this field. We conducted 14 semi-structured interviews with land managers from local, state, and federal agencies in Washington and used thematic analysis grounded in the Theory of Planned Behavior to explore land managers' attitudes, external pressures, and perceived ease or difficulty in integrating science into decision-making. Our findings highlight the complexity of recreation and wildlife management, where managers must balance competing priorities, agency mandates, and social expectations. While managers generally expressed positive attitudes toward science-based decision-making, structural and resource constraints, along with communication gaps and differences in research priorities, emerged as key barriers. In contrast, partnerships and accessible science were key facilitators. Additionally, external pressures from tribes and local communities were identified as playing a critical role in influencing management practices in this field. This research contributes to a growing understanding of how scientific knowledge can be more effectively integrated into conservation management. As outdoor recreation expands and pressures on wildlife intensify, evidence-based management will be essential to reducing these impacts while ensuring sustainable recreation access.

INTRODUCTION

The demand for outdoor recreation has surged in recent years, with global visits to protected areas exceeding 8 billion annually (Balmford et al., 2015). In the United States, outdoor recreation has been both a major driver of land protection designations (Thomas and Reed, 2019) and a significant contributor to wildlife endangerment (Losos et al., 1995). While recreation provides numerous benefits, such as enhancing physical and mental health through exercise and stress relief (Frumkin, 2001; Razani, 2021) and supporting local economies (Mojica and Fletcher, 2020), non-consumptive recreational activities can have direct negative effects on wildlife. These impacts include behavioral disruptions (Arlettaz et al., 2007; Naylor et al., 2009), changes in spatial and temporal habitat use (George and Crooks, 2006), physiological stress (Creel et al., 2002), or shifts in community composition (Lenth and Knight, 2008). Numerous empirical studies have examined these impacts in protected areas, with a meta-analysis revealing a 23.5% average annual increase in recreation and wildlife research publications from 1981 to 2015 (Larson et al., 2016). Despite this growing body of research, the same review found that approximately 40% of studies lacked actionable management recommendations, offering only vague suggestions. Moreover, even when studies provide recommendations, it is unclear how effectively they are received and implemented by land managers (Cook et al., 2013; Larson et al., 2016). This disconnect represents a "knowing-doing gap," a challenge present across many fields (Pfeffer and Sutton, 1999). Bridging this science-practice implementation gap requires a deeper understanding of the challenges faced by land managers while acknowledging the inherent limitations of scientific research. This is of particular importance in regions like the western United States, where recreational pressures on protected areas are increasing and so are the negative impacts on wildlife (Larson et al., 2016).

It is widely recognized that multiple forms of knowledge can, and should, inform environmental resource management (Raymond et al., 2010). Conservation managers draw on a wide range of sources to inform their decisions, yet evidence suggests that empirical research rarely plays a direct role in guiding management practices in ecological and conservation contexts (Pullin and Knight 2005; Cook et al., 2012). Several factors contribute to this gap, including limited access to or difficulty interpreting peer-reviewed literature (Arlettaz et al., 2010), capacity constraints to implement findings (Lemieux et al., 2018; Walsh et al., 2019; Thomas and Reed, 2019), mismatched time frames between research and the urgency of management needs (Young and Van Aarde, 2010), and inadequate research scales (Bertuol-Garcia et al., 2018).

It should also be noted that the science-practice gap often assumes a one-way flow of knowledge from research to practice, which overlooks the importance of integrating other knowledge types and the complex, entangled processes that shape decision-making (Adams and Sandbrook, 2013; Toomey et al., 2016). These disconnects, whether stemming from research questions misaligned with management needs (Linklater, 2003; Esler et al., 2010) or limited opportunities for collaboration and co-creation (Shackleton et al., 2009; Pardini et al., 2013), highlight the need to address barriers to evidence-based decision-making while considering the broader context of challenges that managers face in balancing multiple priorities.

Managing natural resources at large scales involves a variety of components, including ecosystem management while considering political, economic, and cultural contexts (Gastón et al., 2008). Furthermore, land managers operate in dynamic environments that are influenced by both social contexts and unpredictable natural systems (Bosch et al., 2003). In these complex settings, decisions must be based on more than just evidence, and should ideally integrate scientific research, local knowledge, and practical expertise (Sutherland et al., 2004; Walsh et al., 2015). Conservation actions often involve limited resources and should therefore be justified by good scientific evidence that can lead to tangible and meaningful outcomes (Pullin and Knight, 2001). Moreover, even if scientific knowledge is being produced, it must be accessible and relevant to managers to be actionable (Cook et al., 2013).

Understanding the types of evidence that recreation and wildlife managers use in decision-making can shed light on the barriers they face when integrating scientific findings into management practices. This insight can inform strategies to bridge the gap between science and practice in this field. For instance, it can help distinguish between challenges related to the co-production of knowledge and those from the disconnect between research and management. These questions are especially relevant in the Western U.S., where significant research is being produced on the impacts of recreation on wildlife (Larson et al., 2016). At the same time, there are also many public spaces for outdoor recreation that are easily accessible, and the growth of recreational activities has contributed to an influx of people moving to the West, driven by a desire for natural amenities such as scenic landscapes and recreational opportunities (Hjerpe et al., 2020).

As recreation continues to expand, the potential for greater impacts on natural ecosystems, including wildlife, is growing. Washington is one state experiencing this trend, where outdoor recreation is a major economic driver, and participation in hiking doubled from 2013–2021 (Balk, 2018). These pressures were further intensified during the 2020 COVID-19 pandemic, when Washington public lands experienced heightened use, leading to notable environmental degradation and a lack of enforcement in many public recreational areas, including national forests and state parks (Mapes, 2020). Although these pressures have decreased, we are at a critical juncture where understanding the effectiveness of recreation and wildlife management research is crucial for the sustainable management of public lands in the future.

We evaluated how land managers in Washington from non-governmental organizations (NGOs) and local, state, and federal agencies use scientific evidence in their decision-making and examined the barriers, facilitators, and interaction factors within the complex management systems in which they operate. We addressed two questions: (1) What drives the science-practice gap in recreation and wildlife management? and (2) What factors influence the integration of scientific research into management decisions?

To explore these questions, we applied the Theory of Planned Behavior (TPB), a widely used framework for examining individual factors that shape human behavior (Ajzen, 1991). The TPB provides a useful lens for understanding the factors that influence individual decision-making. The TPB dictates that human behavior is driven by an individual's intention to perform the behavior which is shaped by three constructs: attitudes toward the behavior (positive or negative), subjective norms (perceived social pressures), and perceived behavioral control (perceived ease or difficulty of performing the behavior). The TPB has been extensively applied in the environmental research to understand the determinants of decision-making (Si et al., 2019). For example, Swan et al. (2020) examined gamekeeper's motivations in predator management, highlighting how behaviors central to conservation are shaped by both social and ecological drivers. Similarly, Savari and Khalegi (2023) applied the TPB to understand how attitudes, subjective norms, and perceived behavioral control shape the intentions of local communities to protect forests in Iran, finding that positive influences from all three factors promote forest conservation intentions. By applying the TPB to land managers' decision-making process, we examined attitudes toward the use of science in decision-making, the social pressures and expectations managers faced in doing so, and their perceived ease or difficulty of implementing research in decision-making within the context of recreation and wildlife management.

METHODS

Participant recruitment

We conducted semi-structured interviews with 14 land managers. To be included in the study, participants had to meet our definition of a land manager: Washington-based practitioners with expertise in managing landscapes for non-consumptive recreation and wildlife. Participants were selected using a combination of purposive and snowball sampling (Miles and Huberman, 1994, p. 27).

Initial participants were identified and contacted through internet searches and cold emailing. Internet searches involved looking up terms including "recreation manager Washington" and "wildlife manager Washington," followed by additional searches to identify how those positions are titled across different organizations. We also identified major public agencies, land trusts, and non-governmental organizations with land management components and added the name of the organization followed by the original search terms. This process included looking through agency websites, publicly available contact lists, and professional directories. Additionally, personal recommendations were made for potential participants, and the lead researcher reached out to those who fit the criteria or were likely to provide further contacts. We asked recommenders if we could share their name when reaching out to potential participants and otherwise ensured anonymity. Through this process, we received additional referrals from some of the recommended individuals, which led to further participant recruitment.

In total, we contacted 27 interview candidates and 7 professionals who we thought could provide contacts between January and May 2024. Of those contacted, 15 practitioners agreed to participate in the interviews. We aimed to include representation from local, state, and federal management levels, with at least two managers from each. Our interviewees were land managers from eight management agencies, representing two managers from local agencies (one from a county government agency and one from a non-governmental organization) along with eight from state agencies and four from federal agencies. All interviewees met our criteria, except for one individual whose role more closely aligned with a scientist position rather than a management role. As our focus was on capturing perspectives from management positions, we excluded this interview from our data.

Interview process and data collection

Interviews were 1-hour long and conducted virtually over Zoom. Interviews were recorded and transcribed using Zoom's built-in audio transcription tool. The interview guide consisted of 17 open-ended questions with prompts and follow-ups to encourage in-depth responses (Breakwell, 1995). The interview guide was developed with the TPB as the guiding framework. Questions were designed to explore participant's attitudes, subjective norms, and perceived behavioral control in relation to the use of scientific research in decision-making. Additionally, broader questions were included to capture other factors influencing recreation and wildlife management (Box 1). The guide was designed to adapt to the conversation, so it was broad and covered managers' experiences in recreation and wildlife management, decision-making processes, use of scientific research, information sources, and perceived barriers and facilitators to research implementation in decision-making.

Interview questions were not shared with participants in advance to allow for flexibility in follow-up questions and to adapt the direction of the interview as needed. After the first three interviews, we briefly paused interview scheduling to review the interview guide to ensure we accurately captured the desired information and refined some questions to encourage participants to share more about their experiences with recreation and wildlife management.

At the end of the interviews, we asked the interviewees whether they would like to add or emphasize particular points about the science-practice gap in recreation and wildlife management. To minimize the likelihood of missing important insights, we emphasized the purpose of the research, reassured participants that we were not seeking specific answers, and highlighted that their responses would be anonymized in reporting both at the beginning and in the middle of the interviews.

After each interview, a memo summarizing the main content of the interview was written up to help us remember the context of the interview and aid in interpreting content. Interviews and memos were assigned unique IDs and stored securely on an encrypted hard drive, in accordance with the IRB guidelines. There were no repeat interviews. While we were ultimately constrained by timing, the completed interviews appear to have produced saturation in responses based on coded themes, and we argue that they allow us to draw meaningful conclusions and answer our research questions. The first author conducted all interviews and performed data analysis and verification with the feedback from the other authors.

Data analysis

We used thematic analysis to code and derive recurrent themes from the data (Daly et al., 1997). We used a combination of deductive and inductive coding, starting with a set of codes based on our research questions while allowing for patterns and themes to emerge from the data (Fereday and Muir-Cochrane, 2006). Coding was completed in ATLAS.ti (version 25.0.0). The first stage of coding involved systematically analyzing each sentence or section of each interview and assigning codes that best characterized the statements. Multiple codes were assigned to sections when relevant. After each script was coded, we grouped and sorted individual codes into broad themes which were then further categorized under the three TPB constructs: attitudes, subjective norms, and perceived behavioral control. This organization helped us examine the factors that shape managers' intentions to implement science in decision-making which in turn predicts their actual implementation (Ajzen, 1991; Figure 5).

Ethics

When reaching out to potential participants, we included information about the project and highlighted the data confidentiality of the project. All interviewees signed an electronic consent form for the collection and processing of interview data. This research was approved by the University of Washington Internal Review Board Protocol (Application number: STUDY00019350).

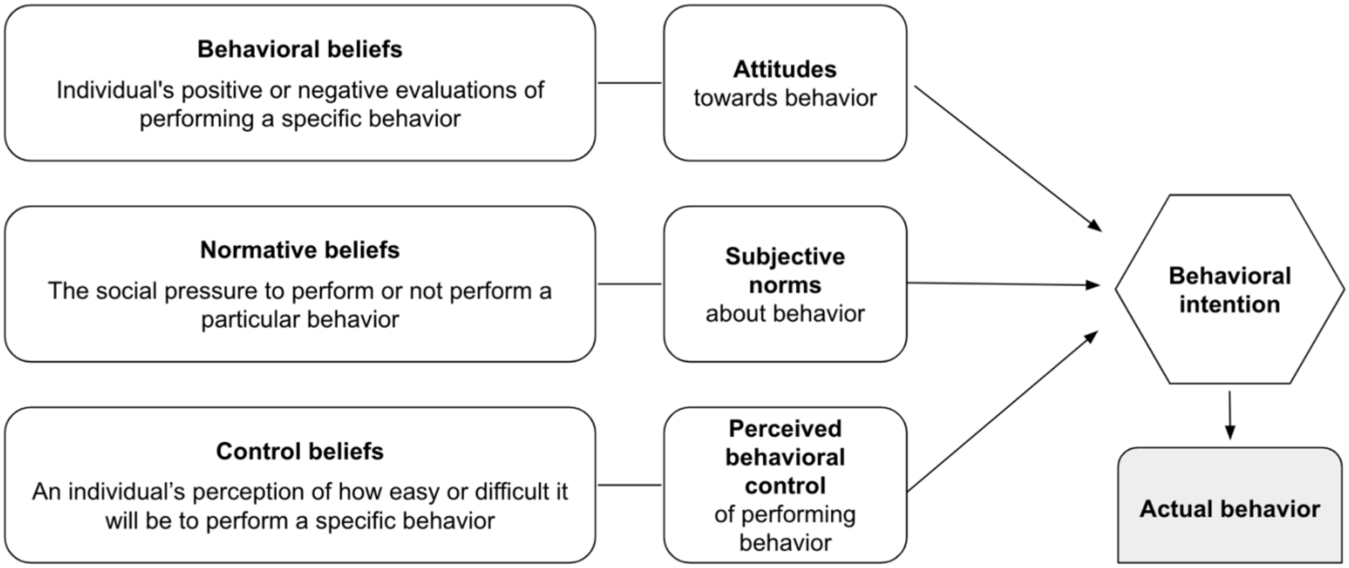


Figure 5. The Theory of Planned Behavior (TPB) posits that human behavior is driven by an individual's intention to perform a behavior which is influenced by three key constructs: attitudes toward the behavior (positive or negative), subjective norms (perceived social pressures), and perceived behavioral control (perceived ease or difficulty of performing the behavior). These constructs shape behavioral intention, which in turn influence actual behavior.

Box 1. Questions used to guide semi-structured interviews with Washington land managers to explore the drivers of the science-practice gap and the factors facilitating the integration of research into decision-making in recreation and wildlife management.

Interview guide

1. Tell me about your experience working as a land manager in your current role.
2. Could you provide a brief overview of how decisions are made within your organization and your role within that process?
3. What does non-consumptive recreation look like on your landscape?
4. What are some management priorities regarding wildlife in the natural areas you manage?
5. Tell me about your experience with the effects of recreational activities on wildlife on the landscape you manage.
6. What sources of information do you access to aid your decision-making regarding recreation and wildlife?
7. Can you please explain why you use those sources and how you access them?
8. Can you describe your access to scientific journals or reports and how it influences your work?
9. Can you share with me a few examples that come to mind of the management of recreation impacts on wildlife in the areas you manage.
10. What key barriers limit the implementation of scientific literature in managing recreation impacts on wildlife?
11. What are some key factors that promote the implementation of scientific literature in managing recreation impacts on wildlife?
12. What do you think would help land managers better receive recommendations from the scientific literature?
13. What is your perception of the role of science in guiding management decisions for recreation and wildlife?
14. Can you describe any instances where recreation users, your organization, or stakeholders have influenced your management actions regarding recreation impacts on wildlife?
15. What do you think is the future of recreation and wildlife management in the landscapes?

Additional questions

16. What is your organization's attitude or policy towards using scientific research in decision-making?
17. What is your perception of the dynamic between researchers and decision-makers?

RESULTS

Our thematic analysis identified five main themes: 1) Changing Perspectives on Recreation and the Role of Science 2) Tribal Influence on Recreation Management, 3) Community Influence on Recreation and Conservation Decisions, 4) Barriers to the Implementation of Science in Decision-Making and 5) Leveraging Science and Collaboration for Effective Management. These themes align with the three TPB constructs: attitudes, subjective norms, and perceived behavioral control illustrating how these factors influence behavioral intentions and management decisions (Figure 6). The following sections present these results, followed by a discussion within the broader literature and the TPB framework.

Contextual Factors in Recreation and Wildlife Management

Managers operate within structured agencies where decision-making authority varies by agency and management level. While local agencies, including non-governmental organizations and land trusts, have greater autonomy in management decisions, larger government-managed natural areas face more complex management structures with multiple layers of approval. Regardless of agency type, decision-making is also influenced by a range of stakeholders including legislators, external committees, and political commissions. This complexity in management structure means that managers navigate multiple perspectives and interests while playing key roles in setting agendas, making recommendations, and overseeing planning processes.

Beyond bureaucratic processes, managers must also balance competing priorities within their agencies. Many land management agencies are mission-driven with priorities tied to specific legal mandates, agency mission, and land acquisition agreements. Recreation and wildlife management is integrated within these frameworks and must align with broader conservation goals. While recreation access differs by agency, managers described working to meet both agency responsibilities of conserving natural resources with their obligation to provide public recreation opportunities.

Managers must also navigate differing priorities on what should take priority in land management. Determining how conservation actions should influence recreation requires balancing both conservation goals and recreation demand. The challenge lies in addressing user needs under diverse management priorities, requiring navigating complex management systems. As one manager reflected:

> “Right now, we are at a standstill, because nobody can agree on what the issue is, number one, and then number two, how to solve the issue… it's such a political hot potato.”

These competing priorities shape how managers balance multiple goals within complex systems. In addition to these structural realities, decision-making is also influenced by manager’s attitudes toward science use in decision-making, external pressures from partners and stakeholders, and their perceived ability to implement science-based strategies.

THEME 1: CHANGING PERSPECTIVES ON RECREATION AND THE ROLE OF SCIENCE

Shifting Views of Recreation Management

There has been a significant increase in recreation in natural areas, especially since the COVID-19 pandemic. While recreation growth has provided an economic boost to many local communities, managers have observed the strain it has placed on public lands, wildlife habitats, and the resources needed to manage these landscapes. Across agencies, there was a shared understanding that indefinite recreation growth is not sustainable. As one manager explained:

> “We're staring at the reality that we can't keep growing recreation access forever. There can’t be trails everywhere and you can't keep building bigger parking lots to accommodate the demand.”

The increasing demand for recreation has led to growing concerns over the negative impacts that recreation poses on wildlife and the landscape. There is increasing acknowledgement that continued growth requires proactive management that may diverge from previous management approaches. Reflecting on the shift in perspective, one manager noted:

> “When I first started in the recreation [management] space, we were not having conversations like that, it was all about access and the benefits of recreation only. It does feel like those conversations are increasing around how do we manage use in a way that is sustainable?”

Managers emphasized a need to balance recreation and wildlife conservation by making informed decisions that incorporate various perspectives including those of stakeholders, conservation-focused groups, and recreation advocates.

Balancing science and experience in management

Land managers recognized that science is an important part of decision-making, with its incorporation dependent on the management agency's context and specific needs. Managers described using science in various ways, including searching for peer-reviewed literature, seeking expert guidance based on scientific backgrounds, and engaging in collaborative efforts that integrate scientific research. Managers viewed science as a foundational tool for understanding the landscape they manage, guiding recreation management, and justifying decisions that might face public disagreement. Some managers also note there are many opportunities in this field of recreation and wildlife management for more incorporation of science in decision-making through increased collaboration, research, and practices. As a manager emphasized:

> "We're managing things on the ground… so we're dependent on people who are doing the research to really give us a better sense of what's actually happening."

However, across the board, managers emphasized that science alone does not drive management actions and that experience-based knowledge is a vitally important resource. To guide their decision-making, managers draw on a variety of information sources including peer-reviewed scientific literature, technical expertise from partner organizations, Traditional Ecological

Knowledge from tribal partners, and practical experiences from staff and community members. Internal conversations, informal networking, and historical knowledge from experienced staff are also crucial information sources. Managers view their on-the-ground observations as an essential tool in decision-making, though they recognize the importance of integrating empirical data when available. As one manager explained:

> "It is an expertise to understand what the operational implications are of implementing science and I think that knowledge is often undervalued."

Ultimately, while managers recognize shifting perspectives on recreation management and the role of science, their decision-making is shaped not only by personal viewpoints but also external influences that play a significant role in shaping recreation management.

THEME 2: TRIBAL INFLUENCE ON RECREATION MANAGEMENT

Many managers noted that their relationships and pressures from tribes are important drivers of recreation management decisions. Tribes have raised strong concerns about the impacts of recreation on wildlife, habitat, cultural resources, and their tribal treaty rights (Nelson and Bailey, 2021). One manager stated:

> "The tribes have made the statement that they view outdoor recreation in the State as the biggest threat to their treaty rights."

Managers noted that tribes have placed mounting pressure on agencies to address the issues stemming from recreation, calling for a better understanding of recreation impacts and better management of recreation. As one manager recalled from a forum with tribes:

> “The first thing they said was they wanted us to pause all recreation expansion… and we functionally don’t know how to do that.”

To be responsive to these concerns, many managers emphasized the importance of their efforts in engaging with tribal partners early in the decision-making process. They described efforts to foster collaborative relationships through formal consultations, incorporating Traditional Ecological Knowledge, and developing relationships between agencies and Tribal nations.

THEME 3: COMMUNITY INFLUENCE ON RECREATION AND CONSERVATION DECISIONS

Managers identify local recreation users, particularly long-term residents, as sources of external pressure in recreation management. These individuals can be vocal about recreation access and, in some cases, exert political and financial pressure to influence management actions. Tensions arise when land management prioritizes wildlife protection or limits recreational activities. This pressure centers on users advocating for increasing recreational access and opportunities, as illustrated by one manager:

> “We found that when we started the closure people were furious.”

Local user groups can be strong advocates for conservation, having observed changes to wildlife populations and landscape conditions. Yet, managers note that conflicts arise when recreational priorities clash with conservation goals. This is evident in wealthier or recreation-driven communities, where users may prioritize access to outdoor recreation over conservation efforts such as preserving wildlife habitat:

> “You have to have a populace that understands about land conservation because if they're so recreation-based they're not concerned about preserving.”

To navigate competing pressures, managers engage the public in decision-making through advisory committees and public input processes. These forums allow individuals affected by recreation decisions to provide input about management actions. Despite these processes, public pushback remains a challenge, particularly when access is restricted. Skepticism about closures or recreation restrictions can drive oppositions to management actions. Some managers emphasized that transparent communication is crucial to reducing conflict as clear explanations of the rationale behind restrictions can help improve public acceptance.

THEME 4: BARRIERS TO THE IMPLEMENTATION OF SCIENCE IN DECISION-MAKING

Beyond competing priorities within agencies, managers also face various constraints that limit their ability to implement science in decision-making for recreation and wildlife management decisions. These include institutional constraints, a disconnect between science and management, and the challenge of translating science into management.

Institutional constraints

While science is an important tool for decision-making, political, economic, and institutional considerations are crucial drivers. Organizational policies and processes often dictate the scope of decisions, sometimes resulting in limited flexibility to implement science-based recommendations. Reflecting on this constraint, a manager explained:

> “It's not like we would go read a journal from another neighboring agency and say, ‘Oh, we want to implement that on our land’ because our hands are so tied with our [agency] policy and our management plans.”

Financial and staffing limitations are also significant barriers. Many managers operate under a “scarcity mentality” where limited resources force them to prioritize immediate responsibilities over long-term planning for recreation. As a result, recreation management often remains reactive rather than proactive, as managers respond to immediate responsibilities over forward-thinking strategies. Managers recognized the importance and, at times, the desire of conducting scientific research for decision-making, but they also noted the limited funding available to support technical recreation staff. A manager described this challenge:

> “It's one thing to be familiar with literature but then it's totally another thing to use the literature to implement management changes. That would require a lot of capacity that we don't have and recreation in general is pretty underfunded.”

Limited staffing creates additional challenges as agency staff are spread thin, making it difficult to implement comprehensive management strategies or to collect and analyze wildlife and recreation-related data. Even when managers have access to scientific literature, these constraints make it difficult to engage with new research or incorporate it into decision-making processes. One manager highlighted this reality:

> “I'm already doing too many things in a day that I'm not going to sit and read new literature.”

Another added:

> "I don’t think it’s a barrier of we don't know where we could find the data, or we don't have the means to access academic journals or peer-reviewed literature. But we don't have the staff capacity or the prioritization from an agency level.”

These capacity limitations reflect the complexity of management where decisions may have to be made without the application of scientific research.

Disconnects between science and management

A significant gap exists between research and land management due to differences in priorities, timelines, and communication. Managers often feel that research doesn’t address practical management needs or is too slow to provide useful results. Researchers may also focus on questions that are not applicable to on-the-ground issues. One manager reflected on this disconnect:

> “The researchers don't have a great grounding in applied science, and they might be answering or asking an intellectually interesting question, but it just isn't relevant to land management.”

This disconnect is compounded by poor communication between scientists and managers. Scientists may not reach out to managers or managers may feel they don’t have time to engage with scientific findings. As one manager explained:

> “Sometimes I think people who do research and only research think of themselves above people who do management, and sometimes people who do management are like, ‘That's an ivory tower thing, I don't have time’.”

The slow pace of scientific research and the time-consuming nature of decision-making create barriers to effectively apply science in management. Bureaucratic approval processes and logistical constraints, such as managing large natural areas, exacerbate these delays and make timely action difficult. One manager expressed this frustration:

> “The research takes a while… but oh, man, it could take years to get approval to do any little simple thing on the ground."

These challenges illustrate the barriers managers face in applying scientific research to recreation and wildlife management. While institutional constraints, limited resources, and communication gaps can hinder the application of science in decision-making, managers recognize its importance, find ways to navigate these obstacles, and seek opportunities to incorporate science into their management where possible.

In practice, managers draw on internal expertise, institutional knowledge, and technical staff to inform decision-making. Resources like centralized databases, internal reports, and agency-led research and monitoring can provide important information. In some cases, decision-making leans more on professional judgment and internal discussions than on direct engagement with external scientific studies. There are also varying degrees of access to scientific literature though access to scientific literature was not identified as a major barrier. Some managers directly access open-source articles, while others rely on institutional subscriptions, university affiliations, personal networks, interagency contacts, or direct outreach to authors.

Translating science into management actions

Managers noted navigating the balance between the need for clear scientific evidence to back up their management decisions and the reality that decisions sometimes must be made without perfect data. They value clear scientific evidence to justify their management actions, such as restrictions, especially when they may be unpopular with the public. However, uncertainty remains a challenge when applying science. As a result, managers rely not just on science but also on experience, existing research, and stakeholder expectations.

When science is applied in decision-making, managers describe a process that involves reviewing existing studies, seeking technical expertise, and integrating multiple forms of knowledge. While the implementation is not perfect, and uncertainties remain, managers highlight cases were research successfully informed recreation and wildlife management. Decision-making in recreation and wildlife management is not straightforward, it’s a collaborative process involving scientific data, expert consultation, public input, environmental reviews, and policy guidelines. To reduce wildlife viewing impacts on wildlife, a manager described:

> “Just by implementing a few quick changes that were science-based… we saw a positive change, one that was not [like] anything we'd seen before. It wasn't perfect… but to see a collapse and failure from the year before to something that I feel was successful in the best way it could be, with the limited staff we have, was amazing.”

However, limitations in scientific literature can reduce its direct application. Managers note that gaps in the data, the range in specificity of studies, a lack of direct management recommendations, and operational feasibility across different contexts make implementation difficult. Research may be too species-specific, place-specific, or not directly applicable to local conditions. As one manager explained:

> “Because so much of our work is place specific there are limits to what we can apply to research that's done say in New Zealand.”

While managers recognize the value of science, they may lack sufficient or relevant data to make informed decisions. Without directly relevant information, they must navigate uncertainty when applying scientific findings. As another manager put it:

> “The signal in the data is, you're always looking through the fuzziness and the managers just want an answer.”

THEME 5: LEVERAGING SCIENCE AND COLLABORATION FOR EFFECTIVE MANAGEMENT

Partnerships and Collaborations for Science-Informed Management

Managers highlighted the benefits of collaboration in bridging gaps between research and practice. Managers emphasized the importance of networking and collaboration across agencies, universities, and non-governmental organizations to enhance management through knowledge exchange through partnerships, formal groups, and informal networks. These collaborations help managers learn from peers in other agencies, avoid duplicating efforts, and stay informed about emerging research and best management practices. Some managers noted partnerships with universities and graduate students provide valuable opportunities for research, and long-term relationship-building can foster respect and knowledge exchange.

These partnerships can also bring diverse expertise, knowledge sources, community support, and outreach opportunities that enhance the effectiveness of management decisions. However, managers acknowledged that these relationships can also bring tension. For example, some partner organizations may push for more recreation opportunities, but bureaucratic processes and different expectations can create challenges in meeting those requests. Despite these challenges, managers emphasized that working with a broad range of partners is important, particularly those with enforcement abilities and technical or observational expertise. One manager explained the importance of partnerships:

> “[A partner agency] can talk to their constituents because when you all work together and are sharing the same message because you're working off the same science, you reach a broader range of people.”

Managers also noted the difficulty of prioritizing reviewing literature among competing demands and emphasized the need for scientists to provide clear, digestible summaries of their findings. Furthermore, direct engagement between scientists and managers ensures that relevant research reaches decision-makers. Internal collaborations, conservation-minded staff, and a "community of practice" can help managers keep up with emerging research and work towards incorporating it into decision-making.

While managers face various constraints and disconnects between research and management, collaborative partnerships that encourage communication and knowledge exchange can strengthen their ability to integrate science into decision-making. By leveraging these strategies, managers navigate the various constraints they’re faced with and seek ways to integrate science into decision-making when applicable.

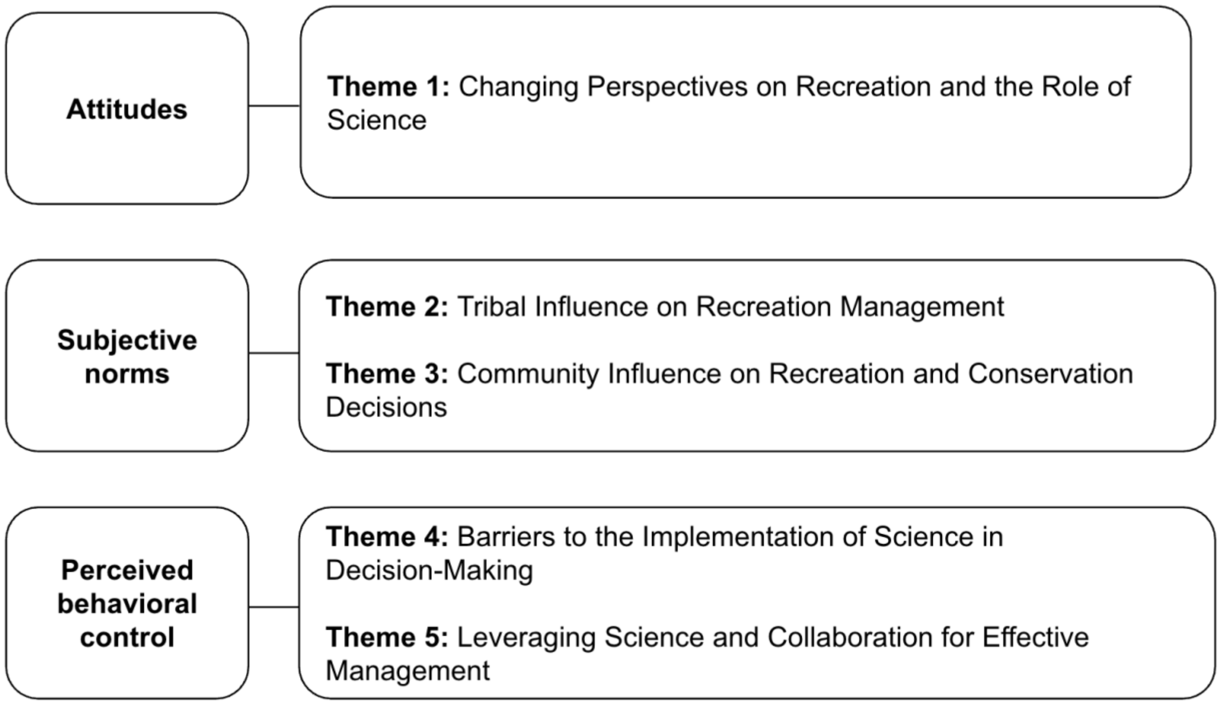


Figure 6. Application of the Theory of Planned Behavior (TPB) to thematic analysis findings. The five themes identified in our analysis correspond to attitudes, subjective norms, and perceived behavioral control in the context of recreation and wildlife management.

DISCUSSION

This study explored the science-practice gap in recreation and wildlife management through the theoretical framework of the TPB. We identified key barriers and facilitators that influence the integration of scientific research into land management decisions to understand unique perspectives relevant to recreation and wildlife management compared to the broader conservation field. Our findings align with broader research on the challenges of integrating science into decision-making, but highlight unique pressures faced by recreation and wildlife managers, particularly in the context of recreation management, where there is a strong need to balance ecological protection with public use and competing land management priorities.

Contextual Factors in Recreation and Wildlife Management

Our findings highlight the complexity of decision-making in recreation and wildlife management, where managers must navigate competing priorities within structured organizational frameworks. Managers described operating within complex management systems, where agency missions, political frameworks, and the level of decision-making shape their recreation management approaches. Decision-making authority varies by agency type with private land trusts having greater decision autonomy compared to government-managed lands, where multiple layers of approval influence outcomes. These structural complexities can shape the extent to which managers are able to directly implement science-based approaches.

Similar to Fuller et al. (2020), we found that practitioners managing landscapes for multiple objectives navigate difficulty and competing priorities in decision making. Managers described balancing recreation access with conservation mandates while responding to external pressures from stakeholders, legislators, and political commissions. This aligns with previous findings that agency visions, policies, and legal frameworks strongly influence large-scale strategic decisions compared to day-to-day decisions which may rely more on professional experience (Ausden and Walsh, 2020). The influence of external factors further complicates decision-making, as managers must navigate conflicting perspectives on recreation and wildlife management priorities reflected in the challenges some managers identified in reaching agreements on management issues.

Given these complexities, the role of organizational priorities in shaping the use of science in decision-making is important. If scientific evidence does not align with organizational priorities this may limit the integration of science in decision-making (Black et al., 2011; Cvitanovic et al., 2016). While our study did not explicitly examine this relationship, our findings suggest that managers operate within complex systems where competing priorities and bureaucratic structures may limit flexibility in decision-making. Research has suggested that having internal policies encouraging the use of science (Walsh et al., 2019), and leadership and strong organizational cultures that value science (Black et al., 2011; Cvitanovic et al., 2014b) are key enablers to tackling conservation challenges and in using research in decision-making. Given the complexities of management, organizational support may be critical in enabling the use of science in recreation and wildlife management and is an avenue for future exploration to better understand how organizational structures influence the science-practice gap. Beyond structural constraints, managers' attitudes toward recreation management also shape how science is integrated into decision-making.

ATTITUDES

Theme 1: Changing Perspectives on Recreation and the Role of Science

In the context of the TPB, attitudes toward science and recreation shape land managers willingness to incorporate scientific research into decision-making. Managers in our study recognized the need for a more intentional approach to non-consumptive recreation management and that while recreation serves as an economic driver for communities, it also places major strains on public lands. Research has shown that recreation may not always be compatible with biodiversity conservation and land protection (Reed and Merenlender, 2008), particularly with documented negative impacts on wildlife species (Losos et al., 1995; Larson et al., 2016). Managers in our study expressed an understanding that recreation actively shapes landscapes and wildlife behavior and viewed science as an important tool to mitigate potential ecological impacts. Manager's perceptions of recreation as a growing and evolving field of management indicate a shift in attitude that could drive more science-informed management in the future.

Managers generally expressed positive attitudes towards scientific research, acknowledging its importance in guiding management decisions. This aligns with findings across various management contexts, including studies in Brazil (Giehl et al., 2017), Australia (Cook et al., 2014), and the United States (Seavy and Howell, 2010), where science is recognized as a valuable tool for decision-making. While having positive attitudes towards research can facilitate its implementation in management (Walsh et al., 2019), effective decision making often relies on multiple sources of knowledge. Managers in our study highlighted that decision-making is not based solely on empirical research and that it relies on experience-based knowledge such as professional expertise, on-the-ground observations, and knowledge of past management experiences. This highlights the role of diverse expertise in shaping recreation and wildlife management decisions and is also important for effective decision-making (Walsh et al., 2019). Pullin et al. (2003) found that many conservation practitioners in the UK rely heavily on experience-based knowledge and use traditional land management practices over empirical research. Adams and Sandbrook (2013) argue that experience-based knowledge can provide deep insights into management issues that scientists may only superficially understand. While science is valued, its application is mediated by individual expertise and the practical realities of land management.

SUBJECTIVE NORMS

Theme 2: Tribal Influence on Recreation Management

We found that managers face external pressures from tribes and local communities, which play important roles in shaping recreation management decisions. Land managers noted that tribes have expressed strong concerns about the impacts of recreation on various aspects of their treaty rights including effects on wildlife and habitat. In a broader context, tribes in western Washington have raised concerns about how recreation may be compromising the health of the ecosystems in which their treaty rights depend on.

In a review of recreation impacts on wildlife and the implications for treaty tribes, Nelson and Bailey (2021) note that tribes are calling for a stronger effort to understand and mitigate recreation impacts, which they view as currently missing. Additionally, they note that structural challenges in recreation management are currently in place, such as funding programs requiring public access as a condition for restoration or land acquisition (Nelson and Bailey, 2021). As a result, tension is created for managers trying to balance conservation with recreation expansion, particularly as tribes push for stronger protections. In response to these pressures, managers in our study reported making efforts to engage with tribes early in the decision-making process and fostering more collaborative relationships through formal consultations and the incorporation of Traditional Ecological Knowledge.

Theme 3: Community Influence on Recreation and Conservation Decisions

Beyond tribal influence, we found that local recreation users also exert influence on recreation management decisions. Public pressure can drive decision-making in recreation settings to the extent that public interest is prioritized over conservation actions (Carruthers Den Hoed et al., 2020). Our results similarly suggest that local recreation users can advocate strongly for recreation access and apply political and financial pressure over specific management actions. However, public influence can also be positive, as community members can be strong advocates for conservation, drawing from long-term observational changes to the landscape they recreate on. This aligns with research emphasizing the value of 'practice-based' environmental knowledge from experienced members of the public, demonstrating a valuable form of expertise (Ingold, 2000; Adams and Sandbrook, 2013). Peterson et al. (2010) note that 'hearing local voices speak' can uncover deep knowledge and complement empirical evidence by contextualizing research through on the ground observations. Furthermore, Jacmarcq et al. (2024) suggest that understanding and valuing local views, including their needs and expertise, is crucial for successful management plans by reducing polarization between decision-makers and the public.

Managers in our study highlighted the importance of engaging the public through advisory committees and public input processes to ensure local opinions are included in management processes. Despite these efforts, public pushback to management decisions may still occur. Public opposition, particularly for recreation access, has been identified as a challenge for managers in other studies as constituents can spend significant effort appealing management decisions (Thomas and Reed, 2019). In our study, managers emphasized that transparent communication about rationale behind decisions is critical for improving public acceptance of management actions and in reducing conflict (Thomas and Reed, 2019; Fuller et al., 2020). Having the empirical evidence to support management decisions is critical in increasing public acceptance.

Subjective norms shape perceived expectations around integrating science in recreation and wildlife management actions. When scientific evidence is perceived as an expectation to management decisions, managers may be more inclined to incorporate it into their decision-making process. This may be the case if managers face pressures to justify management decisions under scrutiny from external stakeholders, such as the public, and tribes as legal entities with treaty rights. Alternatively, if social and political pressures emphasize recreation access, managers may prioritize these external expectations over scientific recommendations, particularly when facing a community strongly opposed to closures or other recreation restrictions that prioritize conservation over access. These dynamics highlight the complex relationship between external pressures and science-based decision-making. Science-driven management decisions, transparent communication, and early engagement with key partners can help align social expectations with management goals. This may in turn support science-informed decision-making in recreation and wildlife management.

PERCEIVED BEHAVIORAL CONTROL

Despite recognizing the value of science in recreation and wildlife management, managers face significant barriers to integrating science in decision-making. These barriers stem from institutional and resource constraints and persistent disconnects between research and management.

Theme 4: Barriers to the Implementation of Science in Decision-Making

Institutional Constraints

Within the structured organizational frameworks in which managers operate, policies themselves may act as constraints on knowledge mobilization, limiting managers' ability to move from scientific findings to management actions. Previous research has emphasized the role of leadership in facilitating or limiting knowledge exchange activities, with leadership that doesn't support science leading to negative outcomes for knowledge exchange (Cvitanovic et al., 2016). While we did not explicitly examine leadership influence, our findings suggest that organizational policies themselves may act as structural constraints on knowledge mobilization. Managers expressed feeling restricted in their ability to implement science-based actions when agency policies or mission-driven mandates heavily dictate the process of decision-making. This raises important questions about how institutional frameworks shape the extent to which scientific knowledge can be applied in recreation and wildlife management. Practitioners in Walsh et al. (2019) identified organizational cultures and social contexts to be the greatest facilitators of research use in management, warranting future consideration in recreation and wildlife management.

Capacity Constraints

Beyond organizational constraints, financial and staffing limitations pose significant barriers to integrating science into recreation and wildlife management, aligning with challenges identified across conservation and natural resource management (Lemieux et al., 2018; Walsh et al., 2019; Thomas and Reed, 2019). Managers in our study highlighted several constraints related to resource availability, including limited funding for technical recreation staff and insufficient staff to implement long-term recreation management strategies. Resource constraints, such as lack of time, staff, and financial resources for internal research, monitoring, and enforcement, have been identified as key barriers to science integration in decision-making (Esler et al., 2010; Cvitanovic et al., 2015; Lemieux et al., 2018; Walsh et al., 2019; Thomas and Reed, 2019). Furthermore, managers described being spread thin, making it difficult to engage with new research or integrate scientific findings into decision-making, consistent with findings from Walsh et al. (2019).

Staffing and capacity constraints not only limit manager’s engagement with science, but also limit the implementation of science-based strategies (Walsh et al., 2019), reflecting the challenges faced by the managers in our study. These limitations may cause managers to prioritize immediate responsibilities over long-term management and contribute to a cycle of reactive recreation management. While some management actions are expected to be reactive in dynamic management contexts (Fuller et al., 2020), focusing entirely on short-term planning may limit the ability to implement long-term science-informed strategies, reinforcing a cycle where science remains underutilized in management. Addressing these structural limitations is critical to fostering a more forward-looking approach to recreation and wildlife management.

Disconnect Between Science and Management

Our findings suggest that access to scientific literature itself is not a primary barrier to integrating science into decision-making as managers reported having the ability to access scientific literature through various ways. However, accessibility does not mean applicability. Even when research was widely accessible, its usability was a more significant barrier to implementation, highlighting larger structural barriers (Matzek et al., 2014; Baker et al., 2015; Lemieux et al., 2018).

Managers described a disconnect between science and management shaped by differences in priorities, timelines, and communication between researchers and practitioners. Given the urgent and dynamic nature of recreation and wildlife management, managers often lack the capacity to wait for specific peer-reviewed studies to be published before making decisions (Cvitanovic et al., 2016). Furthermore, timescales involved with bureaucratic approval processes can make the implementation of science-based decisions even more difficult. These time lags between data collection and availability of results are key barriers to integrating science into decision-making (Linklater, 2003; Cvitanovic et al., 2016).

Translating Science into Management Actions

Another challenge faced by managers is the disconnect between the scope of research questions and management needs. Scientific studies may focus on theoretical or academic questions rather than relevant management concerns, limiting their applicability in decision-making (Sunderland et al., 2009). Studies lacking consideration of operational feasibility, including costs, staffing limitations, or policy constraints of management are less likely to be directly integrated into practice (Matzek et al., 2014). This is a critical gap where research must be accessible, but also directly relevant to the decisions managers make within their specific management contexts. For example, while managers in our study expressed a willingness to use science, when possible, our findings underscore the need for more targeted, applied studies that directly address management concerns with managers emphasizing having to make decisions even when scientific findings are incomplete, uncertain, or not directly translatable to their specific landscapes.

Theme 5: Leveraging Science and Collaboration for Effective Management

Partnerships and collaborations play an important role in bridging the science-practice gap by promoting knowledge exchange and supporting science-informed management. These partnerships across agencies, universities, and non-governmental organizations help managers stay informed about emerging research, avoid duplicating efforts, and enhance decision-making through shared expertise. These findings are consistent with previous research emphasizing formal collaborations as essential drivers for integrating research into practice (Walsh et al., 2019). Partnerships with universities, and graduate students specifically, can provide increased opportunities for applied, local research and knowledge transfer as these collaborations can provide direct engagement with stakeholders (Courter, 2012).

Partnerships also provide practical support for implementing management actions, especially when there are resource limitations. Managers emphasized the importance of working with organizations with enforcement capabilities, technical expertise, or outreach capabilities, aligning with broader findings that resource constraints and a lack of enforcement can hinder the implementation of science-based management decisions (Walsh et al., 2019; Thomas and Reed, 2019). Furthermore, partnership organizations can aid managers with stakeholder engagement (Fuller et al., 2020), and provide practical support for implementing management actions, particularly when resources are limited. By leveraging partnerships, managers can reduce some of these limitations and improve their capacity to integrate science into their management decisions despite institutional and resource constraints.

The ability to integrate science into decision-making is shaped by structural and resource constraints which influence managers' perceived behavioral control, or the perceived ease or difficulty of integrating science into decision-making. Bureaucratic processes, capacity constraints, or a disconnect between science and management needs are barriers that increase the perceived difficulty of implementing science into management decisions. To enhance perceived behavioral control, research must address local knowledge gaps and specific information needs (Esler et al., 2010; Young and Van Aarde, 2010). Similarly, joint knowledge production between scientists and decision-makers is important (Young and Van Aarde, 2010; Bertuol-Garcia et al., 2018) as well as digestible summaries of scientific evidence (Walsh et al., 2015) that are effectively communicated with decision-makers (Young and Van Aarde, 2010).

Lastly, collaborative networks, including interagency cooperation, academic partnerships, or communities of practice can further provide managers with resources and knowledge sources necessary to apply science into decision-making despite constraints. By addressing these structural barriers and fostering collaboration, managers may feel an increased perceived ease of integrating science into recreation and wildlife management, ultimately bridging the science-practice gap.

CONCLUSION

Our study contributes to the broader literature by examining the science-practice gap specifically within recreation and wildlife management. Research on recreation impacts on wildlife is rapidly expanding, but where barriers to implementation of results remain unexplored (Larson et al., 2016). By structuring our analysis within the TPB, we found that managers' attitudes toward science are largely positive, but structural constraints, including limited resources, time, and competing mandates, shape their perceived behavioral control over implementing research-based decisions. Additionally, subjective norms, including partner and community expectations, exert pressure on managers and may influence whether science is used as a justification for decisions or if other priorities are more heavily favored. The TPB framework provides a structured way to understand why the science-practice gap exists in this management context, offering a unique perspective to this field aiming to bridge the science-practice gap.

While many of the challenges we identified are well documented in conservation decision-making, such as misaligned timelines, disconnect of research questions, and limited applicability of research, the recreation management context presents distinct challenges. Recreation management must balance public access with ecological considerations, increasing the need to justify decisions to diverse stakeholders and making the integration of science into practice particularly complex. Our findings point to several key strategies that can help facilitate the integration of science into recreation and wildlife management:

1. **Collaborative Partnerships:** Strengthening partnerships between agencies, universities, and NGOs can facilitate knowledge exchange, provide technical support, and increase opportunities for applied research tailored to specific management needs.
2. **Improved Science Communication:** Research should be translated into digestible, actionable formats for managers, such as summaries, decision-support tools, or involve direct engagement with managers.
3. **Capacity building:** Addressing broader structural barriers, such as increased funding, staffing, and technical expertise, is essential to alleviating management pressures and enabling managers to engage with and apply scientific findings. However, we recognize the constraints of current management realities and acknowledge that implementing these changes is challenging.

While this study provides valuable insights into the science-practice gap, our relatively small sample of land managers and narrow focus on Washington state may limit the applicability of our results. Future research could expand on these findings by focusing on a broader geographic range, examine how governance structures influence science integration, and how managers engage with different types of evidence beyond peer-reviewed research. Furthermore, while we focused on managers, decision-making involves multiple perspectives, including those of scientists (Cvitanovic et al., 2014) and legal tribal entities (Weiss et al., 2013) and those perspectives are valuable in understanding best management practices. Examining these factors may provide a more holistic understanding of decision-making within recreation and wildlife management.

As outdoor recreation continues to expand and exert pressure on wildlife and natural landscapes, the need for effective, evidence-based management will continue to grow. Reducing these impacts will require addressing the barriers identified and fostering stronger relationships between science and practice, working towards more informed and sustainable approaches to recreation and wildlife management in the future.

ACKNOWLEDGEMENTS

This research was supported by the Washington State Parks Foundation, the Washington State Parks Wildlife Forever Fund, the School of Environmental and Forest Sciences, and the Conservation, Research and Education Opportunities International (CREOi). Partial support for this research came from a Eunice Kennedy Shriver National Institute of Child Health and Human Development research infrastructure grant, P2C HD042828, to the Center for Studies in Demography & Ecology at the University of Washington. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. Additional support for this research came from support to CSDE from the College of Arts & Sciences, the UW Provost, eSciences Institute, the Evans School of Public Policy & Governance, College of Built Environment, School of Public Health, the Foster School of Business, and the School of Social Work.

Thank you to the 53 processing technicians who contributed over 3,000 hours of image processing work to this project, whose immense contributions made the analysis for Chapter 1 possible. Thank you to the various volunteers who helped with fieldwork throughout the project including Eric Martin, Keenan Ganz, Alex MacKinnon, Nanditha Shivakumar, Leo Wahl, and Oriana Dominguez. We also thank Celine Boillat, our devoted technician who helped with fieldwork and contributed many hours to image processing, quality checks, and data organization. We thank the park rangers at our study parks who helped with fieldwork logistics and to Kevin Lease for helping with camera deployments on multiple occasions. Lastly, thank you to current and former members of the Quantitative Ecology Lab – Sarah Bassing, Eve

Hallock, Sierra Gillman, and Cameron Ho – for unconditional support, encouragement, and motivation throughout this project.

LITERATURE CITED

Adams, W., & Sandbrook, C. (2013). Conservation, evidence, and policy. *Oryx*, *47*. https://doi.org/10.1017/S0030605312001470

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, *50*(2), 179–211. https://doi.org/10.1016/0749-5978(91)90020-T

Alexrk2. (2009). *USA Washington location map* [Map]. Wikimedia Commons. https://en.wikipedia.org/wiki/File:USA_Washington_location_map.svg

Arjo, W. M., Gese, E. M., Bennett, T. J., & Kozlowski, A. J. (2007). Changes in kit fox–coyote–prey relationships in the Great Basin Desert, Utah. *Western North American Naturalist*, *67*(3), 389–401. https://doi.org/10.3398/1527-0904(2007)67[389:CIKFRI]2.0.CO;2

Arlettaz, R., Patthey, P., Baltic, M., Leu, T., Schaub, M., Palme, R., & Jenni-Eiermann, S. (2007). Spreading free-riding snow sports represent a novel serious threat for wildlife. *Proceedings of the Royal Society B: Biological Sciences*, *274*(1614), 1219–1224. https://doi.org/10.1098/rspb.2006.0434

Arlettaz, R., Patthey, P., Baltic, M., Leu, T., Schaub, M., Palme, R., & Jenni-Eiermann, S. (2007). Spreading free-riding snow sports represent a novel serious threat for wildlife. *Proceedings of the Royal Society B: Biological Sciences*, *274*(1614), 1219–1224. https://doi.org/10.1098/rspb.2006.0434

Arlettaz, R., Schaub, M., Fournier, J., Reichlin, T. S., Sierro, A., Watson, J. E. M., & Braunisch, V. (2010). From publications to public actions: When conservation biologists bridge the gap between research and implementation. *BioScience*, *60*(10), 835–842. https://doi.org/10.1525/bio.2010.60.10.10

ATLAS.ti Scientific Software Development GmbH. (2023). *ATLAS.ti* (Version 25.0.0) [Qualitative data analysis software]. https://atlasti.com

Ausden, M., & Walsh, J. C. (2020). The use of evidence in decision-making by practitioners. In W. J. Sutherland, P. N. M. Brotherton, Z. G. Davies, N. Ockendon, N. Pettorelli, & J. A. Vickery (Eds.), *Conservation Research, Policy and Practice* (pp. 145–161). Cambridge University Press. https://doi.org/10.1017/9781108638210.009

Baker, R., Camosso-Stefinovic, J., Gillies, C., Shaw, E. J., Cheater, F., Flottorp, S., Robertson, N., Wensing, M., Fiander, M., Eccles, M. P., Godycki-Cwirko, M., Lieshout, J. van, & Jäger, C. (2015). Tailored interventions to address determinants of practice. *Cochrane Database of Systematic Reviews*, *4*. https://doi.org/10.1002/14651858.cd005470.pub3

Balk, G. (2018). Instagram effect? Number of Seattle-area hikers has doubled in less than 10 years, data show. *Seattle Times*. https://www.seattletimes.com

Balmford, A., Green, J. M. H., Anderson, M., Beresford, J., Huang, C., Naidoo, R., Walpole, M., & Manica, A. (2015). Walk on the wild side: Estimating the global magnitude of visits to protected areas. *PLOS Biology*, *13*(2), e1002074. https://doi.org/10.1371/journal.pbio.1002074

Banks, P. B., & Bryant, J. V. (2007). Four-legged friend or foe? Dog walking displaces native birds from natural areas. *Biology Letters*, *3*(6), 611–613. https://doi.org/10.1098/rsbl.2007.0374

Bar-Massada, A., Radeloff, V. C., & Stewart, S. I. (2014). Biotic and abiotic effects of human settlements in the wildland–urban interface. *BioScience*, *64*(5), 429–437. https://doi.org/10.1093/biosci/biu039

Beery, S., Morris, D., & Yang, S. (2019). Efficient pipeline for camera trap image review. *arXiv*. https://doi.org/10.48550/arXiv.1907.06772

Belotti, E., Mayer, K., Kreisinger, J., Heurich, M., & Bufka, L. (2018). Recreational activities affect resting site selection and foraging time of Eurasian lynx (Lynx lynx). *Hystrix*, *29*(2), 181–189. https://doi.org/10.4404/hystrix-00053-2018

Berger, J. (2007). Fear, human shields and the redistribution of prey and predators in protected areas. *Biology Letters*, *3*(6), 620–623. https://doi.org/10.1098/rsbl.2007.0415

Bertuol-Garcia, D., Morsello, C., N. El-Hani, C., & Pardini, R. (2018). A conceptual framework for understanding the perspectives on the causes of the science–practice gap in ecology and conservation. *Biological Reviews*, *93*(2), 1032–1055. https://doi.org/10.1111/brv.12385

Black, S. A., Groombridge, J. J., & Jones, C. G. (2011). Leadership and conservation effectiveness: Finding a better way to lead. *Conservation Letters*, *4*(5), 329–339. https://doi.org/10.1111/j.1755-263X.2011.00184.x

Bolger, D., Scott, T., & Rotenberry, J. (2001). Use of corridor-like landscape structures by bird and small mammal species. *Biological Conservation*, *102*, 213–224. https://doi.org/10.1016/S0006-3207(01)00028-3

Bosch, O. J. H., Ross, A. H., & Beeton, R. J. S. (2003). Integrating science and management through collaborative learning and better information management. *Systems Research and Behavioral Science*, *20*(2), 107–118. https://doi.org/10.1002/sres.536

Breakwell, G. M. (1995). Interviewing. In G. M. Breakwell, S. Hammond, & C. Fife-Schaw (Eds.), *Research methods in psychology* (pp. 293–301). Sage Publications.

Carruthers Den Hoed, D., Murphy, M. N., Halpenny, E. A., & Mucha, D. (2020). Grizzly bear management in the Kananaskis Balley: Forty years of figuring it out. *Land*, *9*(12), Article 12. https://doi.org/10.3390/land9120501

Cook, C. N., Carter, R. W. B., Fuller, R. A., & Hockings, M. (2012). Managers consider multiple lines of evidence important for biodiversity management decisions. *Journal of Environmental Management*, *113*, 341–346. https://doi.org/10.1016/j.jenvman.2012.09.002

Cook, C. N., Mascia, M. B., Schwartz, M. W., Possingham, H. P., & Fuller, R. A. (2013). Achieving conservation science that bridges the knowledge–action boundary. *Conservation Biology*, *27*(4), 669–678. https://doi.org/10.1111/cobi.12050

Cook, C. N., Possingham, H. P., & Fuller, R. A. (2014). Contribution of systematic reviews to management decisions. *Conservation Biology*, *27*(5), 902–915. https://doi.org/10.1111/cobi.12114

Cooper, C., Larson, L., Dayer, A., Stedman, R., & Decker, D. (2015). Are wildlife recreationists conservationists? Linking hunting, birdwatching, and pro-environmental behavior. *The Journal of Wildlife Management*, *79*(3), 446–457. https://doi.org/10.1002/jwmg.855

Coppes, J., Burghardt, F., Hagen, R., Suchant, R., & Braunisch, V. (2017). Human recreation affects spatio-temporal habitat use patterns in red deer (Cervus elaphus). *PLOS ONE*, *12*(5), e0175134. https://doi.org/10.1371/journal.pone.0175134

Courter, J. R. (2012). Graduate students in conservation biology: Bridging the research–implementation gap. *Journal for Nature Conservation*, *20*(1), 62–64. https://doi.org/10.1016/j.jnc.2011.10.001

Creel, S., Fox, J. E., Hardy, A., Sands, J., Garrott, B., & Peterson, R. O. (2002). Snowmobile activity and glucocorticoid stress responses in wolves and elk. *Conservation Biology*, *16*(3), 809–814.

Crooks, K. R. (2002). Relative sensitivities of mammalian carnivores to habitat fragmentation. *Conservation Biology*, *16*(2), 488–502. https://doi.org/10.1046/j.1523-1739.2002.00386.x

Cvitanovic, C., Marshall, N. A., Wilson, S. K., Dobbs, K., & Hobday, A. J. (2014b). Perceptions of Australian marine protected area managers regarding the role, importance, and achievability of adaptation for managing the risks of climate change. *Ecology and Society*, *19*(4). https://www.jstor.org/stable/26269674

Cvitanovic, C., McDonald, J., & Hobday, A. J. (2016). From science to action: Principles for undertaking environmental research that enables knowledge exchange and evidence-based decision-making. *Journal of Environmental Management*, *183*, 864–874. https://doi.org/10.1016/j.jenvman.2016.09.038

Daly, J., Kellehear, A., & Gliksman, M. (1997). *The public health researcher: A methodological approach.* Oxford University Press.

Devictor, V., Julliard, R., & Jiguet, F. (2008). Distribution of specialist and generalist species along spatial gradients of habitat disturbance and fragmentation. *Oikos*, *117*(4), 507–514. https://doi.org/10.1111/j.0030-1299.2008.16215.x

Erb, P. L., McShea, W. J., & Guralnick, R. P. (2012). Anthropogenic influences on macro-level mammal occupancy in the Appalachian Trail Corridor. *PLoS One*, *7*(8), e42574. https://doi.org/10.1371/journal.pone.0042574

Esler, K. J., Prozesky, H., Sharma, G. P., & McGeoch, M. (2010). How wide is the “knowing-doing” gap in invasion biology? *Biological Invasions*, *12*(12), 4065–4075. https://doi.org/10.1007/s10530-010-9812-x

ESRI. (2022). *ArcGIS* (Version 3.4) [Software]. Environmental Systems Research Institute. https://www.esri.com/en-us/arcgis/about-arcgis

Fereday, J., & Muir-Cochrane, E. (2006). Demonstrating rigor using thematic analysis: A hybrid approach of inductive and deductive coding and theme development. *International Journal of Qualitative Methods*, *5*(1), 80–92. https://doi.org/10.1177/160940690600500107

Frid, A., & Dill, L. M. (2002). Human-caused disturbance stimuli as a form of predation risk. *Conservation Ecology*, *6*(1), Article 11. https://doi.org/10.5751/ES-00404-060111

Frumkin, H. (2001). Beyond toxicity: Human health and the natural environment. *American Journal of Preventive Medicine*, *20*(3), 234–240. https://doi.org/10.1016/S0749-3797(00)00317-2

Fuller, A. K., Decker, D. J., Schiavone, M. V., & Forstchen, A. B. (2020). Ratcheting up rigor in wildlife management decision making. *Wildlife Society Bulletin*, *44*(1), 29–41. https://doi.org/10.1002/wsb.1064

Gaston, K. J., Jackson, S. F., Cantú-Salazar, L., & Cruz-Piñón, G. (2008). The ecological performance of protected areas. *Annual Review of Ecology, Evolution, and Systematics*, *39*, 93–113. https://doi.org/10.1146/annurev.ecolsys.39.110707.173529

Gaynor, K. M., Hojnowski, C. E., Carter, N. H., & Brashares, J. S. (2018). The influence of human disturbance on wildlife nocturnality. *Science*, *360*(6394), 1232–1235. https://doi.org/10.1126/science.aar7121

George, S. L., & Crooks, K. R. (2006). Recreation and large mammal activity in an urban nature reserve. *Biological Conservation*, *133*(1), 107–117. https://doi.org/10.1016/j.biocon.2006.05.024

George, S. L., & Crooks, K. R. (2006). Recreation and large mammal activity in an urban nature reserve. *Biological Conservation*, *133*(1), 107–117. https://doi.org/10.1016/j.biocon.2006.05.024

Gese, E. M., Morey, P. S., & Gehrt, S. D. (2012). Influence of the urban matrix on space use of coyotes in the Chicago metropolitan area. *Journal of Ethology*, *30*(3), 413–425. https://doi.org/10.1007/s10164-012-0339-8

Giehl, E. L. H., Moretti, M., Walsh, J. C., Batalha, M. A., & Cook, C. N. (2017). Scientific evidence and potential barriers in the management of Brazilian protected areas. *PLOS ONE*, *12*(1), e0169917. https://doi.org/10.1371/journal.pone.0169917

Granados, A., Sun, C., Fisher, J.T., & others. (2023). Mammalian predator and prey responses to recreation and land use across multiple scales provide limited support for the human shield hypothesis. *Ecology and Evolution*, *13*, e10464. https://doi.org/10.1002/ece3.10464

Greenberg, S., Godin, T., & Whittington, J. (2019). Design patterns for wildlife-related camera trap image analysis. *Ecology and Evolution*, *9*(24), 13706–13730. https://doi.org/10.1002/ece3.5767

Gulsby, W. D., Cherry, M. J., Johnson, J. T., Conner, L. M., & Miller, K. V. (2018). Behavioral response of white-tailed deer to coyote predation risk. *Ecosphere*, *9*(3), e02141. https://doi.org/10.1002/ecs2.2141

Hennings, L. (2017). Hiking, mountain biking and equestrian use in natural areas: A recreation ecology literature review. (Technical report). Oregon Metro Parks and Nature.

Hjerpe, E., Hussain, A., & Holmes, T. (2020). Amenity migration and public lands: Rise of the protected areas. *Environmental Management*, *66*(1), 56–71. https://doi.org/10.1007/s00267-020-01293-6

Hubbard, T., Cove, M. V., & Lafferty, D. J. R. (2022). Human recreation impacts seasonal activity and occupancy of American black bears (Ursus americanus) across the anthropogenic-wildland interface. *Scientific Reports*, *12*(1), Article 1. https://doi.org/10.1038/s41598-022-15665-x

Ingold, T. (2000). *The Perception of the Environment: Essays on Livelihood, Dwelling and Skill*.

Jacqmarcq, M., Siggery, B., & Collins, C. T. (2024). Landholder perceptions and attitudes towards the rewilding of private land: An analysis from Surrey, UK. *Ecosystems and People*, *20*(1). https://doi.org/10.1080/26395916.2024.2344842

Jenerette, G. D., Anderson, K. E., Cadenasso, M. L., Fenn, M., Franklin, J., Goulden, M. L., Larios, L., Pincetl, S., Regan, H. M., Rey, S. J., Santiago, L. S., & Syphard, A. D. (2022). An expanded framework for wildland–urban interfaces and their management. *Frontiers in Ecology and the Environment*, *20*(9), 516–523. https://doi.org/10.1002/fee.2533

Kaczensky, P., Huber, D., Knauer, F., Roth, H., Wagner, A., & Kusak, J. (2006). Activity patterns of brown bears (Ursus arctos) in Slovenia and Croatia. *Journal of Zoology*, *269*, 474–485. https://doi.org/10.1111/j.1469-7998.2006.00114.x

Karanth, K. U., Nichols, J. D., & Kumar, N. S. (2010). Estimating tiger abundance from camera trap data: Field surveys and analytical issues. In A. F. O’Connell, J. D. Nichols, & K. U. Karanth (Eds.), *Camera traps in animal ecology: Methods and analyses* (pp. 97–117). Springer.

Kasworm, W. F., & Manley, T. L. (1990). Road and trail influences on grizzly bears and black bears in northwest Montana. *Bears: Their Biology and Management*, *8*, 79–84. https://doi.org/10.2307/3872905

Kays, R., Parsons, A. W., Baker, M. C., Kalies, E. L., Forrester, T., Costello, R., Rota, C. T., Millspaugh, J. J., & McShea, W. J. (2017). Does hunting or hiking affect wildlife communities in protected areas? *Journal of Applied Ecology*, *54*(1), 242–252. https://doi.org/10.1111/1365-2664.12700

Kellner, A., Carver, S., Gramza, A., Lewis, J. S., VandeWoude, S., & Crooks, K. R. (2017). Outdoor recreation at the wildland—urban interface: xamining human activity patterns and compliance with dog management policies. *Natural Areas Journal*, *37*(4), 515–529. https://doi.org/10.3375/043.037.0408

Kitchen, A. M., Gese, E. M., & Schauster, E. R. (2000). Changes in coyote activity patterns due to reduced exposure to human persecution. *Canadian Journal of Zoology*, *78*(5), 853–857. https://doi.org/10.1139/z00-003

Kluever, B. M., Gese, E. M., & Dempsey, S. J. (2016). Influence of free water availability on a desert carnivore and herbivore. *Current Zoology, 63*(2), 121-129. https://doi.org/10.1093/cz/zow071

Knight, R. L., & Cole, D. N. (1992). Effects of recreational activity on wildlife in wildlands. *Transactions of the 56th North American Wildlife and Natural Resources Conference*.

Knight, R. L., & Gutzwiller, K. J. (Eds.). (1995). *Wildlife and recreationists: Coexistence through management and research*. Island Press.

Ladle, A., Steenweg, R., Shepherd, B., & Boyce, M. S. (2018). The role of human outdoor recreation in shaping patterns of grizzly bear-black bear co-occurrence. *PLOS ONE*, *13*(2), e0191730. https://doi.org/10.1371/journal.pone.0191730

Larson, C. L., Reed, S. E., Merenlender, A. M., & Crooks, K. R. (2016). Effects of recreation on animals revealed as widespread through a global systematic review. *PLOS ONE*, *11*(12), e0167259. https://doi.org/10.1371/journal.pone.0167259

Larson, C. L., Reed, S. E., Merenlender, A. M., & Crooks, K. R. (2016). Effects of recreation on animals revealed as widespread through a global systematic review. *PLOS ONE*, *11*(12), e0167259. https://doi.org/10.1371/journal.pone.0167259

Lemieux, C. J., Groulx, M. W., Bocking, S., & Beechey, T. J. (2018). Evidence-based decision-making in Canada's protected areas organizations: Implications for management effectiveness. *FACETS*, *3*(1), 392–414. https://doi.org/10.1139/facets-2017-0107

Lenth, B. E., Knight, R. L., & Brennan, M. E. (2008). The effects of dogs on wildlife communities. *Natural Areas Journal*, *28*(3), 218–227. https://doi.org/10.3375/0885-8608(2008)28[218:TEODOW]2.0.CO;2

Lewis, J. S., Logan, K. A., Alldredge, M. W., Bailey, L. L., VandeWoude, S., & Crooks, K. R. (2015). The effects of urbanization on population density, occupancy, and detection probability of wild felids. *Ecological Applications*, *25*(7), 1880–1895. https://doi.org/10.1890/14-1664.1

Lewis, J. S., Spaulding, S., Swanson, H., Keeley, W., Gramza, A. R., VandeWoude, S., & Crooks, K. R. (2021). Human activity influences wildlife populations and activity patterns: Implications for spatial and temporal refuges. *Ecosphere*, *12*(5), e03487. https://doi.org/10.1002/ecs2.3487

Linklater, W. L. (2003). Science and management in a conservation crisis: A case study with rhinoceros. *Conservation Biology*, *17*(4), 968–975. https://doi.org/10.1046/j.1523-1739.2003.01449.x

Longshore, K., Lowrey, C. & Thompson, D. B. (2013). Detecting short-term responses to weekend recreation activity: desert bighorn sheep avoidance of hiking trails. *Wildlife Society Bulletin, 37*, 698–706. https://doi.org/10.1002/wsb.349

Lonsinger, R. C., Gese, E. M., Bailey, L. L., & Waits, L. P. (2017). The roles of habitat and intraguild predation by coyotes on the spatial dynamics of kit foxes. *Ecosphere*, *8*(3), e01749. https://doi.org/10.1002/ecs2.1749

Losos, E., Hayes, J., Phillips, A., Wilcove, D., & Alkire, C. (1995). Taxpayer-subsidized resource extraction harms species. *BioScience*, *45*(7), 446–455. https://doi.org/10.2307/1312788

MacKenzie, D.I., Bailey, L.L., & Nichols, J.D. (2004). Investigating species co-occurrence patterns when species are detected imperfectly. *Journal of Animal Ecology*, *73*, 546–555. https://doi.org/10.1111/j.0021-8790.2004.00828.x

Mapes, L. V. (2020). Recreation becomes 'wreckreation' as careless outdoor adventures turn destructive, spark wildfires. *The Seattle Times*. https://www.seattletimes.com/seattle-news/environment/recreation-becomes-wreckreation-as-careless-outdoor-adventures-turn-destructive-spark-wildfires/

Marion, S., Santos, G. C., Herdman, E., Hubbs, A., Kearney, S. P., & Burton, A. C. (2024). Mammal responses to human recreation depend on landscape context. *PLoS One*, *19*(7), e0300870. https://doi.org/10.1371/journal.pone.0300870

Matzek, V., Covino, J., Funk, J. L., & Saunders, M. (2014). Closing the knowing–doing gap in invasive plant management: Accessibility and interdisciplinarity of scientific research. *Conservation Letters*, *7*(3), 208–215. https://doi.org/10.1111/conl.12042

Meredith, M., & Ridout, M. (2017). *Overview of the overlap package* (Version 0.3.9). Comprehensive R Archive Network (CRAN). http://cran.nexr.com/web/packages/overlap/vignettes/overlap.pdf

Miles, M. B., & Huberman, A. M. (1994). *A qualitative data analysis* (2nd ed.). SAGE Publications.

Miller, A. B., King, D., Rowland, M., Chapman, J., Tomosy, M., Liang, C., Abelson, E., & Truex, R. L. (2020). Sustaining wildlife with recreation on public lands: A synthesis of research findings, management practices, and research needs (*General Technical Report PNW-GTR-993*). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. https://www.fs.usda.gov/pnw/pubs/pnw_gtr993.pdf

Mojica, J., & Fletcher, A. (2020). *Economic analysis of outdoor recreation in Washington State, 2020 update.* Earth Economics.

Morrison, C. D., Boyce, M. S., Nielsen, S. E., & Bacon, M. M. (2014). Habitat selection of a re-colonized cougar population in response to seasonal fluctuations of human activity. *The Journal of Wildlife Management*, *78*(8), 1394–1403. https://doi.org/10.1002/jwmg.799

Moss, W. E., Alldredge, M. W., & Pauli, J. N. (2016). Quantifying risk and resource use for a large carnivore in an expanding urban–wildland interface. *Journal of Applied Ecology*, *53*(2), 371–378. https://doi.org/10.1111/1365-2664.12563

Naidoo, R., & Burton, A. C. (2020). Relative effects of recreational activities on a temperate terrestrial wildlife assemblage. *Conservation Science and Practice*, *2*(10). https://doi.org/10.1111/csp2.271

Naylor, L. M., Wisdom, M. J., & Anthony, R. G. (2009). Behavioral responses of North American Elk to recreational activity. *Journal of Wildlife Management*, *73*(3), 328–338. https://doi.org/10.2193/2008-102

Naylor, L. M., Wisdom, M. J., & Anthony, R. G. (2009). Behavioral responses of North American elk to recreational activity. *Journal of Wildlife Management*, *73*(3), 328–338. https://doi.org/10.2193/2008-102

Nelson, L. H., & Bailey, D. (2021). The "recreation boom" on public lands in western Washington: Impacts to wildlife and implications for treaty tribes: A summary of current literature. The Tulalip Tribes Natural Resources Department Treaty Rights Office.

Nickel, B. A., Suraci, J. P., Allen, M. L., & Wilmers, C. C. (2020). Human presence and human footprint have non-equivalent effects on wildlife spatiotemporal habitat use. *Biological Conservation*, *241*, 108383. https://doi.org/10.1016/j.biocon.2019.108383

Niedballa, J., Sollmann, R., Courtiol, A., & Wilting, A. (2016). camtrapR: an R package for efficient camera trap data management. *Methods in Ecology and Evolution*, *7*(12), 1457–1462. doi:10.1111/2041-210X.12600

Nouvellet, P., Rasmussen, G. S. A., Macdonald, D. W., & Courchamp, F. (2012). Noisy clocks and silent sunrises: Measurement methods of daily activity pattern. *Journal of Zoology*, *286*(3), 179–184. https://doi.org/10.1111/j.1469-7998.2011.00864.x

Ordeñana, M. A., Crooks, K. R., Boydston, E. E., Fisher, R. N., Lyren, L. M., Siudyla, S., Haas, C. D., Harris, S., Hathaway, S. A., Turschak, G. M., Miles, A. K., & Van Vuren, D. H. (2010). Effects of urbanization on carnivore species distribution and richness. *Journal of Mammalogy*, *91*(6), 1322–1331. https://doi.org/10.1644/09-MAMM-A-312.1

Pardini, R., da Rocha, P. L. B., El-Hani, C., & Pardini, F. (2013). Challenges and opportunities for bridging the research–implementation gap in ecological science and management in Brazil. *Conservation Biology*, 75–85. https://doi.org/10.1002/9781118679838.ch10

Peral, C., Landman, M., & Kerley, G. I. H. (2022). The inappropriate use of time-to-independence biases estimates of activity patterns of free-ranging mammals derived from camera traps. *Ecology and Evolution*, *12*(10), e9408. https://doi.org/10.1002/ece3.9408

Peterson, R. B., Russell, D., West, P., & Brosius, J. P. (2010). Seeing (and doing) conservation through cultural lenses. *Environmental Management*, *45*(1), 5–18. https://doi.org/10.1007/s00267-008-9135-1

Pfeffer, J., & Sutton, R. I. (1999). Knowing "what" to do is not enough: Turning knowledge into action. *California Management Review*, *42*(1), 83–108. https://doi.org/10.1177/000812569904200101

Poisson, M. K. P., Butler, A. R., Tate, P., Bergeron, D. H., & Moll, R. J. (2023). Species-specific responses of mammal activity to exurbanization in New Hampshire, USA. *Journal of Urban Ecology*, *9*(1), juad010. https://doi.org/10.1093/jue/juad010

Prange, S., Gehrt, S. D., & Wiggers, E. P. (2003). Demographic Factors Contributing to High Raccoon Densities in Urban Landscapes. *The Journal of Wildlife Management*, *67*(2), 324–333. https://doi.org/10.2307/3802774

Procko, M., Naidoo, R., LeMay, V. & Burton, A.C. (2022). Human impacts on mammals in and around a protected area before, during, and after COVID-19 lockdowns. *Conservation Science and Practice*, *4*, e12743. https://doi.org/10.1111/csp2.12743

Procko, M., Winder, S. G., Wood, S. A., Sevigny, M., Collins, D. G., Alves, M., & Prugh, L. R. (2024). Quantifying impacts of recreation on elk (Cervus canadensis) using novel modeling approaches. *Ecosphere*, *15*(6), e4873. https://doi.org/10.1002/ecs2.4873

Pullin, A. S., & Knight, T. M. (2001). Effectiveness in conservation practice: Pointers from medicine and public health. *Conservation Biology*, *15*(1), 50–54. https://doi.org/10.1111/j.1523-1739.2001.99499.x

Pullin, A. S., & Knight, T. M. (2005). Assessing conservation management's evidence base: A survey of management-plan compilers in the United Kingdom and Australia. *Conservation Biology*, *19*(6), 1989–1996.

Pullin, A. S., Knight, T. M., Stone, D. A., & Charman, K. (2004). Do conservation managers use scientific evidence to support their decision-making? *Biological Conservation*, *119*(2), 245–252. https://doi.org/10.1016/j.biocon.2003.11.007

R Core Team (2021). *R: A language and environment for statistical computing.* [Software]. R Foundation for Statistical Computing. https://www.R-project.org/.

Radeloff, V. C., Hammer, R. B., Stewart, S. I., Fried, J. S., Holcomb, S. S., & McKeefry, J. F. (2005). The wildland–urban interface in the United States. *Ecological Applications*, *15*(3), 799–805. https://doi.org/10.1890/04-1413

Raymond, C. M., Fazey, I., Reed, M. S., Stringer, L. C., Robinson, G. M., & Evely, A. C. (2010). Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management*, *91*(8), 1766–1777. https://doi.org/10.1016/j.jenvman.2010.03.023

Razani, N. (2021). Nature and health in practice. *Parks Stewardship Forum*, *37*(1). https://doi.org/10.5070/P537151708

Reed, S. E., & Merenlender, A. M. (2008). Quiet, nonconsumptive recreation reduces protected area effectiveness. *Conservation Letters*, *1*(3), 146–154. https://doi.org/10.1111/j.1755-263X.2008.00019.x

Reed, S. E., & Merenlender, A. M. (2008). Quiet, nonconsumptive recreation reduces protected area effectiveness. *Conservation Letters*, *1*(3), 146–154. https://doi.org/10.1111/j.1755-263X.2008.00019.x

Reed, S. E., & Merenlender, A. M. (2011). Effects of management of domestic dogs and recreation on carnivores in protected areas in Northern California: Managing dogs in protected areas. *Conservation Biology*, *25*(3), 504–513. https://doi.org/10.1111/j.1523-1739.2010.01641.x

Reilly, M. L., Tobler, M. W., Sonderegger, D. L., & Beier, P. (2017). Spatial and temporal response of wildlife to recreational activities in the San Francisco Bay ecoregion. *Biological Conservation*, *207*, 117–126. https://doi.org/10.1016/j.biocon.2016.11.003

Ridout, M. S., & Linkie, M. (2009). Estimating overlap of daily activity patterns from camera trap data. *Journal of Agricultural, Biological, and Environmental Statistics*, *14*(3), 322–337. https://doi.org/10.1198/jabes.2009.08038

Rogala, J. K., Hebblewhite, M., Whittington, J., White, C. A., Coleshill, J., & Musiani, M. (2011). Human activity differentially redistributes large mammals in the Canadian Rockies national parks. *Ecology and Society*, *16*(3). https://www.jstor.org/stable/26268938

Rowcliffe, M.J., Carbone, C., Jansen, P. A., Kays, R., & Kranstauber, B. (2011). Quantifying the sensitivity of camera traps: An adapted distance sampling approach. *Methods in Ecology and Evolution*, *2*(5), 464–476. https://doi.org/10.1111/j.2041-210X.2011.00094.x

Royle, J. A., & Nichols, J. D. (2003). Estimating abundance from repeated presence–absence data or point counts. *Ecology*, *84*(3), 777–790. https://doi.org/10.1890/0012-9658(2003)084[0777:EAFRPA]2.0.CO;2

Royle, J. A., Nichols, J. D., & Kéry, M. (2005). Modelling occurrence and abundance of species when detection is imperfect. *Oikos*, *110*(2), 353–359. https://doi.org/10.1111/j.0030-1299.2005.13534.x

Savari, M., & Khaleghi, B. (2023). Application of the extended theory of planned behavior in predicting the behavioral intentions of Iranian local communities toward forest conservation. *Frontiers in Psychology*, *14*. https://doi.org/10.3389/fpsyg.2023.1121396

Seavy, N. E., & Howell, C. A. (2010). How can we improve information delivery to support conservation and restoration decisions? *Biodiversity and Conservation*, *19*(5), 1261–1267. https://doi.org/10.1007/s10531-009-9752-x

Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(40), 16083–16088. https://doi.org/10.1073/pnas.1211658109

Shackleton, C. M., Cundill, G., & Knight, A. T. (2009). Beyond just research: Experiences from Southern Africa in developing social learning partnerships for resource conservation initiatives. *Biotropica*, *41*(5), 563–570. https://doi.org/10.1111/j.1744-7429.2009.00559.x

Si, H., Shi, J., Tang, D., Wen, S., Miao, W., & Duan, K. (2019). Application of the theory of planned behavior in environmental science: A comprehensive bibliometric analysis. *International Journal of Environmental Research and Public Health*, *16*(15), 2788. https://doi.org/10.3390/ijerph16152788

Soccorsi, A. E., & LaPoint, S. D. (2023). Assessing spatiotemporal patterns of mesocarnivores along an urban-to-rural gradient. *The Journal of Wildlife Management*, *87*(7), e22474. https://doi.org/10.1002/jwmg.22474

Stankowich, T. (2008). Ungulate flight responses to human disturbance: A review and meta-analysis. *Biological Conservation*, *141*(9), 2159–2173. https://doi.org/10.1016/j.biocon.2008.06.026

Stankowich, T., & Blumstein, D. T. (2005). Fear in animals: A meta-analysis and review of risk assessment. *Proceedings of the Royal Society B: Biological Sciences*, *272*(1581), 2627–2634. https://doi.org/10.1098/rspb.2005.3251

State of Washington Geospatial Open Data Portal. (2023). *Hydrography - NHD Flowlines* [Data set]. https://geo.wa.gov/datasets/waecy::hydrography-nhd-flowlines/about

Stein, T. V. (2005). Planning and managing for recreation in the wildland–urban interface. In S. W. Vince, M. L. Duryea, E. A. Macie, & L. A. Hermansen (Eds.), *Forests at the wildland–urban interface: Conservation and management* (pp. 139–157). CRC Press. doi.org/10.1201/9780203484463

Strava, Inc. (2019). *Strava Global Heatmap*. Retrieved from https://www.strava.com/heatmap

Sunderland, T., Sunderland-Groves, J., Shanley, P., & Campbell, B. (2009). Bridging the gap: How can information access and exchange between conservation biologists and field practitioners be improved for better conservation outcomes? *Biotropica*, *41*(5), 549–554. https://doi.org/10.1111/j.1744-7429.2009.00557.x

Sutherland, W. J., Pullin, A. S., Dolman, P. M., & Knight, T. M. (2004). The need for evidence-based conservation. *Trends in Ecology & Evolution*, *19*(6), 305–308. https://doi.org/10.1016/j.tree.2004.03.018

Swan, G. J. F., Redpath, S. M., Crowley, S. L., & McDonald, R. A. (2020). Understanding diverse approaches to predator management among gamekeepers in England. *People and Nature*, *2*(2), 495–508. https://doi.org/10.1002/pan3.10091

Sytsma, M. L. T., Lewis, T., Gardner, B., & Prugh, L. R. (2022). Low levels of outdoor recreation alter wildlife behaviour. *People and Nature*, *4*, 1547–1559. https://doi.org/10.1002/pan3.10402

Thomas, S. L., & Reed, S. E. (2019). Entrenched ties between outdoor recreation and conservation pose challenges for sustainable land management. *Environmental Research Letters*, *14*(11), 115009. https://doi.org/10.1088/1748-9326/ab4f52

Tigas, L. A., Van Vuren, D. H., & Sauvajot, R. M. (2002). Behavioral responses of bobcats and coyotes to habitat fragmentation and corridors in an urban environment. *Biological Conservation*, *108*(3), 299–306. https://doi.org/10.1016/S0006-3207(02)00120-9

Toomey, A., Knight, A., & Barlow, J. (2016). Navigating the space between research and implementation in conservation. *Conservation Letters*, *10*. https://doi.org/10.1111/conl.12315

USDA Forest Service. (2023). *USFS NLCD Percent Tree Canopy CONUS v2021-4*. [Data set]. Sioux Falls, SD.

Walsh, J. C., Dicks, L. V., & Sutherland, W. J. (2015). The effect of scientific evidence on conservation practitioners’ management decisions. *Conservation Biology: The Journal of the Society for Conservation Biology*, *29*(1), 88–98. https://doi.org/10.1111/cobi.12370

Walsh, J. C., Dicks, L. V., Raymond, C. M., & Sutherland, W. J. (2019). A typology of barriers and enablers of scientific evidence use in conservation practice. *Journal of Environmental Management*, *250*, 109481. https://doi.org/10.1016/j.jenvman.2019.109481

Wang, Y., Allen, M. L., & Wilmers, C. C. (2015). Mesopredator spatial and temporal responses to large predators and human development in the Santa Cruz Mountains of California. *Biological Conservation*, *190*, 23–33. https://doi.org/10.1016/j.biocon.2015.05.007

Washington State Parks and Recreation Commission. (2025). WA State Parks Web Map. Retrieved March 5, 2025, from https://experience.arcgis.com/experience/6bf98bfe61ac454a9d6964c855a0ca15

Weiss, K., Hamann, M., & Marsh, H. (2013). Bridging knowledges: Understanding and applying Indigenous and Western scientific knowledge for marine wildlife management. *Society & Natural Resources*, *26*(3), 285–302. https://doi.org/10.1080/08941920.2012.690065

WildCo Lab. (2021). *WildCo-FaceBlur* [Software]. GitHub. https://github.com/WildCoLab/WildCo_Face_Blur.

Young, K. D., & Van Aarde, R. J. (2011). Science and elephant management decisions in South Africa. *Biological Conservation*, *144*(2), 876–885. https://doi.org/10.1016/j.biocon.2010.11.023

Zaradic, P. A., Pergams, O. R. W., & Kareiva, P. (2009). The impact of nature experience on willingness to support conservation. *PLOS ONE*, *4*(10), e7367. https://doi.org/10.1371/journal.pone.0007367

APPENDIX

Appendix A. Number of weeks each camera station was active across study sites.

Station ID	Weeks	Station ID	Weeks
BCRO_Cam1	120	LARR_Cam10	23
BCRO_Cam10	150	LARR_Cam1_old	36
BCRO_Cam2	104	LARR_Cam2	104
BCRO_Cam3	46	LARR_Cam3	38
BCRO_Cam4	104	LARR_Cam3_old	37
BCRO_Cam5	104	LARR_Cam41	38
BCRO_Cam54	87	LARR_Cam43	87
BCRO_Cam6	104	LARR_Cam5	104
BCRO_Cam7	109	LARR_Cam6	66
BCRO_Cam8	58	LARR_Cam7	104
BCRO_Cam9	104	LARR_Cam8	66
BCRO_CamGT1	57	LARR_Cam9	104
BCRO_CamGT11	11	LARR_CamGT1	63
BCRO_CamGT2	57	LARR_CamGT2	63
FTEB_Cam1	35	MORA_Cam1	60
FTEB_Cam10	102	MORA_Cam10	39
FTEB_Cam11	40	MORA_Cam100	39
FTEB_Cam118	87	MORA_Cam10_old	60
FTEB_Cam2	102	MORA_Cam2	39
FTEB_Cam3	102	MORA_Cam2_old	60
FTEB_Cam4	62	MORA_Cam3	124
FTEB_Cam5	102	MORA_Cam4	99
FTEB_Cam6	167	MORA_Cam5	81
FTEB_Cam8	40	MORA_Cam6	99
FTEB_Cam8_old	14	MORA_Cam7	99
FTEB_Cam9	149	MORA_Cam8	144
FTEB_CamGT2	60	MORA_Cam9	144

FTEB_CamGT3	60	MORA_CamGT2	68
FTEB_CamGT84	60	MORA_CamGT3	68
LARR_Cam1	87	MORA_CamGT1	68
OLAL_Cam103	45	DEPA_CamGT3	60
OLAL_Cam121	49	SQMT_Cam113	43
OLAL_Cam24	38	SQMT_Cam114	43
OLAL_Cam24_old	6	SQMT_Cam33	92
OLAL_Cam28	96	SQMT_Cam34	92
OLAL_Cam29	96	SQMT_Cam35	43
OLAL_Cam30	44	SQMT_Cam37	43
OLAL_Cam4	54	SQMT_Cam48	43
OLAL_Cam41	54	SQMT_Cam74	42
OLAL_Cam4_old	2	SQMT_Cam82	92
OLAL_Cam66	45	SQMT_Cam91	43
OLAL_Cam90	47	SQMT_CamGT1	66
OLAL_CamGT1	62	SQMT_CamGT2	66
OLAL_CamGT2	61	SQMT_CamGT3	65
OLAL_CamGT3	61	WAFA_Cam101	57
DEPA_Cam115	94	WAFA_Cam131	44
DEPA_Cam120	94	WAFA_Cam23	44
DEPA_Cam13	44	WAFA_Cam31	83
DEPA_Cam130	44	WAFA_Cam39	51
DEPA_Cam15	93	WAFA_Cam40	43
DEPA_Cam21	44	WAFA_Cam56	92
DEPA_Cam22	12	WAFA_Cam6	92
DEPA_Cam42	45	WAFA_Cam8	44
DEPA_Cam93	44	WAFA_Cam95	92
DEPA_Cam97	45	WAFA_CamGT1	61
DEPA_CamGT1	60	WAFA_CamGT3	61
DEPA_CamGT2	60		

Appendix B. Summary of all species detected across 113 camera stations in western Washington State Parks from summer 2021 to fall 2024. Detection independence for each species was determined using a 30-minute threshold.

Species name	Number of Detections	Counts
Black-Tailed Deer	8737	10261
Coyote	1935	2139
Bobcat	403	408
Raccoon	323	365
Elk	266	470
Black Bear	185	198
Cougar	180	187
Squirrel spp.	168	183
Bird	131	185
Douglas Squirrel	119	122
Rabbit spp.	109	111
Opossum	84	96
Piebald Black-Tailed Deer	66	70
Unknown	31	33
Eastern Cottontail	26	29
Mountain Goat	18	26
Crow	15	18
Unknown Small Mammal	10	10
Rodent spp.	8	8
Raptor	6	6
Porcupine	5	5
Fisher	4	4
River Otter	4	6
Striped Skunk	3	3
Common Raven	2	2

Turkey	1	9
Squirrel, Northern Flying	1	1
Weasel, Short-tailed	1	1

Appendix C. Summary of the seven most detected species across 113 camera stations in western Washington State Parks from summer 2021 to fall 2024 in western Washington State Parks used for occupancy modeling. Detection independence for each species was determined using a 30-minute threshold.

Species	Sites (113 total)	Detections	Counts
Black-tailed deer	108	8801	10331
Coyote	74	1935	2139
Bobcat	46	403	408
Raccoon	44	323	365
Elk	22	266	470
Black bear	33	185	198
Cougar	39	180	187

Appendix D. Summary of all offspring detected across 113 camera stations in western Washington State Parks from summer 2021 to fall 2024. Detection independence for each species was determined using a 30-minute threshold.

Species	Offspring count	Park
Black Bear	23	Beacon Rock, Olallie, Wallace Falls, Squak Mountain
Cougar	7	Larrabee, Squak Mountain
Bobcat	4	Larrabee, Squak Mountain
Coyote	36	Fort Ebey, Squak Mountain, Beacon Rock

Appendix E. Summary of the seven most detected species by year across 113 camera stations in western Washington State Parks from summer 2021 to fall 2024. Detection independence for each species was determined using a 30-minute threshold.

Species	Counts 2021	Counts 2022	Counts 2023	Counts 2024	Total
Coyote	74	599	1095	371	2139
Deer	932	3253	3955	2191	10331
Bobcat	2	113	253	40	408
Bear	6	42	104	46	198
Raccoon	35	120	166	44	365
Cougar	7	30	79	71	187
Elk	2	190	219	59	470

Appendix F. Summary of ungulate age and sex classifications detected across 113 camera stations in Western Washington State Parks from summer 2021 to fall 2024. Detection independence for each species was determined using a 30-minute threshold. Counts are presented by species, age/sex category, and year.

Species	Category	Counts 2021	Counts 2022	Counts 2023
Deer	Adult Male	162	515	151
	Adult Female	310	973	360
	Offspring	171	528	168
	Unknown	40	67	8
	Adult Unknown	46	491	470
	Total	**729**	**2574**	**1157**
Elk	Adult Male	0	11	21
	Adult Female	0	37	10
	Offspring	0	23	15
	Unknown	0	0	0
	Adult Unknown	0	0	31
	Total	**0**	**71**	**77**

Appendix G. Summary of independent human detections for the activities observed across 113 camera stations from summer 2021 to fall 2024 in western Washington State Parks used for occupancy modeling. Detection independence for humans was determined using a 1-minute threshold.

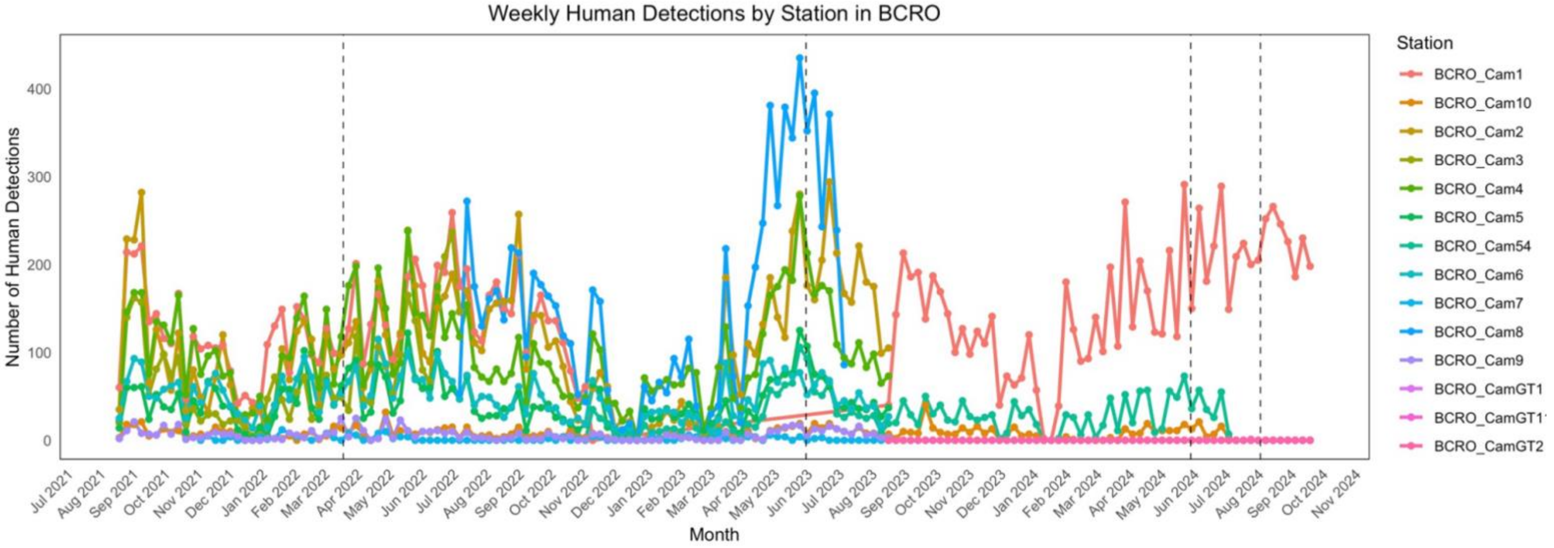
Human Activity	# sites (113 total)	# detections	Avg. group size
Hikers	100	476,395	1.74
Hikers with animals	97	120,410	1.76
Mountain bikers	79	60,152	1.31
Mountain bikers with dogs	54	3,294	1.42
Horseback rider	24	1,174	1.76
Motorized vehicles	46	3,079	-

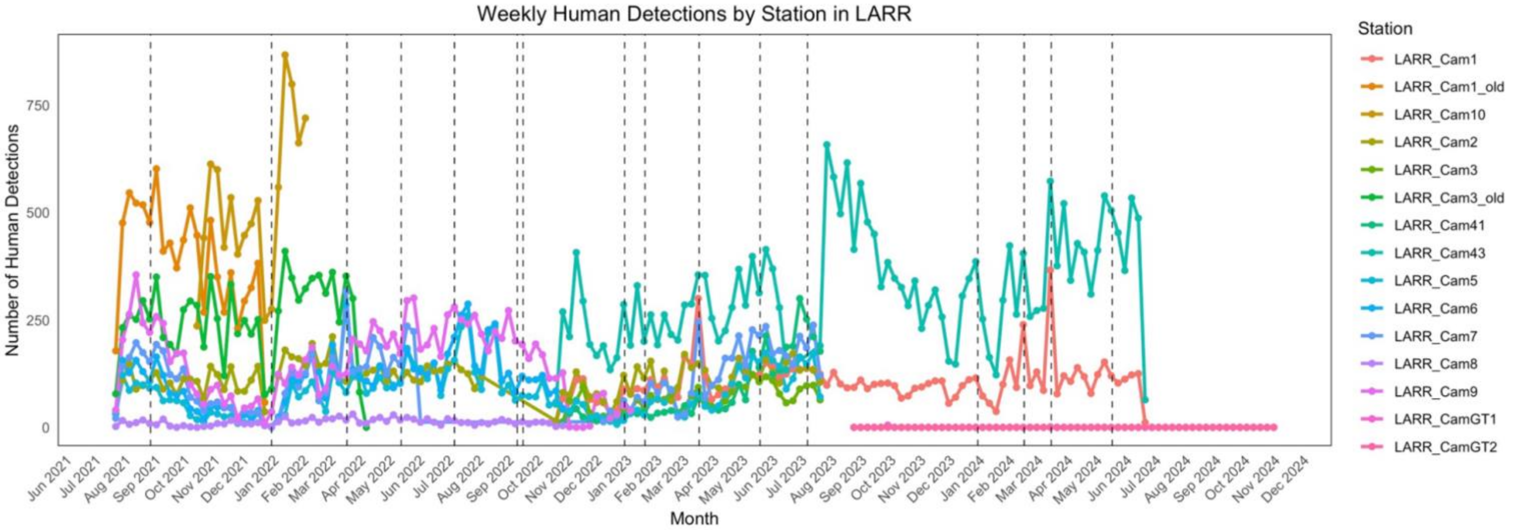
Appendix H. Detections of domestic animals associated with human activity across 113 camera stations in western Washington State Parks from summer 2021 to fall 2024. Domestic animal detections were grouped with independent human detections if they occurred immediately before or after a human detection.

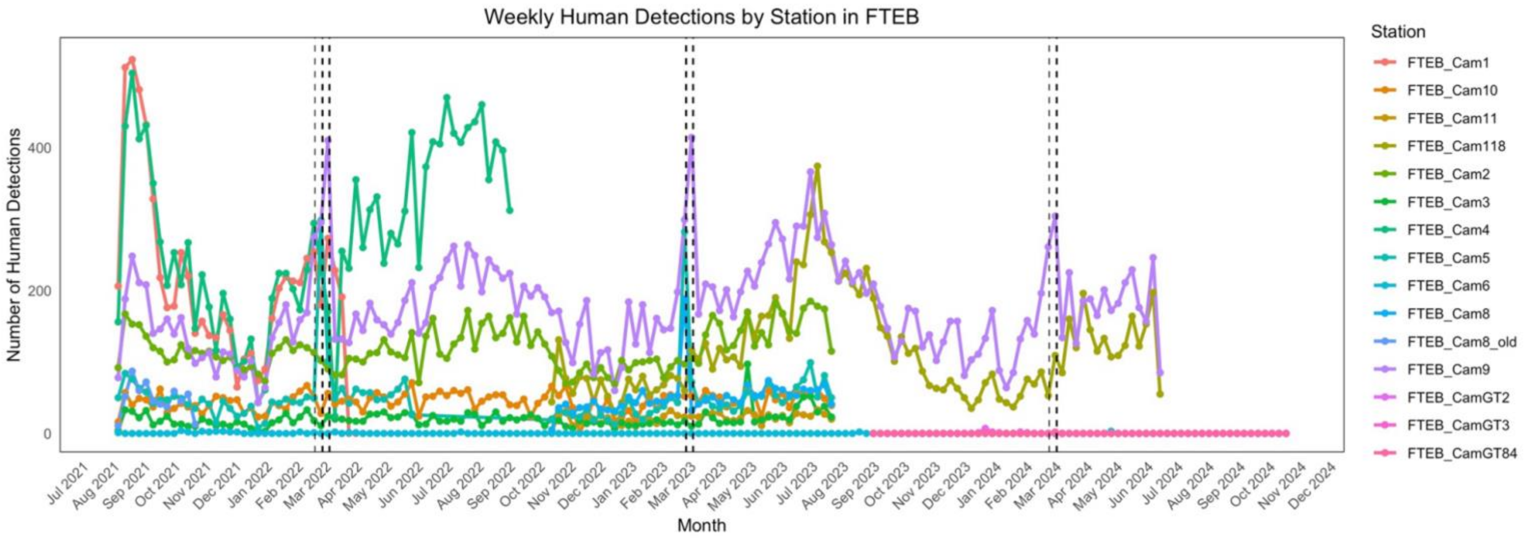
Domestic animals	# detections	# on- leash^{+}	# off- leash^{+}
Dogs	94,558	16,457	9,997
Cats	16	-	-
Horses	1,162	-	-
Goats or llamas	16	-	-

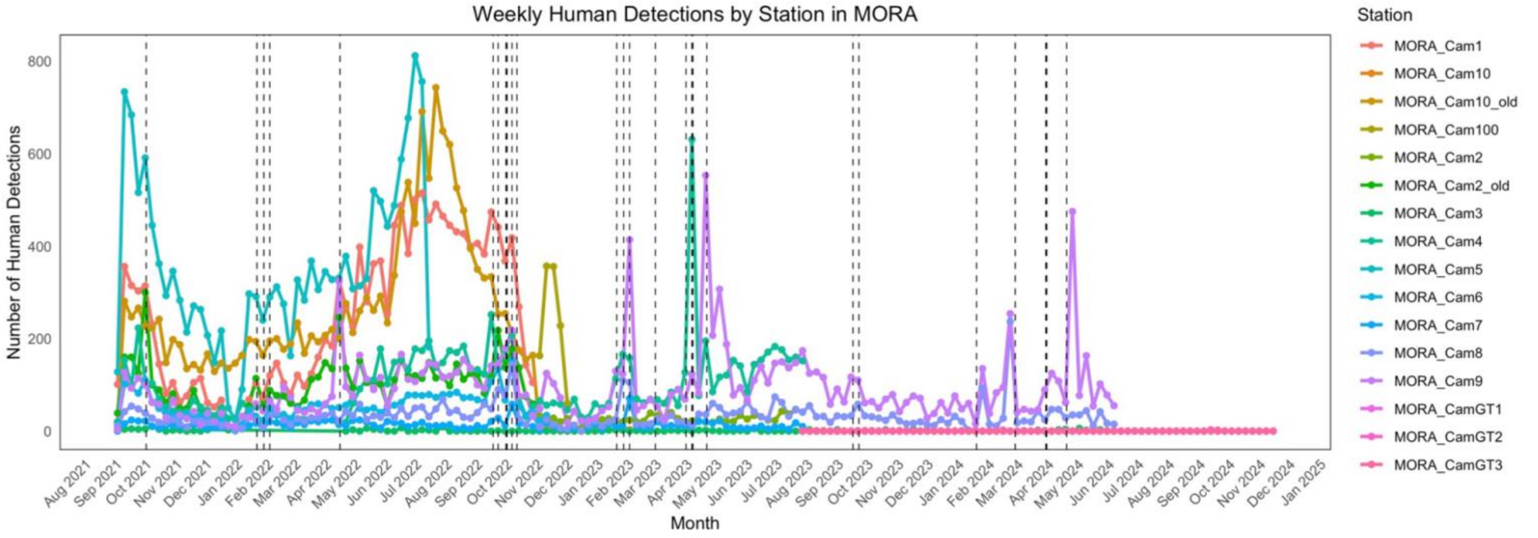
(+) Fields marked with this symbol represent counts from image sets tagged to a finer scale which are not representative of all dog detections.

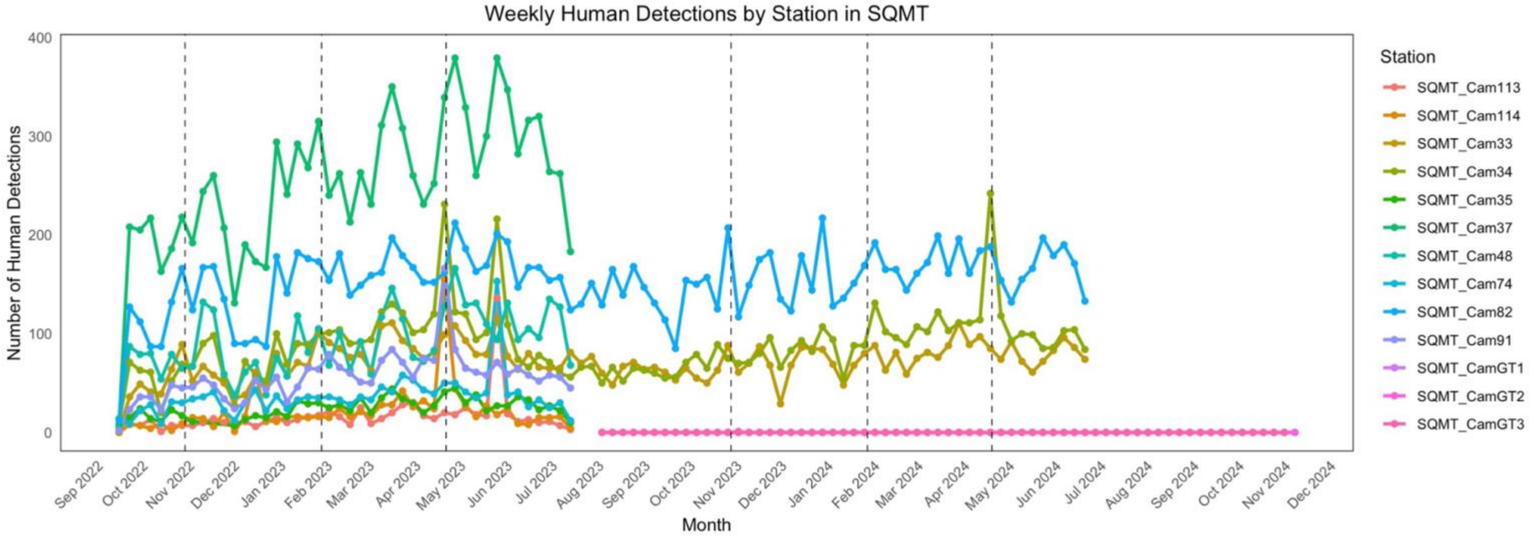
Appendix I. Weekly human detections by camera station in Beacon Rock (BCRO), Larrabee (LARR), Fort Ebey (FTEB), Moran (MORA), Squak Mountain (SQMT), Deception Pass (DEPA), Olallie (OLAL), and Wallace Falls (WAFA) from summer 2021 to fall 2024. Each colored line represents a different camera station, showing fluctuations in human activity. Peaks in detections correspond to seasonal trends in recreation, with higher activity during summer months. Dashed vertical lines indicate special recreation events.

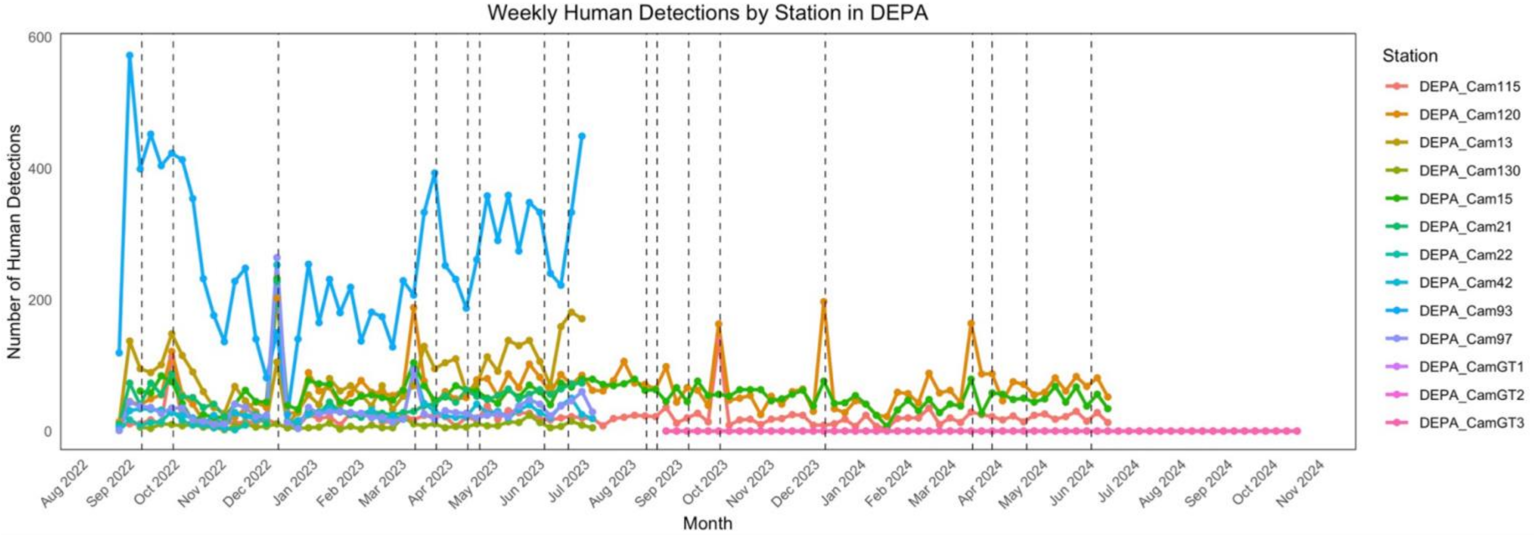


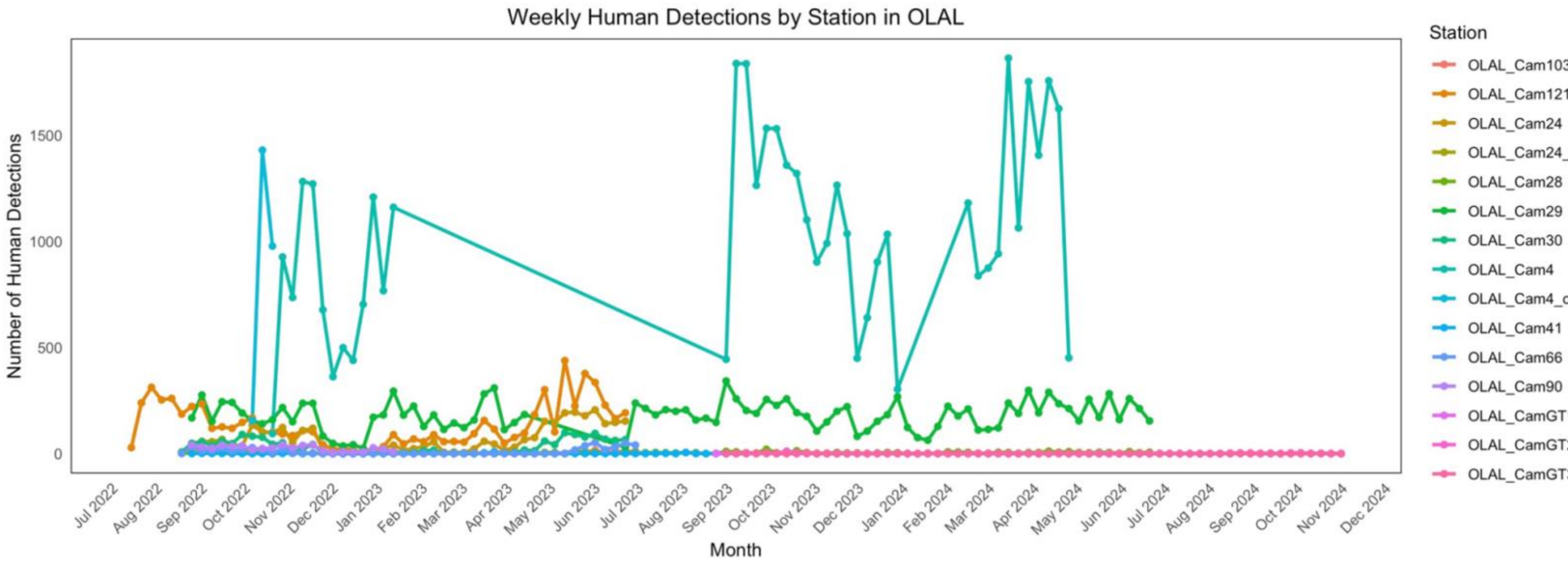


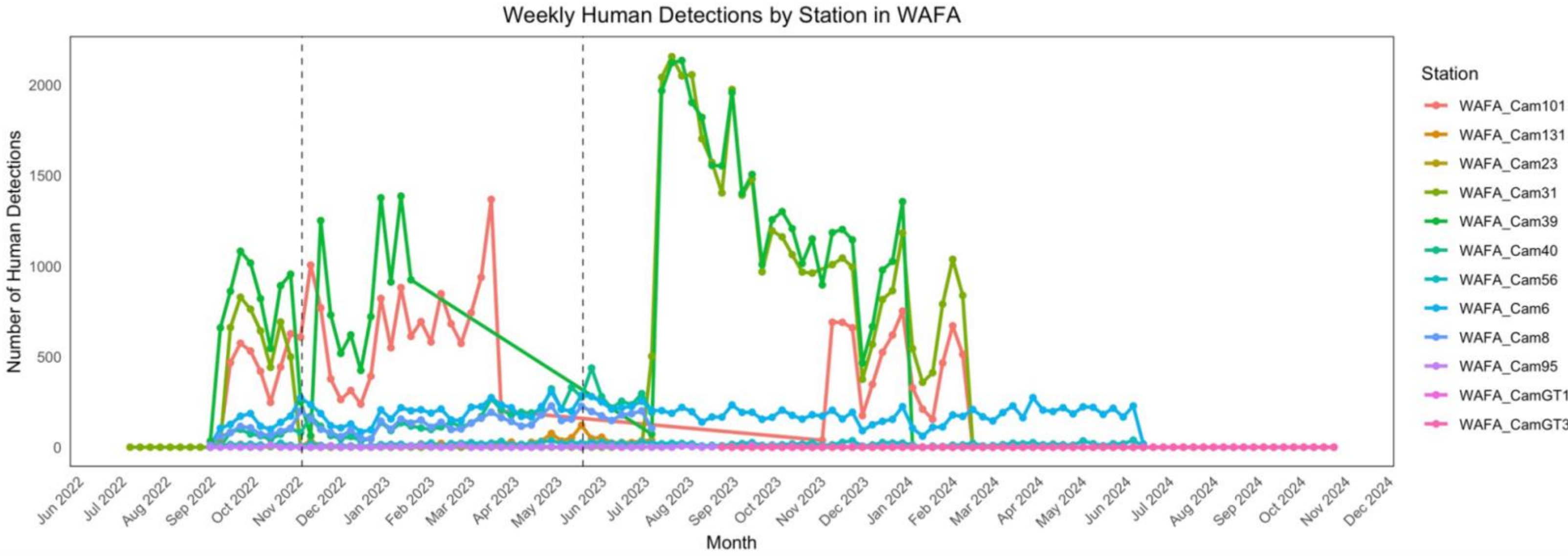

Weekly Human Detections by Station in FTEB


Weekly Human Detections by Station in MORA


Weekly Human Detections by Station in SQMT
Number of Human Detections
0
100
200
300
400
Month
Sep 2022
Oct 2022
Nov 2022
Dec 2022
Jan 2023
Feb 2023
Mar 2023
Apr 2023
May 2023
Jun 2023
Jul 2023
Aug 2023
Sep 2023
Oct 2023
Nov 2023
Dec 2023
Jan 2024
Feb 2024
Mar 2024
Apr 2024
May 2024
Jun 2024
Jul 2024
Aug 2024
Sep 2024
Oct 2024
Nov 2024
Dec 2024
Station
SQMT_Cam113
SQMT_Cam114
SQMT_Cam33
SQMT_Cam34
SQMT_Cam35
SQMT_Cam37
SQMT_Cam48
SQMT_Cam74
SQMT_Cam82
SQMT_Cam91
SQMT_CamGT1
SQMT_CamGT2
SQMT_CamGT3


Weekly Human Detections by Station in DEPA
Number of Human Detections
0
200
400
600
Month
Aug 2022
Sep 2022
Oct 2022
Nov 2022
Dec 2022
Jan 2023
Feb 2023
Mar 2023
Apr 2023
May 2023
Jun 2023
Jul 2023
Aug 2023
Sep 2023
Oct 2023
Nov 2023
Dec 2023
Jan 2024
Feb 2024
Mar 2024
Apr 2024
May 2024
Jun 2024
Jul 2024
Aug 2024
Sep 2024
Oct 2024
Nov 2024
Station
DEPA_Cam115
DEPA_Cam120
DEPA_Cam13
DEPA_Cam130
DEPA_Cam15
DEPA_Cam21
DEPA_Cam22
DEPA_Cam42
DEPA_Cam93
DEPA_Cam97
DEPA_CamGT1
DEPA_CamGT2
DEPA_CamGT3


Weekly Human Detections by Station in OLAL
Number of Human Detections
0
500
1000
1500
Month
Jul 2022
Aug 2022
Sep 2022
Oct 2022
Nov 2022
Dec 2022
Jan 2023
Feb 2023
Mar 2023
Apr 2023
May 2023
Jun 2023
Jul 2023
Aug 2023
Sep 2023
Oct 2023
Nov 2023
Dec 2023
Jan 2024
Feb 2024
Mar 2024
Apr 2024
May 2024
Jun 2024
Jul 2024
Aug 2024
Sep 2024
Oct 2024
Nov 2024
Dec 2024
Station
OLAL_Cam103
OLAL_Cam121
OLAL_Cam24
OLAL_Cam24_
OLAL_Cam28
OLAL_Cam29
OLAL_Cam30
OLAL_Cam4
OLAL_Cam4_c
OLAL_Cam41
OLAL_Cam66
OLAL_Cam90
OLAL_CamGT
OLAL_CamGT
OLAL_CamGT


Weekly Human Detections by Station in WAFA
Number of Human Detections
0
500
1000
1500
2000
Month
Jun 2022
Jul 2022
Aug 2022
Sep 2022
Oct 2022
Nov 2022
Dec 2022
Jan 2023
Feb 2023
Mar 2023
Apr 2023
May 2023
Jun 2023
Jul 2023
Aug 2023
Sep 2023
Oct 2023
Nov 2023
Dec 2023
Jan 2024
Feb 2024
Mar 2024
Apr 2024
May 2024
Jun 2024
Jul 2024
Aug 2024
Sep 2024
Oct 2024
Nov 2024
Dec 2024
Station
WAFA_Cam101
WAFA_Cam131
WAFA_Cam23
WAFA_Cam31
WAFA_Cam39
WAFA_Cam40
WAFA_Cam56
WAFA_Cam6
WAFA_Cam8
WAFA_Cam95
WAFA_CamGT1
WAFA_CamGT3

Appendix J. Weekly average of human counts per station throughout the study years, including total number of human counts.

Station	2021	2022	2023	2024	Total Counts
BCRO_Cam1	166	221	194	305	28739
BCRO_Cam10	13	11	12	12	1548
BCRO_Cam2	193	214	250	-	23473
BCRO_Cam3	103	159	-	-	6418
BCRO_Cam4	154	161	176	-	17610
BCRO_Cam5	62	77	79	-	8024
BCRO_Cam54	-	28	56	62	4762
BCRO_Cam6	84	81	78	-	8548
BCRO_Cam7	4	6	4	-	218
BCRO_Cam8	-	212	411	1	16217
BCRO_Cam9	13	11	11	-	1019
BCRO_CamGT11	-	-	-	1	1
DEPA_Cam115	-	25	33	28	2941
DEPA_Cam120	-	66	89	84	8046
DEPA_Cam13	-	113	164	-	6565
DEPA_Cam130	-	8	11	-	450
DEPA_Cam15	-	69	86	64	7417
DEPA_Cam21	-	66	61	-	2897
DEPA_Cam22	-	15	-	-	199
DEPA_Cam42	-	44	39	-	1880
DEPA_Cam93	-	452	469	-	21235
DEPA_Cam97	-	45	39	-	1941
FTEB_Cam1	408	367	-	-	13371
FTEB_Cam10	47	52	54	-	5387
FTEB_Cam11	-	18	26	-	985
FTEB_Cam118	-	88	202	158	15704

FTEB_Cam2	179	176	201	-	19329
FTEB_Cam3	25	32	50	-	3744
FTEB_Cam4	492	649	-	-	34183
FTEB_Cam5	83	82	100	-	7613
FTEB_Cam6	3	2	2	3	46
FTEB_Cam8	-	41	70	-	2584
FTEB_Cam8_old	72	-	-	-	861
FTEB_Cam9	205	272	304	261	41586
FTEB_CamGT2	-	-	6	2	19
FTEB_CamGT84	-	-	1	2	3
LARR_Cam1	-	93	164	182	14262
LARR_Cam10	749	1271	-	-	16611
LARR_Cam1_old	619	-	-	-	14243
LARR_Cam2	146	177	179	-	16500
LARR_Cam3	-	54	109	-	3804
LARR_Cam3_old	437	599	-	-	18865
LARR_Cam41	-	28	143	-	4568
LARR_Cam43	-	321	497	568	41571
LARR_Cam5	92	196	168	-	17377
LARR_Cam6	124	255	-	-	14195
LARR_Cam7	130	206	178	-	13706
LARR_Cam8	15	23	-	-	1308
LARR_Cam9	146	186	45	-	12909
LARR_CamGT1	-	-	9	2	11
MORA_Cam1	276	627	-	-	32582
MORA_Cam10	-	5	6	-	70
MORA_Cam100	-	420	-	-	2099
MORA_Cam10_old	257	553	-	-	28936
MORA_Cam2	-	26	37	-	1387

MORA_Cam2_old	153	203	-	-	11678
MORA_Cam3	7	5	3	4	255
MORA_Cam4	99	176	229	-	16610
MORA_Cam5	605	694	-	-	31030
MORA_Cam6	70	94	-	-	5595
MORA_Cam7	17	21	22	-	2106
MORA_Cam8	30	50	48	53	6904
MORA_Cam9	92	187	215	191	27557
MORA_CamGT1	-	-	1	-	1
MORA_CamGT2	-	-	1	2	12
OLAL_Cam103	-	7	10	-	151
OLAL_Cam121	-	278	303	-	14845
OLAL_Cam24	-	81	86	-	3141
OLAL_Cam24_old	-	52	-	-	362
OLAL_Cam28	-	4	6	6	528
OLAL_Cam29	-	240	270	273	23776
OLAL_Cam30	-	50	38	-	1579
OLAL_Cam4	-	1252	1924	1476	79270
OLAL_Cam41	-	2	3	-	33
OLAL_Cam4_old	-	2234	-	-	6702
OLAL_Cam66	-	19	25	-	558
OLAL_Cam90	-	31	34	-	685
OLAL_CamGT1	-	-	1	-	2
OLAL_CamGT2	-	-	5	3	59
OLAL_CamGT3	-	-	4	2	21
SQMT_Cam113	-	10	23	-	828
SQMT_Cam114	-	15	28	-	1046
SQMT_Cam33	-	60	91	99	8345
SQMT_Cam34	-	72	109	133	10391

SQMT_Cam35	-	16	32	-	1187
SQMT_Cam37	-	261	376	-	15092
SQMT_Cam48	-	83	120	-	4814
SQMT_Cam74	-	33	53	-	2025
SQMT_Cam82	-	146	211	224	19361
SQMT_Cam91	-	45	77	-	2948
SQMT_CamGT2	-	-	1	-	1
WAFA_Cam101	-	729	1047	662	39030
WAFA_Cam131	-	12	37	-	1197
WAFA_Cam23	-	4	6	-	190
WAFA_Cam31	-	1044	1989	1028	69251
WAFA_Cam39	-	1138	2316	933	90901
WAFA_Cam40	-	96	283	-	9555
WAFA_Cam56	-	12	23	19	1918
WAFA_Cam6	-	196	280	259	24605
WAFA_Cam8	-	127	228	-	8664
WAFA_Cam95	-	5	4	2	164

Appendix K. Human pressure (human detections per trap effort) for each season from summer 2021 to fall 2024. Pressure was calculated using data from the four initial parks (Fort Ebey, Moran, Larrabee, and Beacon Rock) where cameras were more likely to operate throughout the entire study period. Off-trail locations were excluded.

Season	Season average	Human Detections	Camera Trap Effort	Human Pressure
Summer 2021	18.97	19652	779	25.23
Summer 2022		42514	2162	19.66
Summer 2023		22816	1898.5	12.02
Fall 2021	9.96	39185	2618	14.97
Fall 2022		21428	2355	9.10
Fall 2023		7953	1365	5.83
Winter 2021	8.21	4584	597	7.68
Winter 2022		30864	2470	12.50
Winter 2023		14562	2144	6.79
Winter 2024		6782	1155	5.87
Spring 2022	12.18	36029	2305	15.63
Spring 2023		29629	2456.5	12.06
Spring 2024		11959	1352	8.85