RECREATION DISTURBANCE TO A SHRUB-STEPPE RAPTOR: BIOLOGICAL CONSEQUENCES, BEHAVIORAL MECHANISMS, AND MANAGEMENT IMPLICATIONS

By

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DEDICATION

To my family.

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ABSTRACT

With rapid increases in outdoor recreation, and mounting evidence of impacts to wildlife, public land managers and biologists need better information on the nature of this potential disturbance. Outdoor recreation may impact wildlife negatively via human disturbance or habitat degradation. Golden eagles (*Aquila chrysaetos*) in shrub-steppe habitats face several current and emerging threats, including increased non-motorized and motorized (off-highway vehicle, OHV) recreation. We tested the hypothesis that recreation affects eagle breeding biology by monitoring eagle behavior and reproduction in response to recreation volume and activity types, and landscape features associated with recreation. We also investigated the probability that an adult golden eagle would flush, examined flight initiation distance (FID), and documented total time off the nest following flushing events in response to motorized and non-motorized recreationists.

Territories with higher seasonal-average OHV volumes were less likely to be occupied than territories with lower seasonal-average OHV volumes, despite uniformly low OHV volume across all territories during the pre-breeding period. For non-migratory species, like eagles in southern Idaho, decreased occupancy during the breeding season may be the result of carry-over effects of disturbance in the non-breeding season, degraded habitat, or both. At occupied territories, early season volumes of pedestrians and other non-motorized recreationists negatively influenced adult eagle nest attendance and the likelihood of egg-laying. Behavioral observations of breeding birds revealed that adult nest attendance, a strong predictor of success, was associated negatively with the

volume of pedestrians, and most pedestrians observed near the nests reached the area via motorized vehicles. In addition, nest survival was affected negatively by interval-specific OHV volume recorded by trail cameras.

In most (87.1%, n = 279) instances, adult eagles did not respond to recreationists passing within 1200 m. Flushing was more likely to occur if eagles were perched away from the nest than if eagles were at the nest. FID was greater in the earlier portion of the breeding season, suggesting seasonal changes in the costs and benefits of responding to disturbance. Type of recreation activity did not affect the probability of flushing or FID, but flushing occurred frequently (36%, n = 36) when motorized recreationists stopped and changed their behavior near eagles. Recreationists on foot frequently go off trail and follow less predictable movement patterns than motorized recreationists and might create greater perceived risk.

Taken together, these results suggest that OHVs may facilitate disturbance events leading to nest failure by transporting motorized recreationists, who become pedestrians, to areas near eagle nests. We propose that landscape features suitable for eagle nesting, like steep canyons and rocky outcrops, also inspire recreationists to transition from predictable movements along a trail to less predictable stop-and-go hiking; less predictable recreation activities may increase perceived risk for eagles. Expanding existing trail management efforts to consider the effects of pedestrian and non-motorized recreation, especially during the early portion of the breeding season, could help improve eagle productivity. Limiting motorized and non-motorized recreation activities within 650 m and 1000 m of nest sites may decrease flushing events by 77% and 100%, respectively. Trail management efforts on public lands may strike a balance between the needs of recreationists and eagles by implementing “no-stopping” zones near known eagle nesting areas.

PREFACE

This thesis is separated into two chapters, formatted to facilitate publication as individual manuscripts. Each chapter examines the potential impacts of non-motorized and motorized recreation to different aspects of golden eagle ecology, but there is some overlap in material from the introduction, study area, and field methods. The focus of Chapter One is to assess the volume of recreation activities on key breeding parameters of golden eagles and examine the linkage between potentially altered behavioral regimes of eagles and breeding success, in response to recreation activities. Chapter Two focuses on factors that lead to flight responses to recreation activities, and examines factors that influence the distance at which flight responses occur.

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INTRODUCTION

Vast public lands in the American west support diverse wildlife communities and are an attractive location for humans seeking a variety of recreational activities, including non-motorized (horseback riding, mountain biking and walking) and motorized activities. Of approximately 258 million acres of Bureau of Land Management (BLM) land, 32% is available to off-highway vehicle (OHV) use as “open” access, 48% is considered “limited” access, 16% is “undesignated” and 4% is “closed” (USDI, BLM Travel Management Plan 2012). As of 2008, 20% of Americans had participated in OHV recreation, and 32.6% had participated in day hiking activities, within the past year (Cordell et al. 2009). Understanding the nature of interactions between wildlife and humans is important for maintaining the integrity of these lands.

Much ecological research has focused on the effects of non-consumptive human disturbance to wildlife breeding success, habitat quality, and behavior (Gill et al. 2001, Frid and Dill 2002). Disturbance is defined as “a deviation in an animal’s behavior from those patterns occurring without human influence” (Frid and Dill 2002). This is often described using models that consider human perturbation analogous to predation risk, regardless of actual predation threat (Frid and Dill 2002, Beale and Monaghan 2004). Wildlife avoidance of human activities and associated changes in breeding site selection, breeding behavior, and productivity may be the result of disturbance. The effects of recreation disturbance have been assessed for multiple species and ecosystems

(Gutzwiller 1991, Knight and Gutzwiller 1995, Rodgers and Schwikert 2002, Ouren et al. 2007, Zielinski et al. 2008, Barton and Holmes 2007, Watson et al. 2014).

Past research often suggests that multiple direct and indirect influences play a role in disturbing wildlife, and distinguishing between these can be challenging (Barton and Holmes 2007). As research on anthropogenic disturbance to wildlife has improved, so has the understanding of the interaction between altered behavior and fitness (Gill et al. 2001, Kight and Swaddle 2007). Attempts to measure direct recreation disturbance effects on avian nesting parameters and breeding behavior may be complicated by the effects of habitat degradation, extraneous environmental factors, and variation in tolerance to disturbance between individuals.

Studies of direct human disturbance to birds of prey have focused on aerial, road traffic and pedestrian influences (Andersen et al. 1990, White and Thurrow 1985, Schueck et al. 2001, Gonzalez et al. 2006). Such work has documented little or no impact from helicopter and fixed wing aircraft (Shueck et al. 2001, Grubb et al. 2010), increased nest failure due to road vehicle disturbance (Strasser and Heath 2013), and marked disturbance and disruption of nesting from direct pedestrian encounters (White and Thurrow 1985, Gonzalez et al. 2006). Single disturbance events may have a minor effect, but the accumulation of these events over a breeding season can contribute to reduced breeding success (McGarigal et al. 1991, Anthony et al. 1995).

The effect of recreation disturbance on various raptor species has been examined (Steidl and Anthony 2000, Brambilla et al. 2004, Gonzalez et al. 2006), but direct responses of raptors to OHV use has not been surveyed systematically, and responses to non-motorized use have been evaluated infrequently. OHV users often stop and dismount, spend prolonged time in an area, and travel in large groups at variable speeds. Use of firearms is common, and riders sometimes travel off trail (Fraser et al. 2012). Non-motorized users may have less impact on habitat quality, but still pose the potential for direct disturbance, and may induce avoidance behavior and changes in distributions (Gonzalez et al. 2006, Reed and Merenlender 2008). As increased outdoor recreation is relatively recent and projected to increase in coming decades (Cordell et al. 2009, Bowker et al. 2010), the full range of impacts have yet to be fully understood (Matchett et al. 2004). This increase poses new challenges for managers of public land operating under multiple use management objectives.

In Chapter 1, I present research investigating three temporal scales of recreation use in eagle territories and the potential influence on territory occupancy, egg-laying, and nest survival of golden eagles. I present results of focused behavioral observations of breeding eagles, aimed at understanding the behavioral patterns of successful breeding, and examine the influence of recreation activities that may alter these behavioral regimes.

In Chapter 2, I present an assessment of interactions between different recreationists and golden eagles, and investigate factors that predict the likelihood of eliciting a flight response in eagles. I also present the results of an analysis of the temporal and spatial mechanisms contributing to the Flight Initiation Distance of eagles, in response to recreation activities.

To conclude this thesis, I discuss the importance of considering multiple mechanisms of recreation disturbance to wildlife, and raptors in particular. I synthesize the results of each chapter and discuss the management strategies proposed therein.

Management strategies are aimed at facilitating continued recreation use within the study site, while using this research to minimize negative effects on breeding golden eagles.

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EFFECTS OF NON-MOTORIZED AND MOTORIZED RECREATION ON THE BREEDING BIOLOGY OF GOLDEN EAGLES (*AQUILA CHRYSAETOS*) IN SHRUB-STEPPE HABITATS

Abstract

Outdoor recreation may affect wildlife negatively via human disturbance or habitat degradation. Golden eagles (*Aquila chrysaetos*) in shrub-steppe habitats face several current and emerging threats, including increased non-motorized and motorized (off-highway vehicle, OHV) recreation. We tested the hypothesis that recreation affects eagle breeding biology by monitoring eagle behavior and reproduction in response to recreation volume and activity types, and landscape features associated with recreation. Territories with higher seasonal-average OHV volumes were less likely to be occupied than territories with lower seasonal-average OHV volumes, despite uniformly low OHV volume across all territories during the pre-breeding period. For non-migratory species, like eagles in southern Idaho, decreased occupancy during the breeding season may be the result of carry-over effects of disturbance in the non-breeding season, degraded habitat, or both. At occupied territories, early season volumes of pedestrians and other non-motorized recreationists negatively influenced adult eagle nest attendance and the likelihood of egg-laying. Behavioral observations of breeding birds revealed that adult nest attendance, a strong predictor of success, was associated negatively with the volume of pedestrians; most pedestrians occurring near the nest reached the area using motorized vehicles. In addition, nest survival was affected negatively by interval-specific OHV

volume recorded by trail cameras. Taken together, these results suggest that OHVs may facilitate disturbance events leading to nest failure by transporting motorized recreationists, who become pedestrians, to areas near eagle nests. We propose that landscape features suitable for eagle nesting, like steep canyons and rocky outcrops, also may inspire recreationists to transition from predictable movements along a trail to less predictable stop-and-go hiking; less predictable recreation activities may increase perceived risk for eagles. Expanding existing trail management efforts to consider the effects of pedestrian and non-motorized recreation, especially during the early portion of the breeding season, may help improve eagle productivity. Management strategies such as "no-stopping" zones for OHV riders may provide an alternative to closing trails and effectively mitigate for disturbance to nesting eagles.

Introduction

Motorized and non-motorized recreation on public lands is increasing (Cordell et al. 2009) and represents a major threat to species of conservation concern (Losos et al. 1995, Ouren et al. 2007). As the number of users increase, recreation activity spreads farther into remote areas, bringing recreationists into potential conflict with wildlife. Recreation activities have been shown to affect individual behavior (McGarigal et al. 1991, Steidl et al. 1993), population level patterns of distribution (Kangas et al. 2010), and reproductive success (Watson et al. 2014). Studies that simultaneously investigate both individual and population-level impacts of recreation may be particularly useful for determining mechanisms and consequences of recreation to wildlife (Anthony et al. 1995, Beale and Monaghan 2004, Rodríguez-Prieto and Fernández-Juricic 2005, Kight and Swaddle 2007). Further, because recreation patterns often vary seasonally, research investigating temporal scales of recreation patterns may reveal whether impacts are from short-term peaks in recreation that result in discrete disturbance events, or long-term high use patterns, which may result in consistent disturbance or habitat degradation.

Motorized recreation, such as snowmobiles and off-highway vehicles (OHVs), can affect wildlife via human disturbance (Buick and Paton 1989, McGowan and Simons 2006, Harris et al. 2014) or affect habitat use and quality (Shanley and Pyare 2011, Brehme et al. 2013). OHVs can influence ecosystem function adversely through deleterious effects to soil and watershed health, plant, mammalian, and avian communities (Ouren et al. 2007). OHV trail systems often have become mazes of braided trails (Matchett et al. 2004), causing habitat fragmentation, which is generally negative to avian nest success (Stephens et al. 2004).

Non-motorized recreation, such as hiking, horseback riding, and biking, may have less of an effect on habitat quality, but mounting research suggests it can induce avoidance behavior (Finney et al. 2005, Reed and Merenlender 2008), potentially to a higher degree than motorized activities (Gonzalez et al. 2006, Brown et al. 2012, Costello et al. 2013). Animals may perceive less predictable activities, such as stop-and-go walking and off-trail use, as higher risk than more predictable, evenly paced activities that stay on trails (Finney et al. 2005).

Eagles and other raptor species are vulnerable to human disturbance during nest initiation and early incubation (Fyfe and Olendorff 1976, Steidl and Anthony 2000) and are vulnerable to habitat degradation and loss (Booms et al. 2014). Steenhof et al. (2014) found that golden eagles (*Aquila chrysaetos*) experienced reduced reproductive success in OHV impacted areas of southwestern Idaho compared to non-impacted areas during

2000-2010, a time of rapid increase in OHV activity. However, the mechanism of disturbance to eagles is still unclear, and a broader suite of recreation activities may have combined effects. Golden eagles are long-lived, territorial, cliff and tree nesting raptors, with large home ranges, and limited suitable nesting locations (Kochert et al. 2002). In the sagebrush shrub-steppe ecosystem, eagles are often year round residents (Beecham and Kochert 1975) and do not breed annually. The number of pairs breeding and their subsequent productivity can be influenced by cyclical prey cycles and winter weather (Steenhof et al. 1997). The golden eagle is currently a federally protected species in the US, under the Bald and Golden Eagle Protection Act, which prohibits any action that constitutes a "take," including disturbance (The Bald and Golden Eagle Protection Act [16 U.S.C. 668-668c]). Accordingly, federal land managers and private landowners have a responsibility to manage lands to avoid any unpermitted take through disturbance. Therefore, understanding the consequences and mechanisms of recreation disturbance to golden eagle reproduction is important for managing and conserving the species.

We studied whether non-motorized recreation, including horseback riding, mountain biking, and pedestrian (hiking, walking, and running), and motorized recreation, including OHVs and road vehicles, affected eagle breeding behavior, territory occupancy, egg-laying, and nest survival. We hypothesized that both non-motorized and motorized recreation may disrupt eagle behavior and result in decreased territory occupancy, egg-laying, and nest survival. We examined the effects of recreation volume at three different temporal scales: seasonal average, early season average, and interval-specific volume, to evaluate which recreation pattern best explained eagle occupancy, egg-laying, and nest survival. In addition, we investigated which behaviors best predicted the probability that a golden eagle pair would lay eggs and successfully produce young; we then examined effects of motorized and non-motorized recreation on breeding behavior.

Methods

Study Site

All field work was conducted in southwestern Idaho on public lands administered by the Bureau of Land Management (BLM) managed by the Owyhee Field Office (OFO). In 2009, the OFO adopted the Murphy Subregion Travel Management Plan (Murphy TMP) in the Owyhee Front Special Recreation Management Area. The Murphy TMP redefined a network of ~1350 km of existing roads and trails as open year-round or seasonally to motorized use. Nearly 80 km of existing trails and roads were permanently closed for vegetative restoration or to decrease disturbance to bighorn sheep (*Ovis canadensis*), greater sage grouse (*Centrocercus urophasianis*), and golden eagles (USDI, BLM 2009). This research was part of the assessment and monitoring component of an adaptive management plan aimed at improving the efficacy of trail management efforts on BLM land to sustain golden eagle populations in southwestern Idaho (Sutter 2011).

Study territories were within the Murphy TMP, the Wilson Creek TMP, the Morley Nelson Snake River Birds of Prey National Conservation Area, and other sites within the OFO, but outside designated travel management units (Figure 1.1). The area is a sagebrush (*Artemesia tridentata*) dominated shrub-steppe ecosystem, including many canyons and rocky buttes, on the northern front of the Owyhee Mountains and south of the Snake River. The vegetative community is a mosaic of sagebrush subspecies, rabbitbrush (*Chrysothamnus* and *Ericameria* ssp), antelope bitterbrush (*Purshia* *tridentata*), greasewood (*Sarcobatus spp.*), many other shrub species, and well established exotic annuals, mainly cheat grass (*Bromus tectorum*).

Field Techniques

We used a stratified-random approach to select 23 historical golden eagle territories that allowed for research observation and had diverse recreation patterns. Eight territories were the same ones assessed by Steenhof et al. (2014). From mid-January through mid-April, we surveyed territories for adult eagles by checking the most recently occupied nest locations, then checking alternate nests, using protocols outlined in Pagel et al. (2010) and Steenhof and Newton (2007). We considered territories occupied if we saw an incubating eagle, nestlings in the nest, or a pair of eagles engaged in courtship behavior on more than two visits. We considered territories unoccupied if we detected no eagles after three, 4-hour observations, spaced ~30 days apart (Pagel et al. 2010). At occupied territories, we documented whether a pair laid eggs by the presence of an incubating eagle, the presence of eggs, egg shell fragments, or young in the nest. We made additional visits through early July to monitor nesting and conduct behavioral observations (see below). We considered nesting attempts successful if at least one nestling reached 51 days old, and confirmed fledging by the absence of dead nestlings within 200 m of the nest (Steenhof and Newton 2007, Pagel et al. 2010).

Every ~30 days, from pre-breeding (Jan-15) through fledging (Jul-6), we conducted 4-hour observations (mean of 3.87 hrs (SD = 0.60 hrs, n = 212)) of potential and occupied nests from standardized positions 600 m -1200 m away from the nest to minimize researcher disturbance (Pagel et al. 2010). At least two observations occurred on both weekend and midweek days, so each territory was observed under peak recreational disturbance and more moderate disturbance levels (see Appendix). Observers were either in a truck or pop-up hunting blind. We recorded adult behavior every five seconds and categorized them into the following: *Soaring*, *Attacking*, *Perched* (away from the nest, including preening), *Nest Maintenance*, *Copulation, Incubating*, *Brooding*, *Perched At the Nest* (including preening and shading), *Feeding* (actively feeding nestlings), *Defensive Posturing*, and *Absent*. If an eagle was flushed from the nest, behavioral surveys continued until the eagle returned to the nest and resumed its pre-disturbance activity. We identified males and females by size (when perched next to each other) or during copulation and by unique plumage/molt characteristics. Behavioral observations focused on the adult at the nest or the female if both eagles were present but neither was at the nest, because females perform more parental care (Collopy 1984). For analysis, behavioral categorizations were converted to percent time of the entire survey, to standardize for small variations in survey duration.

While conducting behavioral observations, we identified and tallied all-terrain vehicles (ATVs), rock crawler/utility terrain-vehicles (UTVs), dirt bikes, truck/SUVs/sedans (road vehicles), mountain bikes, horseback riders, and pedestrians within 1200 m of the nest. At territories where eagle pairs did not lay eggs, the most recently used nest site was used as reference, hereafter called the “focal nest.” We conducted 192 surveys at occupied territories. We calculated “Recreationists Per Hour” (Rec_Per_Hour) across each survey for analysis. Behavioral surveys at breeding territories lasted for a mean of 3.87 hrs (SD = 0.59 hrs, n = 116), and occurred at 10 and 11 territories in 2013 and 2014, respectively. Behavioral surveys were categorized to the following breeding stage categories: Unoccupied, Pre-Breeding, Incubation, Early Brood-rearing (0 - 21 day old nestlings), and Late Brood-rearing (22 - 71 day old nestlings; based on the oldest nestling, aged by sight (Hoechlin 1976)).

We sampled recreation volume across the entire territory, using trail cameras (Bushnell ® HD Trophy Cameras and Moultrie ® D55IR Gamespy Digital Cameras) placed along trails within 1200 m of the focal nest. We placed cameras greater than 100 m beyond the entrance or junction of a trail. Trail cameras were 8-10 m from trail edges, for five, 8-10 day sampling periods, every five weeks throughout the breeding season. All cameras were set to a 15-second time delay between pictures. An observer unfamiliar with each territory's location conducted image analysis by recording type of recreation activity, date, and time. We categorized recreationists into five groups: 1) *OHVs* (including all ATVs, UTVS, and dirt bikes), 2) *Road vehicles* (including all SUVs, trucks, and passenger vehicles), 3) *Non-motorized riders* (including mountain bikes and horseback riders), and 4) *Pedestrians,* with the additional category 5) *Unknown* when the image only captured evidence of a passer-by. Recreation volume was calculated on a per day, per trail basis, and tabulated in 3 ways for analysis: 1) breeding season mean volume (Rec_AVG_DAY), averaged from 15 Jan – 6 July; 2) early season mean volume (Rec_PreLay), averaged from 15 Jan through the mean laying date, and 3) interval-specific mean volume (Int_Rec_Day), average of the camera survey closest to each nest check. Mean laying date was determined by backdating nestlings aged by sight (Hoechlin 1976), or by the date halfway between the first confirmed evidence of incubation and the prior nest check.

At each territory, we assessed proximity of the focal nest to a suite of recreation sites using trail and road data from the BLM-OFO and imported into ArcGIS 10.1 (ESRI, Redlands, CA). We validated and corrected trails by digitizing from orthoimagery. We pooled all trail types for trail density (km/km^2) calculations. We estimated trail density at three spatial scales, in fixed-radius buffers of 400 m (~50 ha), 1 km (~314 ha), and 3 km (~2827 ha) from the focal nest. A 3-km buffer around the nest is the closest approximation available for a territory size of golden eagles in southwestern Idaho (Marzluff et al. 1997).

We also measured the distances from focal nests to the nearest trail or road, the nearest *open* trail or road, the nearest campsite, the nearest recreational shooting spot, and the nearest trailhead (Table 1.1). Campsites were identified by the presence of fire rings or direct observation. Recreational shooting sites were identified either by seeing people engaged in target practice, or by finding large numbers of leftover shell casings. Nest height (the vertical distance (m) between the nest and the bottom of the cliff) and nest-trail height differential (the vertical distance between the nest and the closest trail) were measured in the field using a clinometer and a laser rangefinder.

Statistical Analysis

We created generalized linear mixed models (GLMMs) in package “lme4” (Bates et al. 2014) with a binomial distribution and log link and territory as a random variable to assess the influence of recreation volume and habitat features (Table 1.1) on naïve territory occupancy and whether occupied territories laid eggs. We used naïve occupancy (the probability of site occupancy when detection probability is less than 1 (MacKenzie et al. 2002)) because eagles are highly detectable (Brown et al. 2013). For the occupancy and egg-laying analyses, we assessed the influence of both breeding season mean volume and early season mean volume from trail cameras. All numerical predictors were centered and scaled before analysis. We ran pair-wise Spearman correlation analyses for recreation volume (at both temporal scales) and habitat features to check for multicollinearity in predictors. For any pair of variables with r > |0.70|, we selected the variable with a higher likelihood of affecting eagle reproduction, or the variable with the most model support. We used a forward-wise two-step process to evaluate factors that affect eagle occupancy and egg-laying. In the first stage, we used an exploratory approach by evaluating single variable models against other models that represented our hypotheses: disturbance (recreation volumes) and habitat features. We selected models within 2 ΔAICc to be in the final model set that contained both volume and habitat features. When predictors were not correlated, we combined variables that had evidence of support (lower AICc than the intercept-only model). We considered models with the lowest AICc to be the most parsimonious for each model parameter. We reported 85% confidence intervals for parameter estimates (Arnold 2010) and considered a variable to be influential when there was evidence for the model and the confidence interval for the parameter did not overlap zero. Descriptive statistics are reported as mean (SD).

We created logistic exposure nest survival models in R 3.1.1 (package “nestsurvival,” courtesy Mark Herzog, USGS) to assess the influence of recreation volume, proximity, and habitat features on nest survival of egg-laying pairs. For this analysis, we assessed breeding season mean recreation volume and interval-specific mean recreation volume from trail cameras. In addition to the recreation covariates, we also assessed the influence of the nest specific parameters, *year* (2013 or 2014), *nest age* (0 = onset of incubation), *middate* (halfway between each nest check), *nesting stage* (incubating or brooding), and *nest height* (Table 1.2). We used an information theoretic approach to evaluate nest survival models. Models with ΔAICc < 2 with variables with 85% confidence intervals that did not overlap zero were considered informative. We calculated model averaged parameter estimates based on the models that made 100% of the weight in the hypothesis model comparison (Anderson 2008).

We ran pair-wise Spearman correlation analyses of the percent time for each behavior. We determined which behaviors during the pre-breeding period best predicted egg-laying in occupied territories, using a GLMM, with a binomial distribution, and a random variable for territory (n = 73 surveys) and then we used a GLMM to examine whether recreation volume (estimated by direct observation) affected behavior. However, because of complete separation between covariates and egg-laying, we compared the amount of recreation volume of different types for observations when eagles made at least one nest visit and when they did not, using one-way ANOVAs, with a bonferroni correction for repeated comparisons. We tested variance of 8 hypothesis predictors (Table 1.9), on whether or not eagles made a nest visit, and used an adjusted p-value of 0.00625.

Among breeding territories, we used a logistic exposure nest survival analysis and AICc model selection to determine which *behavior* was the best predictor of nest survival. *% Total_At_Nest* and nest age were the best indicators of daily nest survival. We used a general linear model of *% Total_At_Nest* and nest age to generate residuals that represented age-corrected %_Total_At_Nest. Using the residuals from this model, we then reincorporated these residuals into the nest survival model, and found it gave improved model fit as the best behavioral predictor of daily nest survival (Table 1.3). We used a linear mixed model (LMM), using package “lme4”, to assess recreation volume on age-corrected %_Total_At_Nest. All analyses were performed in R 3.1.1 (R Core Team 2014).

Results

Trail cameras detected a mean of 1.92 road vehicles per day (SD = 5.12), 0.74 OHVs per day (SD = 1.05), 0.49 pedestrians per day (SD = 0.82), and 0.25 non-motorized riders per day (SD = 0.48). Recreation activity was higher on weekends than weekdays and changed over the course of the breeding season. OHV and road vehicle volume increased during the spring, peaked in the late spring, then declined in the summer (Figure A.1). Pedestrian activity was highest during late winter and dropped off considerably as spring progressed (Figure A.2). Non-motorized riding activities occurred comparatively less frequently than other recreation types throughout the season, but peaked in the spring (Figure A.2). (See Appendix for complete analytical methods, AICc tables and top model equations.)

Trail density (km/km^2) within 400 m, 1 km, and 3 km of the focal nest averaged 2.15 (SD = 2.41, range 0.0-7.67), 2.19 (SD = 1.83, range 0.19 - 8.27), and 2.63 (SD = 1.68, range 0.71 - 7.82), respectively. Mean distance to the closest trail was 307 m (SD = 257), distance to the closest open trail was 386 m (SD = 312), distance to the nearest trailhead was 2471 m (SD = 1731), distance to the nearest campsite was 2314 m (SD = 1554), and distance to the nearest shooting spot was 1829 m (SD = 1614).

Territory occupancy rates were 91.3% in 2013 and 86.9% in 2014. At occupied territories, 46.7% (n = 21) and 55% (n = 20) of eagle pairs laid eggs in 2013 and 2014, respectively. Estimated mean laying date was 6 March (n = 10) and 4 March (n = 11), in 2013 and 2014, respectively. Mean nest height of egg-laying pairs was 34.76 m (SD =

32.95, range 8.92 – 152.35) and mean nest-trail differential was 74.39 m (SD = 73.49, range 20.38 – 209.63). Apparent nest success was 40.0% in 2013 and 36.4%, in 2014. The number of fledglings per breeding territory was 0.40 (n = 10) in 2013 and 0.45 (n = 11) in 2014.

The top model predicting territory occupancy contained the breeding season mean of OHVs/day (*OHV_AVG_DAY*) as the only predictor (Table 1.4). *OHV_AVG_DAY* influenced territory occupancy negatively (β = -1.6482, 85% CI = -2.8282, -0.8224) (Figure 1.2). Trail density within 3 km of the focal nest correlated positively with *OHV_AVG_DAY* (r^2=0.66), but was not determined to be a strong model.

The top model predicting whether pairs laid eggs was early season pedestrian volume (*PED_PreLay*) (Table 1.5). *PED_PreLay* influenced nest initiation negatively (β = -1.5697, 85% CI = -3.8509, -0.2553) (Figure 1.3). The early season volume of non-motorized riders (*NO_MOTOR_PreLay*) was the next best predictor variable. These two variables were strongly and positively correlated (r^2 = 0.81).

Initial AICc model selection, assessing recreation covariates on nest survival produced 12 models that went on to a complete model set. In assessment of these models, the top model showed that golden eagle nest survival was nesting stage specific, and negatively influenced by the interval-specific volume of OHVs (*Int_OHV_Day*) (Table 6). *Int_OHV_Day* negatively influenced daily nest survival (model averaged β = -0.5102, 85% CI = -0.8467, -0.1737) and is shown within the range of collected data for incubating eagles and pairs with nestlings (Figure 1.4).

Activity budgets of golden eagles at occupied nesting territories were typical for nesting raptors (Figures 1.5-1.8), and changed predictably throughout the four stages

(Prebreeding, Incubation, Early Brood-rearing, and Late Brood-rearing). Copulation (mean = 0.04% of time, SD = 0.01%) and nest maintenance (mean = 0.8%, SD = 1.9%) occurred during the Prebreeding stage (n = 73 surveys), and eagles spent 1.45 % (SD = 4.6 %) of their time at the nest, though in many cases eagles were absent from the nest area for most of the survey period (mean of 61.5% of time, SD = 29.2%). Eagles spent 93.1% (SD = 10.3%) of their time incubating, and 0.67% (SD = 9.7%) perched at the nest or engaging in nest or egg maintenance (1.34%, SD = 1.74%) during the incubation stage (n = 26 surveys). Incubating eagles were only absent from the nest area 1.8 % (SD = 6.0%) of the time.

Eagles spent 36.4 % of their time brooding young during the early brood-rearing stage (n = 17 surveys), though this was highly variable (SD = 34.0%), due to variation in brooding time as nestlings matured. Adult eagles perched at the nest or shaded young for 26.6 % of the time (SD = 23.7%), fed nestlings 8.4 % of the time (SD = 7.1%), and performed nest maintenance 2.6 % of the time (SD = 3.1 %), spending a total of 74% of the time at the nest during the early brooding stage. During the late brood-rearing stage (n = 25 surveys), eagles spent no time brooding during our daytime surveys, but spent 13.3 % (SD = 24.0%) of their time at the nest, between feeding (3.5%, SD = 5.8%), perching or shading (9.7 %, SD = 19.5%), and minimal nest maintenance (0.2%). Eagles were completely absent from the nest area for much of the survey period (47.2%, SD = 31.6%) at this time period, as nestlings became more self-reliant.

Behavior patterns often correlated with one another. For example, during prebreeding surveys, *% Perched_At_Nest* correlated with *%Nest_Maintenance* (r = 0.70). During incubating surveys, *%Incubating* correlated with *%Soaring* (r = -0.84), and

%Absent correlated with *%Total_At_Nest* (r = -0.71). During early brooding surveys, *%Brooding* correlated with *%Absent* (r = -0.73). Nest site specific behaviors in particular were commonly correlated with each other, so we used *%Total_At_Nest* as a complete indicator of nest attendance.

%Total_At_Nest during the Prebreeding stage was the best predictor of egg-laying by eagle pairs (Table 1.8). Variances of all predictor variables did not differ significantly between observations when eagles made at least one nest visit and when they did not, with $p > 0.00625$ for all recreation predictor variables. *Ped_Per_Hr* was the best predictor variable of nest-age corrected nest attendance (Table 1.9) and negatively influenced the time eagles spent at the nest ($\beta = -11.99$, 85% CI [-19.25, -4.55] (Figure 1.9). Of the 50 pedestrians observed within 1200 m of incubating or brood-rearing eagles, 66% initially reached the area from a truck or SUV, 30 % initially came on an OHV, and 4% entered the area on foot.

Discussion

Golden eagle occupancy, egg-laying, and nest survival were negatively associated with off-highway vehicle, pedestrian, and other non-motorized recreation volumes, which were likely having direct disturbance impacts. Territories with higher seasonal average OHV volumes also had the highest trail densities and were less likely to be occupied than territories with lower OHV volumes, despite uniformly low OHV volume across all territories during the pre-breeding period. For non-migratory species, like eagles in southern Idaho, decreased occupancy during the breeding season may be the result of carry-over effects of disturbance in the non-breeding season, degraded habitat, or both. At occupied territories, pedestrian and non-motorized rider volume during the early portion of the breeding season negatively influenced the likelihood of golden eagles laying eggs. Response to pedestrians and non-motorized riders, specifically before the mean laying date, supports the theory that large raptors may be particularly vulnerable to disturbance at this crucial time (Stiedl and Anthony 2000). Short-term peaks in OHV volume reduced the daily nest survival rate of golden eagles, and behavioral observations of breeding birds revealed that adult nest attendance, a strong predictor of success, was associated negatively with the volume of pedestrians. However, most pedestrians reached areas near nests using motorized vehicles. Taken together, these results suggest that OHVs may facilitate disturbance events leading to nest failure by transporting motorized recreationists, which become pedestrians, to areas near eagle nests. This study further illustrates the importance of determining the specific mechanisms by which disturbance is occurring. Such insights may best be understood by combining population patterns of reproduction and individual behavioral monitoring.

Sites with higher OHV volume and trail density had lower territory occupancy. Our results are consistent with golden eagle research from Finland, which showed reduced rates of occupancy in relation to tourist areas and greater length of snowmobile and ski trails (Kaisanlahti-Jokimäki et al. 2008). Golden eagles in southwestern Idaho are typically year-round residents, and there may be potential carry-over effects associated with recreational use in fall and early winter, which this project did not assess. Alternatively, OHV activity also may be detrimental to the habitat that supports prey populations (jackrabbits, ground squirrels, upland game birds, etc.) of eagles. This effect on prey could occur through direct disturbance or habitat degradation; research investigating this may be vital to understanding the ecosystem and trophic level at which disturbance to eagles occurs.

Gill et al. (2001) argued that life strategy options for the disturbed individual depend largely on the availability of other suitable habitat. For territorial non-migratory raptors, with specialized nesting habitat, finding additional disturbance-free nesting sites may not be possible. Maintaining the integrity and quality of historical eagle territories, so they are available annually for pairs to establish breeding sites, is important because nest sites are limited and fewer suitable sites will result in a decrease in population size (Watson and Whitfield 2002, The Bald and Golden Eagle Protection Act [16 U.S.C. 668-668c]). Behavioral observations at three adjacent, historically occupied territories, with high OHV volume and high trail density, suggest that one eagle pair now uses portions of all three territories. This behavior is consistent with other research showing that golden eagles may subsume adjoining territories when they become vacant (USGS, Snake River Field Station, unpublished data), perhaps in an attempt to compensate for compromised habitat by using larger home ranges (Andersen et al. 1990).

In long-lived species such as raptors, consistent decisions not to lay eggs may have detrimental effects on populations. The proportion of eagle pairs that lay eggs is highly variable (Steenhof et al. 1997, McIntyre and Adams 1999), but is a critical component of overall eagle productivity. The proportion of pairs laying eggs in this study (52.5%) was lower than average (70.0 %) but within the observed range (38-100%) of more than 20 years of research in southwestern Idaho (Steenhof et al. 1997). The influence of pedestrian activity and non-motorized riding on the probability of egg-laying is consistent with research that similar taxa (*Aquila adalberti*) and golden eagles in

Alaska show a greater response to the unpredictable behaviors of such recreationists, who tend to linger in an area longer than motorized recreationists (Gonzales et al. 2006, McIntyre and Schmidt 2012). At this study site, the high volume of early season pedestrian activity, and comparatively low volume of OHVs, means that pedestrian activity may have a disproportionate amount of influence at this time of year (Figures A.1 and A.2). Temporal trends in pedestrian activities suggest the study site offers attractive hiking opportunities during winter and early spring, at a time when much of southwestern Idaho is icy, snowy, or muddy. Pedestrian activities likely do not cause extensive habitat degradation, but the direct stressor of human presence and the perception of a risky nesting site may preclude eagles from laying eggs. As nest building and refurbishment occur mainly in the 2 months before laying (Watson 2010), and suitable nesting locations are limited, changing nest locations may not an option. Therefore, early season pedestrians and non-motorized riders may negate the breeding potential of a pair of eagles.

Nest survival was stage specific (lower during brood rearing than incubation), and negatively associated with interval-specific OHV volume (Figure 1.4). These findings support, and may help explain, reduced productivity within areas of high OHV trail density, found by Steenhof et al. (2014). OHV volume peaks from March to May, and coincides with hatching and early brood rearing of nestling eagles (Figure A.1). This is a time when nestling eagles are most susceptible to exposure, if the parents are temporarily away from the nest (Watson 2010). Additionally, nestlings are susceptible to starvation at this time, and OHV disturbance may prevent adequate provisioning by the parents, or a reduction of the prey base. Determining whether this disturbance is causing eagles to flush from nests excessively, exposing eggs and nestlings, is important.

Proximity of nests to any of the major recreation sites was not related to any breeding parameters. This suggests that the mere presence, and potential habitat degradation, of trailheads, campsites, shooting spots, and trails does not deter eagles from occupying territories, laying eggs, or nesting successfully near these locations. This may suggest that if OHV, pedestrian, and non-motorized recreation volume within 1200 m is limited, such recreation sites outside this range can remain accessible to recreationists, without directly disturbing eagles. However, this study did not quantify the scale of these sites. Other studies (Steidl et al. 1993, Steenhof et al. 2014) have found such sites to be detrimental to productivity, and they still should be considered in management planning.

Nest height and the nest-trail height differential did not influence nest survival. This suggests that cliffs lying on lower rock outcrops, as they often do in this study site, are not inherently more productive nesting sites than those lying on high cliffs or canyons. Furthermore, nesting sites that are vertically further from trails may be just as susceptible to recreation disturbance as sites with less vertical separation.

Our behavioral surveys showed that total time spent by eagles at nests served as a good predictor of egg-laying for occupied territories. Likewise, the age-corrected total nest attendance of breeding eagles was a good predictor of daily nest survival. Both results suggest that carefully structured activity budgets can serve as an adequate measure of time necessary for successful breeding of golden eagles. Furthermore, age-corrected nest attendance during the incubation and brood-rearing stages were negatively associated with pedestrian volume within 1200 m of the nest. However, pedestrians observed during incubation or brood rearing surveys arrived within 1200 m of the nest from OHVs (30%) or road vehicles (66%). This suggests the negative influence of interval-specific OHV volume on nest survival may actually indicate exposure to pedestrians associated with OHVs. OHVs and trucks observed in this study rarely went off trail, and generally passed through an eagle territory within a few minutes. However, the canyons and cliffs on which eagles nest are landscape features of interest to recreationists, and eagle habitat may be an attractive spot for road vehicle and OHV users to disembark and begin hiking.

Results suggest that eagles perceive pedestrians as a greater threat than motorized activities. Eagles have some ability to tolerate repeated and predictable vehicular disturbance, but exhibit a general wariness of the human form. Pedestrians and non-motorized riders, by the nature of the activity, frequently go off trail, meander, and linger in an area. Although golden eagles face many conservation threats, direct persecution and harassment by illegal shooting continue to threaten individual birds. Differences in life experience among individuals of this eagle population may preclude some eagles to be more wary of such disturbance than others.

Management Recommendations

The results of this study suggest that reducing OHV recreation volume in close proximity to eagle nests, through seasonal or permanent trail closures, could improve the likelihood of territory occupancy, and increase nest survival. The negative influence of pedestrians and non-motorized riders on egg laying and nest attendance demonstrates the importance of managing recreation near golden eagle nesting sites for a full suite of recreationists, not just motorized activities. Existing seasonal trail closures apply only to motorized recreation activities within the study site (U.S. Department of the Interior, Bureau of Land Management 2009). Extending these to pedestrian and other non-motorized activities, especially during the early portion of the breeding season, could increase the probability that pairs would lay eggs. Anecdotal observations of traffic and trail camera data on existing seasonal trail closures from this study suggest increased enforcement in high use areas is necessary for such measures to be effective. Another management option may include implementation of “no-stopping” zones, within close proximity to eagle nests. This could reduce the effective number of pedestrians in many areas that do not typically experience high rates of “traditional” pedestrians. The efficacy of this strategy would need further review.

The amount of pedestrian use was the largest negative influence on eagle nest attendance, but most pedestrians got near eagle nests via either an OHV or a road vehicle. An extensive network of roads and trails, extending throughout golden eagle habitat, brings people in contact with eagles that are perturbed by their presence. It remains to be seen if enhanced recreation management practices can minimize loss in breeding potential. However, it is also important to reduce further expansion into remote areas, which are currently marginally impacted by off highway recreation. Many remote areas within this study site, and across the sagebrush-steppe ecosystem, remain outside regulated travel management areas. Incorporating more eagle habitat into travel management areas and revising existing travel management regulations would both be important components of landscape scale golden eagle conservation. Continued monitoring efforts and further research are important components of long-term golden eagle management. Understanding the potential effects of habitat degradation associated with off-highway recreation, and the influence this may have on eagle prey species, are essential research questions that remain unanswered. Lastly, improved and continued efforts at public education, to impart a broader understanding of the implications of trail system expansions on wildlife, would be useful.

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Tables and Figures

Table 1.1. List of variables included in GLMM analyses; variables were separated by hypothesis categories. AICc model selction was used to select the variables that best represented each hypothesis. Top models, stronger than the intercept and with ΔAICc < 2.00, went into the final candidate model set; no variables correlated (*r* ≥ .7) were in the same model.

Model Category	**Variable**	**Description**
Recreation Volume	OHV_AVG_DAY	Combined OHVs/day across season
	OHV_PreLay	OHVs/day before the Mean Laying Date
	Ped_Per_Hour_Beh	Pedestrians /Hour during behavioral surveys
	PED_PreLay	Pedestrians/day before Mean Laying Date
	TRUCK_AVG_DAY	Road Vehicles/day across the season
	TRUCK_PreLay	Road Vehicles/day before Mean Laying Date
	NO_MOTOR_AVG_DAY	Horseback and Mountain Bikes/day across season
	NO_MOTOR_PreLay	Horseback and Mountain Bikes/day before Mean Laying Date
Trail Density	Trail_Density_3k	Trail density at a 3 km buffer around the focal nest
	Trail_Density_1k	Trail density at a 1 km buffer around the focal nest
	Trail_Density_400m	Trail density at a 400 m buffer around the focal nest
Proximity to Recreation Sites	Closest_Trail	Distance (m) to the Closest Trail or Road
	Closest_Open_Trail	Distance (m) to the Closest Open Trail or Road
	Closest_Trail_Head	Distance (m) to the Closest Trail Head
	Closest_Shoot	Distance (m) to the Closest Recreational Shooting Spot
	Closest_Camp	Distance (m) to the Closest Campsite

Table 1.2. List of variables included in nest survival analysis; variables were separated by hypothesis categories. AICc model selction was used to select the variables that best represented each hypothesis. Top models, stronger than the intercept and with ΔAICc < 2.00, went into the final candidate model set; no variables correlated (*r* ≥ .7) were in the same model.

Model Category	Variable	Description
Recreation Volume	OHV_AVG_DAY	Combined OHVs/day across season
	Int_OHV_Day	Interval specific OHVs/day
	Ped_Per_Hour_Beh	Pedestrians /Hour during behavioral surveys
	Int_PED_Day	Interval specific Pedestrians/day
	TRUCK_AVG_DAY	Road Vehicles/day across the season
	Int_TRUCK_Day	Interval specific Road Vehicles/day
	NO_MOTOR_AVG_DAY	Horseback and Mountain Bikes/day across season
	Int_NO_MOTOR_Day	Interval specific Horseback and Mountain Bikes/day
Trail Density	Trail_Density_3k	Trail density at a 3 km buffer around the focal nest
	Trail_Density_1k	Trail density at a 1 km buffer around the focal nest
	Trail_Density_400m	Trail density at a 400 m buffer around the focal nest
Proximity to Recreation Sites	Closest_Trail	Distance (m) to the Closest Trail or Road
	Closest_Open_Trail	Distance (m) to the Closest Open Trail or Road
	Closest_Trail_Head	Distance (m) to the Closest Trail Head
	Closest_Shoot	Distance (m) to the Closest Recreational Shooting Spot
	Closest_Camp	Distance (m) to the Closest Campsite
	Nest-trail Differential	Vertical distance (m) from the nest to the Closest Trail
Nest Specific	Year	Year of Breeding Attempt
	Age	Number of Days since Estimated Laying Date
	Middate	Middle Julian Day of Interval
	Stage	Whether the pair is Incubating or Brooding
	Nest Height	Vertical distance (m) from the nest to the cliff bottom

Table 1.3. AICc table showing the candidate models of behavioral predictors of daily nest survival (n = 68 behavioral surveys, at 21 nesting attempts).

Model	***K***	**ΔAICc**	**Cum.w_i**
Age Corrected Nest Attendance Residuals*	2	0.00	0.46
Age + Age Corrected Nest Attendance Residuals	3	1.99	0.62
Intercept	1	3.07	0.72
Uncorrected Nest Attendance	2	3.57	0.80
Stage	2	3.67	0.87
Age + Uncorrected Nest Attendance	3	4.06	0.93
Age	2	5.05	0.97
Stage + Uncorrected Nest Attendance	3	5.26	1.00

*AICc of top model = 37.36

Table 1.4. AICc table showing the candidate models predicting territory occupancy (n = 46)[a].

Model	***K***	**ΔAICc**	**Cum.w_i**
OHV_AVG_DAY*	3	0.00	0.93
Trail_Denisty_3k	3	5.55	0.99
Dist_Closest_Trail	3	10.74	1.00
Nearest_Shooting_Spot	3	11.48	1.00
Intercept	2	12.45	1.00

*AICc of top model = 21.74, [a] All models included the random variable of Territory

Table 1.5. AICc table showing the candidate models predicting egg-laying on occupied territories (n=41)[a].

Model	***K***	**ΔAICc**	**Cum.w_i**
PED_PreLay*	3	0.00	0.60
Non-Motorized_PreLay	3	1.57	0.88
Intercept	2	3.23	1.00

*AICc of top model = 57.90, [a] All models included the random variable of Territory

Table 1.6. Nest survival analysis AICc table showing the candidate models explaining nest survival for breeding Golden Eagles (n=21).

Model	***K***	**ΔAICc**	**Cum.w_i**
Stage + Int_OHV_Day*	3	0.00	0.22
Closest_Shoot + Int_OHV_Day + Stage	4	0.20	0.42
Closest_Camp + Int_OHV_Day + Stage	4	0.47	0.59
Closest_Camp + Stage	3	1.22	0.71
Closest_Shoot + Stage	3	1.44	0.82
Stage	2	2.63	0.88
Int_OHV_Day	2	4.36	0.90
Closest_Shoot	2	4.50	0.92
Closest_Shoot + Int_OHV_Day	3	4.58	0.94
Closest_Camp	2	4.74	0.96
Closest_Camp + Int_OHV_Day	3	4.90	0.98
Intercept	1	4.92	1.00

*AICc of top model = 73.28

Table 1.7. Model averaged parameter estimates for the composite model predicting nest survival for breeding Golden Eagles (n = 21).

			85%	
Parameter	Estimate	SE	Upper	Lower
Intercept	4.8066	0.4152	5.4044	4.2087
Stage	1.7085	0.8044	2.8668	0.5501
Int_OHV_Day	-0.5102	0.2337	-0.1737	-0.8467

Table 1.8. AICc table assessing activity budgets on egg-laying at occupied territories, during the pre-breeding portion of the season (n = 73 surveys).

Model	***K***	**ΔAICc**	**Cum.w_i**	**85% CI**
Intercept*	2	0.00	0.28	-------
% Perched_At_Nest	3	1.61	0.40	-0.878 – 2.858
% Total_At_Nest	3	1.71	0.52	0.492 – 1.065
% Nest_Maintenance	3	2.06	0.62	-0.926 – 1.930
% Soaring	3	2.07	0.71	-0.272 – 0.166
% Absent	3	2.11	0.81	-0.052 – 0.082
% Perched	3	2.12	0.91	-0.088 – 0.057
% Copulation	3	2.14	1.00	-28.343 – 17.819

* AICc of Intercept model = 58.56

Table 1.9. Comparison of variance in recreation variables at prebreeding surveys of occupied territories, assessing difference between territories with eagles making nest visits, and not making nest visits (n=73 surveys).

Recreation Variable	$F_{1,71}$	p-value
OHVs/Hour	0.8165	0.3692
Trucks/Hour	0.3399	0.5617
Non_Motorized/Hour	0.6670	0.4168
Ped/Hour	1.221	0.2730
All_Rec/Hour	0.3899	0.5344
TD3k	0.6868	0.4100
TD1k	0.6181	0.4344
TD400m	1.1698	0.2831
Dist_Closest_Trail	0.2027	0.6539

Table 1.10. AICc table assessing the influence of recreation covariates on nest-age corrected total nest attendance (n = 68 surveys).

Model	***K***	**ΔAICc**	**Cum.w_i**
Ped_Per_Hr	4	0.00	0.55
Intercept	3	3.02	0.67
TD3k	4	5.01	0.71
All_Rec_Per_Hr	4	5.02	0.76
TD400	4	5.03	0.80
OHVs_Per_Hr	4	5.22	0.84
TD1k	4	5.25	0.88
No_Motors_Per_Hr	4	5.25	0.92
Trucks_Per_Hr	4	5.27	0.96
Closest_Open-Trail	4	5.28	1.00

* AICc of top model = 598.81

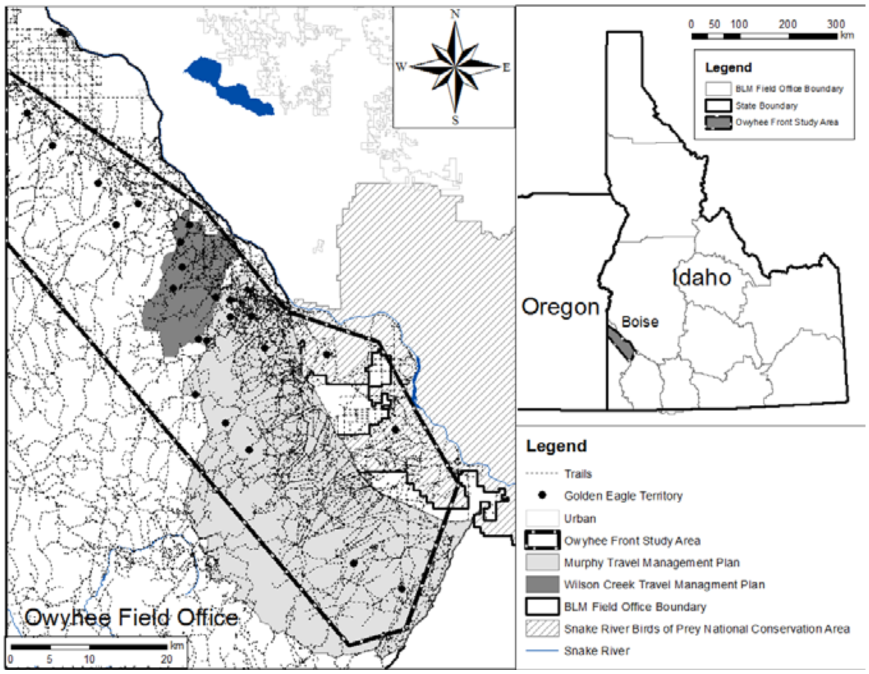


Figure 1.1. Owyhee Front golden eagle off-highway recreation study site.

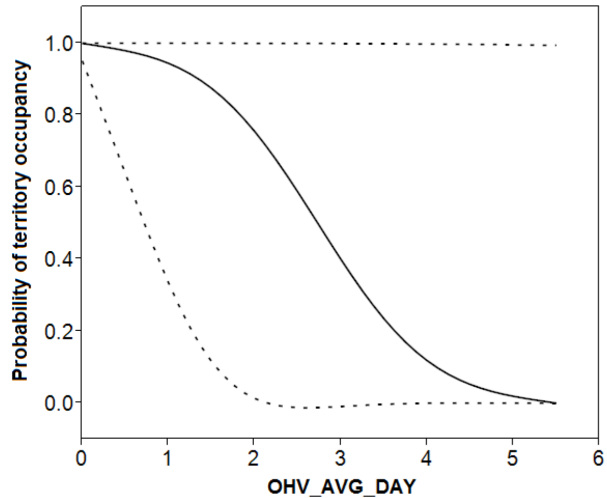


Figure 1.2. The effect of OHV activity across the entire breeding season on territory occupancy of golden eagles (n=46), with solid line for model prediction, and dashed lines for 85% CIs. OHV_AVG_DAY is within the range of collected data.

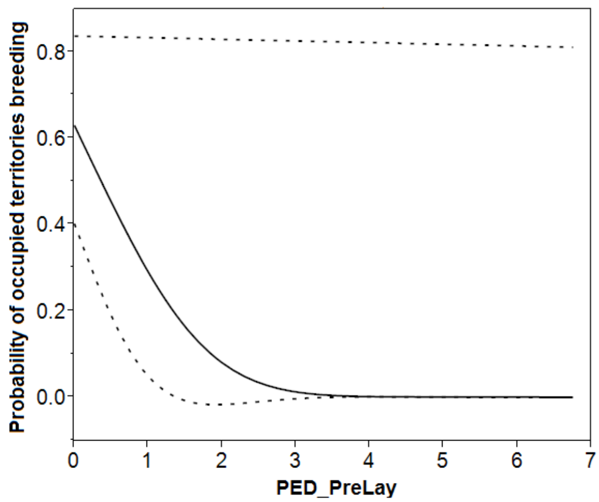


Figure 1.3. The effect of Pedestrian activity before the mean laying date on egg-laying at occupied golden eagle territories (n=41), with solid line for model prediction, and dashed lines for 85% CIs. PED_PreLay is within the range of collected data.

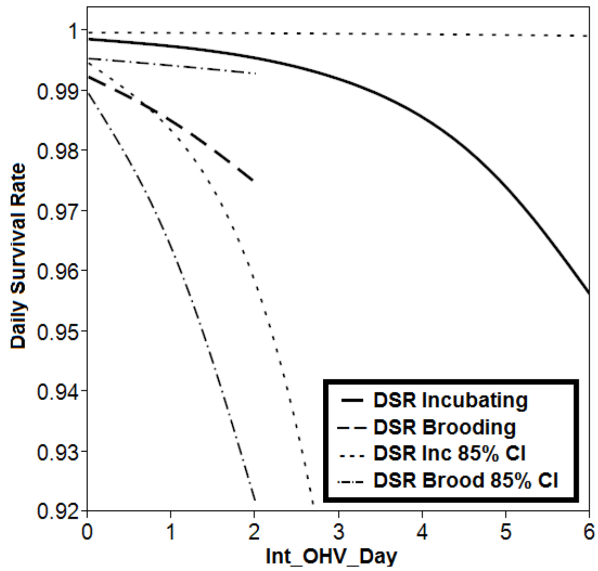
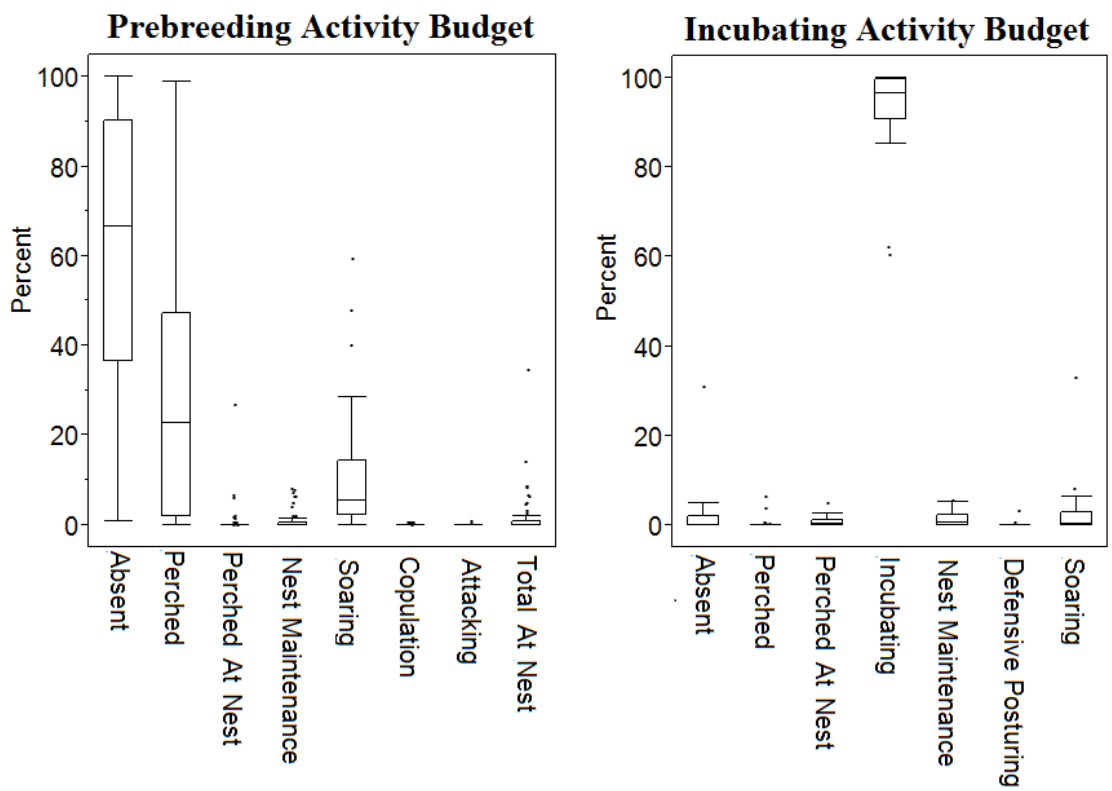
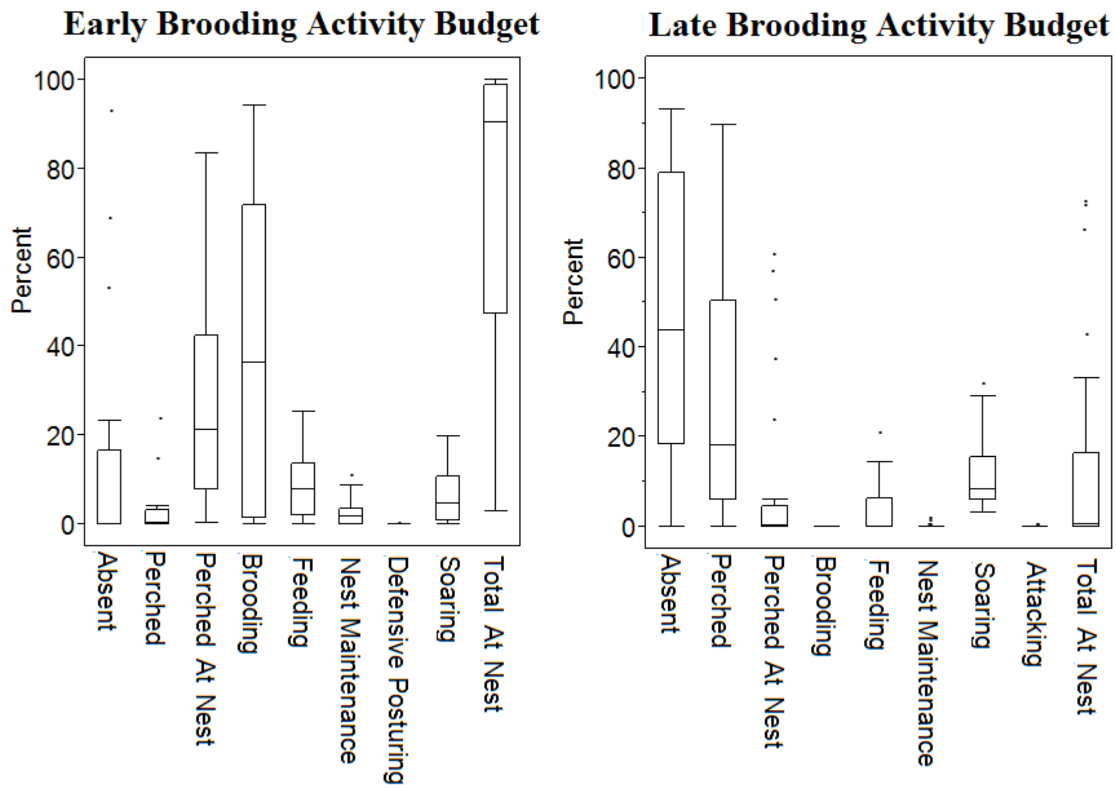


Figure 1.4. Daily nest survival rate (DSR) and the interval specific OHVs per day for golden eagles (n=21). Model is shown within the range of collected data for Int_OHV_Day.



Figures 1.5 and 1.6. Activity budgets of golden eagles at occupied territories during Prebreeding, Incubation.



Figures 1.7 and 1.8. Activity budgets of golden eagles at occupied territories during Early Brood-rearing, and Late Brood-rearing Stages.

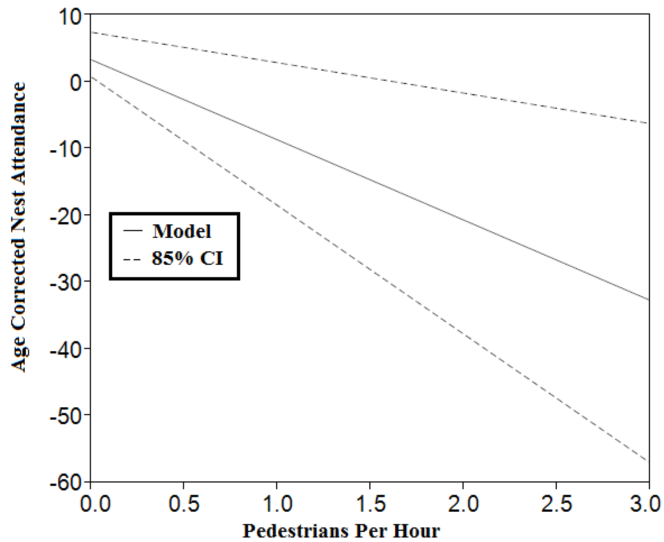


Figure 1.9. Nest-age corrected nest attendance predicted by Pedestrians Per Hour, during behavioral surveys (n = 68 surveys) of nesting golden eagles.

FLIGHT INITIATION RESPONSES OF GOLDEN EAGLES (*AQUILA CHRYSAETOS*) TO MOTORIZED AND NON-MOTORIZED RECREATION

Abstract

Behavioral studies of breeding birds can elucidate the temporal and spatial mechanisms of anthropogenic disturbance to wildlife. With rapid increases in outdoor recreation, and mounting evidence of effects to wildlife, public land managers and biologists need better information on the nature of this potential disturbance. We investigated the probability that an adult golden eagle (*Aquila chrysaetos*) would flush and we recorded flight initiation distances (FID) in response to motorized and non-motorized recreation. If an eagle was flushed from a nest, we also recorded the total time off the nest, to better understand nest exposure time resulting from recreation disturbance. In most (87.1%, n = 279) instances, adult eagles did not respond to recreationists passing within 1200 m. Flushing was more likely to occur if eagles were perched away from the nest than if eagles were at the nest. Eagles at the nest flushed 13 times (7%), at a mean distance of 449 m, and eagles perched away from the nest flushed 23 times (25%) at a mean distance of 506 m. Time off the nest averaged 56.3 minutes (SD = 82.4). FID was greater in the earlier portion of the breeding season, indicating that there may be seasonal changes in the costs and benefits of responding to disturbance. Type of recreation activity did not affect the probability of flushing or FID, but flushing occurred frequently (36%, n = 36) when motorized recreationists stopped and began walking near eagles. Recreationists on foot frequently go off trail, follow less predictable movement patterns than motorized recreationists, and may create greater perceived risk. Limiting motorized

and non-motorized recreation activities within 650 m and 1000 m of nest sites may decrease flushing events by 77% and 100%, respectively. Trail management efforts on public lands may strike a balance between the needs of recreationists and eagles by implementing “no-stopping” zones near known eagle nesting areas.

Introduction

Understanding the spatial and temporal patterns of anthropogenic disturbance, their effects on specific species, and the mechanism of their effect is important to wildlife managers (Gutzwiller 1991, Beale and Monaghan 2004). Wildlife responses to anthropogenic disturbance have been studied under multiple paradigms including risk avoidance (Frid and Dill 2002), physiological stress (Hayward et al. 2011), and altered sensory perception (Halfwerk et al. 2011), all of which can influence regular behavior patterns (Frid and Dill 2002). Disturbance has been shown to change habitat use of avian species (Gill and Sutherland 2000), interfere with their regular foraging ability (Fernandez-Juricic and Telluria 2000), alter regimes of self-maintenance (Kight and Swaddle 2007), and reduce parental care to young (Fernandez and Azkona 1993, Steidl and Anthony 2000). Disturbance ultimately can influence breeding success (Buick and Paton 1989, Brambilla et al. 2004, Watson et al. 2014). An individual may shift its behavior in response to disturbance before reproductive success suffers or otherwise suitable habitat becomes vacant (Gill 2007). However, shifting behavior to avoid perceived risks, and subsequently altering habitat use, may force an individual to make decisions that jeopardize fitness (Gill et al. 2001).

Flight initiation distance (FID), a measure of escape responses to disturbance stimuli, has been a common measure of sensitivity to anthropogenic disturbance in avian species because of its applicability across species and usefulness to wildlife managers (Stankowich and Blumstein 2005, Rodriquez-Pieto and Fernandez-Juricic 2005). Studies of alert distances, the distance at which species first show a behavioral response to disturbance, give more conservative estimates of responses to disturbance (Fernandez-Juricic et al. 2001) but it may not be practical to collect these types of data for all taxa. Alert distances and FID have been used by managers to set buffer distances around raptor nests with the assumption that limiting human activities within this buffer will reduce the likelihood of human disturbance impacts (Gonzalez et al. 2006).

Variation in the probability a bird flushes from a perch and variation in FID have been shown in multiple taxa (Rodgers and Schwikert 2002). A detailed examination of flush responses and FID in Spanish imperial eagles (Gonzalez et al. 2006) found variation among individuals, suggesting that individuals may vary in perceived risk or tolerance of disturbance stimuli. Additionally, the probability a bird flushes may change through the reproductive cycle, as parental investment increases throughout the breeding season, due to increased likelihood of success later in the breeding season (Clark and Ydenberg 1990, de Jong et al. 2013). Research has found greater FID and alert distances in larger avian species (Stankowich and Blumstein 2005, Blumstein et al. 2005), suggesting they may need larger buffer zones.

Golden eagles in southwestern Idaho had decreased productivity (young per territory) in areas impacted by increased OHV traffic (Steenhof et al. 2014). We found that eagles were less likely to lay eggs and had reduced nest survival at sites with higher pedestrian (walkers and runners) and off-highway vehicle volumes, respectively, compared to sites with lower recreation volume (Chapter 1). In addition, territories with high OHV use and trail densities were less likely to be occupied compared to territories with lower recreation use and trail densities (Chapter 1). Furthermore, nest attendance in the pre-breeding, incubation, and brooding periods was negatively associated with pedestrians (Chapter 1). These results suggest that buffer areas may be an important management tool to decrease the impact of recreation on nesting eagles.

We investigated the probability that a perched or nesting bird would flush and recorded the FID of eagles in response to motorized and non-motorized recreation activities to gain information about response distances and to inform management efforts in establishing buffers. We hypothesized that the probability of flushing and FID would vary by recreation type, behavior of bird (at the nest or not), and the time of year. Specifically, we predicted that birds would flush more often and at a further distance in response to non-motorized recreationists compared to motorized recreationists. We predicted that birds on nests would flush less often and at closer distances than birds perched away from the nest because of costs of decreased parental care. We predicted that birds would flush more often and at greater distances as recreationists increased on the landscape. We also investigated the total time spent off the nest, to assess the time nests are exposed during discrete, nest-associated flushing events.

Methods

We studied 23 historical golden eagle territories from 15 Jan to 6 July, during 2013 and 2014 in the Bureau of Land Management's Owyhee Field Office (OFO), in southwestern Idaho. Territories differed in the amount and type of recreation activity that occurred in the area within a variety of travel management units, including the Morley Nelson Snake River Birds of Prey National Conservation Area, the Murphy Travel

Management Plan (TMP), the Wilson Creek TMP, and areas without specific travel management designations (Figure 1.1). The study area included areas of predominantly OHV use (Murphy TMP), predominantly non-motorized use (Wilson Creek TMP), areas with mostly road vehicle traffic, and areas with very little recreation. All territories existed within a sagebrush (*Artemisia tridentata*) dominated, heterogeneous shrub-steppe community, in cliff-nesting habitat south of the Snake River, and along the northern front of the Owyhee Mountains.

Historical territories were surveyed for occupancy and nest initiation from mid-January through March, starting at the most recently occupied nest locations, then checking alternate nesting sites within all occupied territories as needed, in accordance with protocols outlined in Pagel et al. (2010), and supported by Steenhof and Newton (2007). Nest observations were made from standardized observation points, 600 m-1200 m away, to minimize the potential for researcher disturbance (Steidl et al. 1993, Gonzales et al. 2006, Pagel et al. 2010) and were made from a truck or pop-up hunting blind. At least two behavioral observations occurred on both weekend and midweek days, because recreation volume was higher on weekends compared to weekdays (Appendix). We recorded adult eagle behavior every five seconds and stratified them into the following categories: *Soaring*, *Attacking*, *Perched* (away from the nest, including preening), *Nest Maintenance*, *Copulation*, *Incubating*, *Brooding*, *Perched At the Nest* (including preening and shading), *Feeding* (actively feeding nestlings), *Defensive Posturing*, and *Absent*. For this project, *Nest Maintenance*, *Incubating*, *Brooding*, *Perched At the Nest*, *Feeding*, and *Defensive Posturing* were behaviors observed at the nest and *Soaring*, *Attacking*, *Perched*, and *Copulation* were behaviors observed away from the nest.

During behavioral observations, we identified all-terrain vehicles (*ATV*s), rock crawler/utility terrain-vehicles (*UTV*), *Dirt Bikes*, truck/SUVs (*Trucks*), *Mountain Bikes*, Horseback riders (*Horses*), and Pedestrians (*PEDs*) and tallied all recreationists within 1200 m of the nest. Measurements establishing the distance of the recreationist to the nest were based on a GIS database, containing all trails within the study site (BLM-OFO, unpublished data) and their proximity to all nests, to minimize potential error of field-based measurements. We recorded the position of all *perched* eagles in the field, using Garmin® GPSmap 62stc GPS units, and used these points to estimate the distance between recreationists and eagles. If the recreationist passed an eagle under observation within 1200 m, but was greater than 1200 m from the nest, we documented the closest distance it passed to the bird. We recorded whether an eagle flushed and estimated FID based on the location of the recreationist along the trail, in relation to the location of the perched or nesting eagle. If an eagle was flushed from the nest, surveys continued until the eagle returned to the nest and resumed its pre-disturbance activity. This length of time is described as the total time off the nest.

Statistical Analysis

We categorized recreationists into 4 groups based on presence or absence of motors and trail use patterns: 1) *OHVs* (all ATVs, UTVs, and dirt bikes) had motors and most often used trails, but occasionally did not, 2) *Road Vehicles* (all SUVs, Trucks, and passenger vehicles) had motors and stayed on trails, 3) *Non-Motorized Riders* (Horse and Mountain Bikes) had no motors and most often stayed on trails, but occasionally did not, and 4) *Pedestrians* that had no motor and often went off trail.

We used a generalized linear mixed-effect model (GLMM), with a binomial distribution and a log link, and territory as a random effect to assess the factors that affected whether eagles flushed (package “lme4”, R 3.1.1). We used AICc model selection framework (Burnham and Anderson 2002), and tested 4 predictor variables: 1) *At_Nest*, whether the eagle was at the nest or not, 3) *Rec_Dist_to_Bird*, the distance between the eagle and the recreationist, 3) *Rec_Category*, the category of recreationist (*OHV*, *Non-Motorized Rider*, *Road Vehicle* or *Pedestrian*), and 4) *Julian_Date*.

We assessed normality of FID using Shapiro-Wilks normality tests. We used a linear mixed-effect model (LMM), with territory as a random effect, to assess whether 1) *Rec_Category* or 2) *Julian_Date* affected FID of eagles (package “lme4”, R 3.1.1). We assessed FID of eagles at the nest, and FID of eagles perched away from the nest in separate analyses because date and whether they were at the nest were confounded (more birds were at the nest later in the season).

Results

We observed 279 recreation parties passing perched or nesting eagles. Most recreationists (87 %) passed perched or nesting eagles without inducing a flush response. Eagles were 8.6 times more likely to flush when they were perched away from the nest, compared to when they were at the nest. Distance to recreationist, date, and recreation category did not explain probability of flushing (Table 2.1). Flush responses were elicited by all recreation types, except non-motorized riders (Figure 2.1), but we witnessed only 14 instances of non-motorized riders passing eagles, and non-motorized riders tended to pass at a greater distance than other groups (mean distance of 582.8 m (SD = 319.1 m)), so the estimate of effect may be biased low. Many (36% of 36) flushing instances occurred when recreationists stopped motorized activities near an eagle and either became pedestrians, or changed direction of their motorized behavior abruptly.

We observed 187 recreation parties passing within 1200 m of eagles on a nest, at a mean distance of 434 m (SD = 269 m); eagles at the nest flushed 13 times (7%), at a mean distance of 449 m (SD = 311 m, min = 110 m, max = 1000 m). Shapiro–Wilks normality tests found FID of nesting eagles to be non-normally distributed ($W = 0.8525$, $p = 0.031$, Figure 2.2). Recreationists passed eagles perched away from the nest 92 times at a mean distance of 668 m (SD = 266 m), and eagles flushed 23 times (25%), at a mean distance of 506 m (SD = 342 m, min = 300, max = 1300 m). Shapiro–Wilks normality tests found FID of eagles perched away from the nest to be non-normally distributed ($W = 0.8525$, $p = 0.039$, Figure 2.3).

Recreation Category did not affect FID of eagles at the nest or away from the nest (Table 2.2 and 2.3). *Julian_Date* was negatively associated with FID, resulting in shorter FIDs later in the breeding season. There were similar effects of *Julian_Date* on FID when eagles were at the nest ($\beta = (-2.652)$, 85% CI = -4.618, -0.448, Figure 2.4) or perched away from the nest ($\beta = (-2.525)$, 85% CI = -4.618, -0.407, Figure 2.5).

Of 13 instances where eagles were flushed from the nest, the nest was left unattended with eggs or young in it 10 times. Total time off the nest averaged 57.2 min (SD = 86.8, min = 3.9 min, max = 286.2 min). Shapiro–Wilks normality tests found total time off the nest to be non-normally distributed ($W = 0.6505$, $p = 0.0001$, Figure 2.6).

Discussion

Golden eagles were most likely to flush if they were perched away from the nest, and less likely if they were at the nest. Eagles at the nest and eagles perched away from the nest flushed at a greater distance early in the breeding season. Reduced likelihood of flushing when at the nest may be explained by a high level of investment in the nesting attempt. The greater FID during the early season may suggest eagles are more responsive to disturbance early in the season compared to later in the season. This result is consistent with theory about eagle sensitivity to disturbance during nest initiation and egg-laying (Watson 2010). Alternatively, nesting eagles may have a shorter FID when they are incubating or brooding, because of increased costs associated with egg failure or nestling exposure, respectively. As the distance between the recreationist and the bird was not found to be associated with the likelihood of flushing, there seems to be evidence of variation in responses between eagles in this study. This suggests there is some variation in tolerance, or potential habituation to recreation among eagles. There was no significant difference in flushing probability or FID among any of the recreation categories, suggesting either a lack of effect, or a lack of power to detect such a difference. However, total time spent at nest, probability of egg-laying, and nest survival are all affected by different types of recreation (Chapter 1). This may suggest assessments of flushing are not a strong indicator of the full impacts of recreation disturbance to golden eagles.

Many recreationists passed by eagles without eliciting a flush response, but eagles often flushed when motorized recreationists stopped, and either changed their behavior or became pedestrians. This result suggests that the presence of the human form represents a perceived threat to eagles, beyond typical motorized activities. This may suggest eagles have some ability to tolerate repeated and predictable vehicular disturbance, but exhibit a general wariness of the less predictable human form. OHVs and trucks observed in this study rarely went off trail, and generally passed through an eagle territory within a few minutes. Pedestrians, however, frequently went off trail, meandered, lingered in an area, or even directly approached eagles. Direct persecution and harassment by illegal shooting continues to threaten golden eagles. Some eagles may have had encounters that make them wary of pedestrians; differences in experience between individuals may result in some eagles being more wary of disturbance than others.

Research on anthropogenic disturbance to wildlife has led to the recommendation of buffer zones (or setback distances) and seasonal restrictions of human activities near key wildlife habitat. Buffer zones have emerged as a common wildlife management technique around sensitive species (Rodgers and Schwikert 2002, Fernandez-Juricic 2005), and are often used around raptor nests (Knight and Skagen 1988, Knight and Gutzwiller 1995, Klute 2008). Gonzales et al. (2006) demonstrated that pedestrian disturbance to Spanish imperial eagles (*Aquila adalberti*) can affect behavior and reproduction and suggest that a minimum buffer of 500 m should be maintained around nests to reduce direct behavioral disturbance. Stiedl and Anthony (2000) recommended seasonal buffers near nesting bald eagles (*Haliaeetus leucocephalus*) to prevent boaters and campers from adversely affecting feeding allocation behavior. Seasonal restrictions of rock climbing near peregrine falcon (*Falco peregrinus*) aeries have been implemented in some areas because climber disturbance can reduce nest success and potentially expose young to increased predation (Brambilla et al. 2004). Breeding season buffer zones around raptor nests have been developed and implemented on many federal and state lands, and typically regulate natural resource extraction, energy or road development, but do not manage for motorized or non-motorized recreation activities. Such management of human activities around nests sites of “sensitive” raptor species may not consider the full suite of behavioral responses or fitness consequences (Gill et al. 2001) associated with disturbance. If management efforts focus only on nest site protection, other aspects of daily behavior may still be disturbed. For example, if eagles are being displaced from key hunting areas, it may hinder their ability to forage effectively and provide for an incubating mate or nestlings. The increased likelihood of eagles flushing when perched away from the nest may suggest that recreation disturbance exists throughout an entire eagle territory, not just at nest sites (Tarjuelo et al. 2015). However, when considering the time off the nest following flushing events, it is clear that an eagle nest may be exposed for a considerable amount of time following recreation disturbance.

Management Implications and Recommendations

Considering current and future conservation concerns regarding golden eagle management in the continental US (Kochert and Steenhof 2002, Hoffman and Smith 2003, Dahl et al. 2012), enhanced conservation and management of eagle habitat and nesting sites is important. Balancing the mandates of multiple uses on public lands remains a difficult challenge for public land managers. Golden eagles in the US are currently protected from activities that may disturb regular nesting activities (The Bald and Golden Eagle Protection Act [16 U.S.C. 668-668c]). Reducing the potential of eagle-human encounters through the use of permanent or seasonal trail closures may benefit eagle productivity. The results of this study suggest that trail-free buffer zones around nests may reduce nest site disturbance. With a buffer zone of 650 m around nest sites, 77% of nest flushes observed in this study may have been avoided, and may serve as a good buffer zone for recreation activities. With a buffer zone of 1000 m, 100% of nest flushes would be have been avoided, and may serve as a conservative buffer zone. As

FID was greater in the earlier portion of the nesting season, and eagles are more susceptible to nest site disturbance during nest initiation, a buffer greater than 650 m may be prudent. Establishing nest site buffer zones would be especially beneficial during this early portion of the nesting season.

Setting permanent trail closures, establishing buffer zones, and implementing seasonal restrictions of trail use may prove to be effective strategies for managing recreation around eagle nests, but such policies will likely be controversial in some high use recreation areas. The inherent value and long-term sustainability of any conservation initiative directed towards eagle management on public lands will be most successful with public support. One option for achieving this may be the implementation of “no-stopping” zones, where off-highway recreation is permitted, but recreationists are asked to continue moving during the eagle breeding season. One risk of this potential strategy is that nest locations may become public knowledge, because of excessive signage in the area, and ultimately face increased disturbance. Signage could be placed at the beginning of trails that pass within 650 m of eagle nests, in a way that does not explicitly reveal the location of the nests. A combination of management strategies will be most effective if implemented with local recreationists and eagles in mind, by encouraging public involvement in policy design and implementing the best available science. Maintaining existing, relatively recreation-free eagle territories, by limiting the expansion of new trails, would help reduce disturbance to remote nesting sites. Conservative trail closures, increased enforcement of existing trail regulations, and management that considers the full length of the eagle breeding season, would all help reduce negative human-eagle interactions.

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Tables and Figures

Table 2.1. AICc table assessing human-eagle interactions on the probability of an eagle flushing in response to a passing recreationist[a] (n = 292).

Model	***K***	**ΔAICc**	**Cum.w_i**
At_Nest	3	0.00	0.91
Rec_Category	5	4.74	1.99
Rec_Dist_to_Bird	3	13.17	1.00
Intercept	2	14.45	1.00
Julian_Date	3	16.48	1.00

*AIC of top model = 195.60. [a]All models included the random variable of Territory

Table 2.2. AICc table assessing human-eagle interactions on the Flight Initiation Distance (FID) of eagles at the nest, in response to a passing recreationist[a] (n = 13).

Model	***K***	**ΔAICc**	**Cum.w_i**
Intercept*	3	0.00	0.66
Julian_Date	4	1.55	0.96
Rec_Category	5	5.67	1.00

*AICc of top model = 183.86, [a] All models included the random variable of Territory

Table 2.3. AICc table assessing human-eagle interactions on the Flight Initiation Distance (FID) of eagles perched away from the nest, in response to a passing recreationist[a] (n = 23).

Model	***K***	**ΔAICc**	**Cum.w_i**
Intercept*	3	0.00	0.50
Julian_Date	4	0.08	0.98
Rec_Category	5	6.04	1.00

*AICc of top model = 514.68, [a] All models included the random variable of Territory

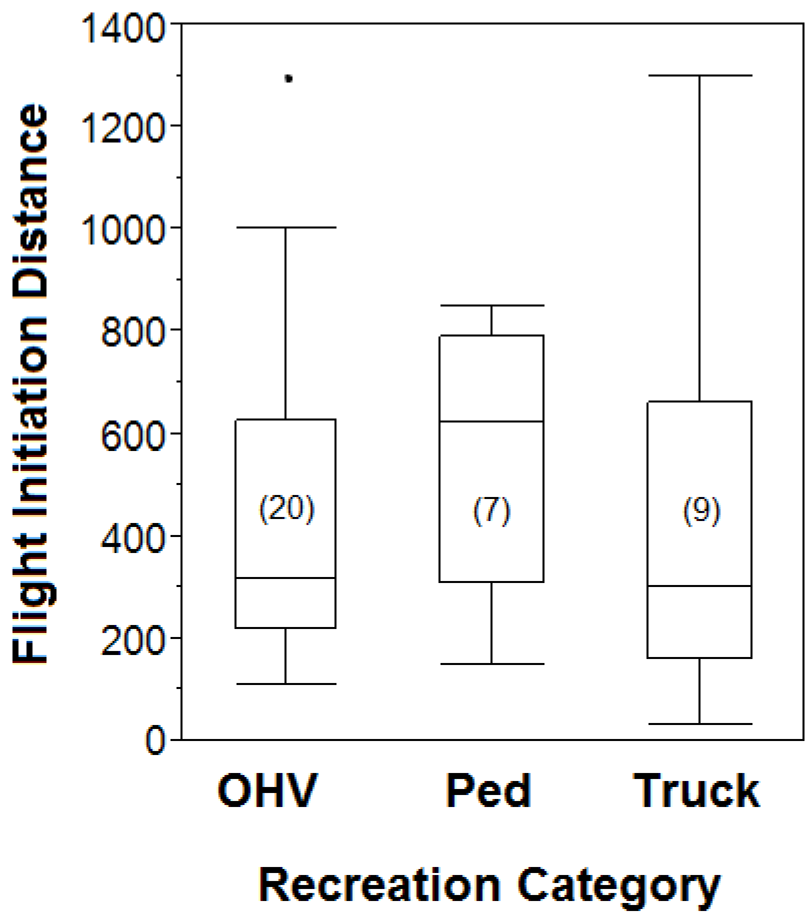

Figure 2.1. Flight Initiation Distance (FID) of golden eagles in response to different recreation categories. Sample sizes of each recreation category are shown in parentheses above each box plot. No flush responses were observed in response to non-motorized recreation activities.

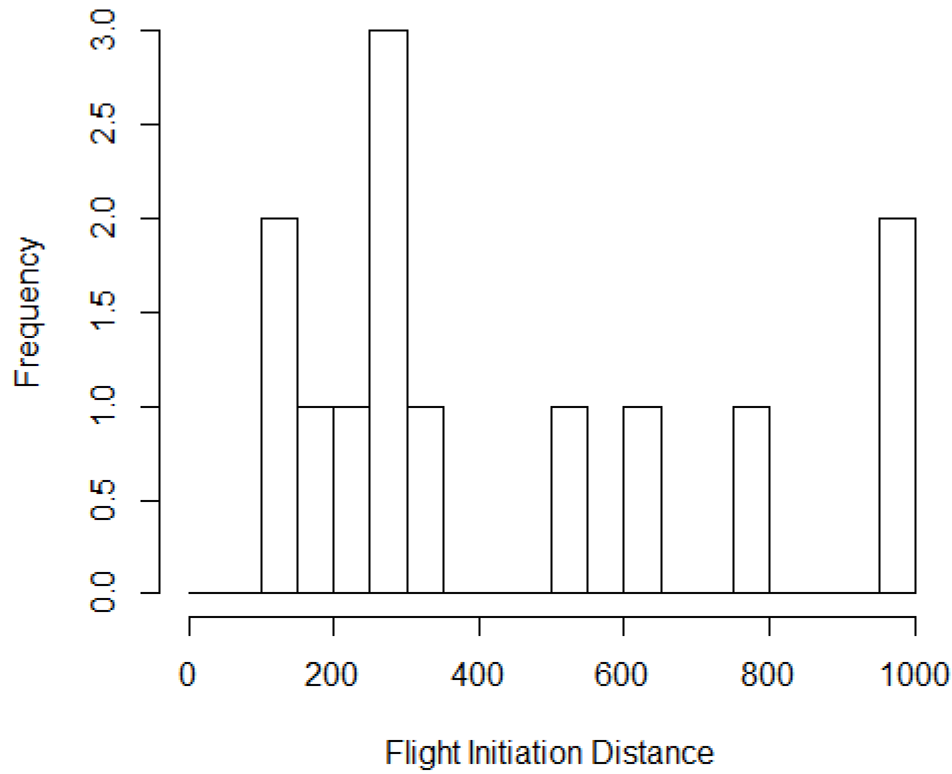

Figure 2.2. Histogram of Flight Initiation Distance of golden eagles flushed from the nest (n= 13).

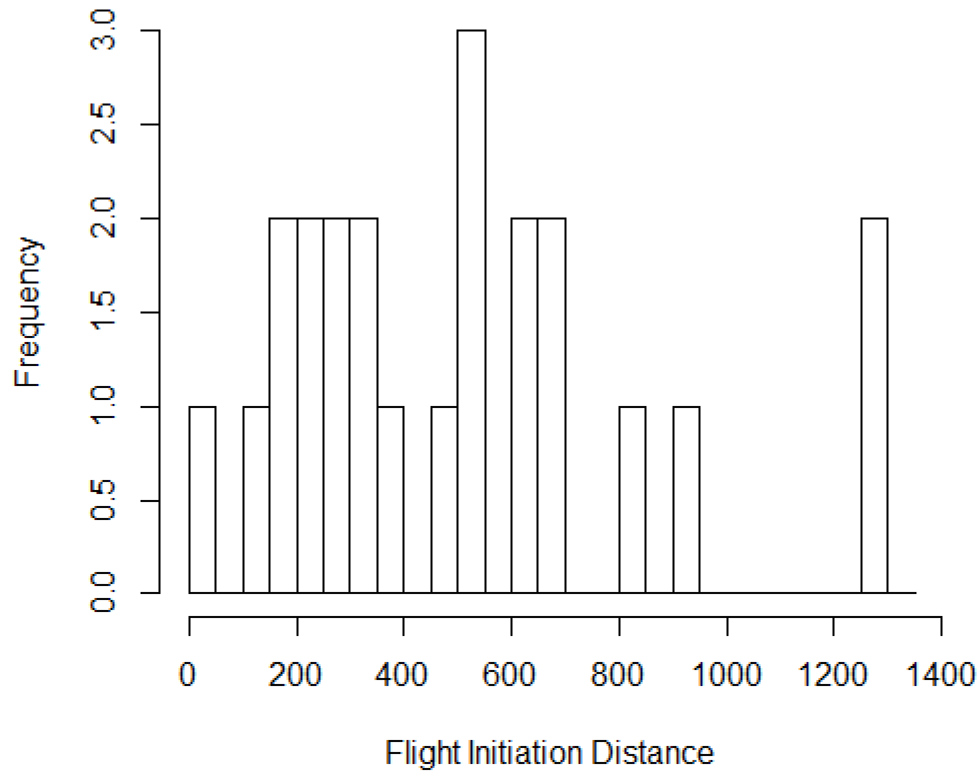

Figure 2.3. Histogram of Flight Initiation Distance of eagles flushed while perched away from the nest (n=23).

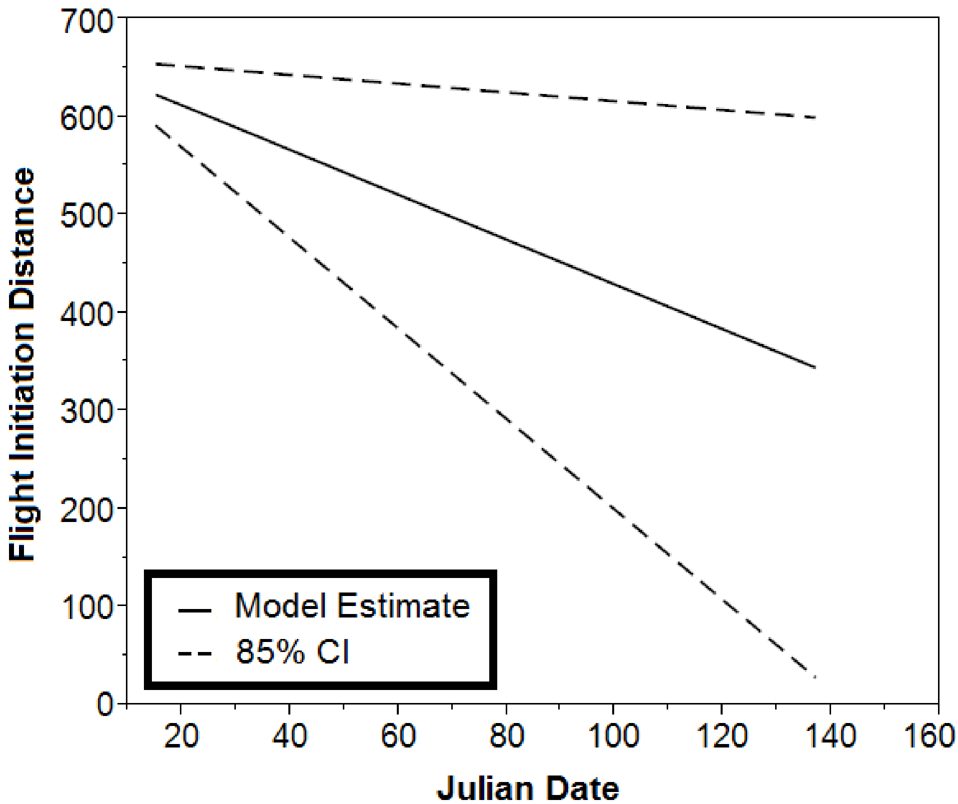

Figure 2.4. Model estimated relationship between Julian Date and Flight Initiation Distance, for eagles flushed from the nest (n = 13).

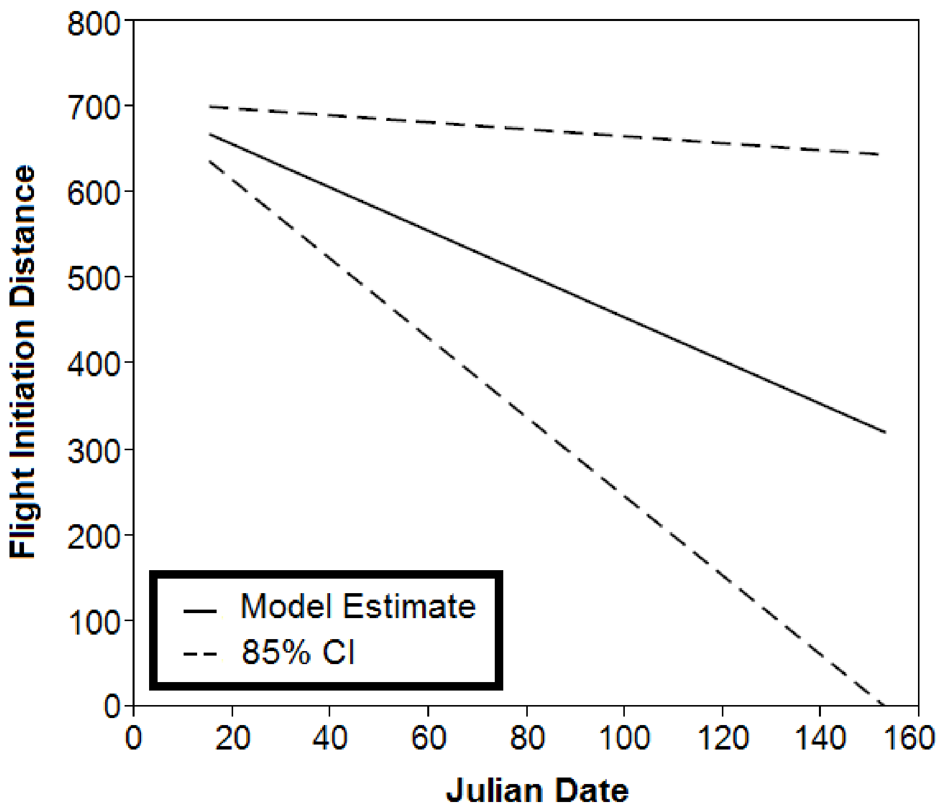

Figure 2.5. Model estimated relationship between Julian Date and Flight Initiation Distance, for eagles flushed while perched away from the nest (n = 23).

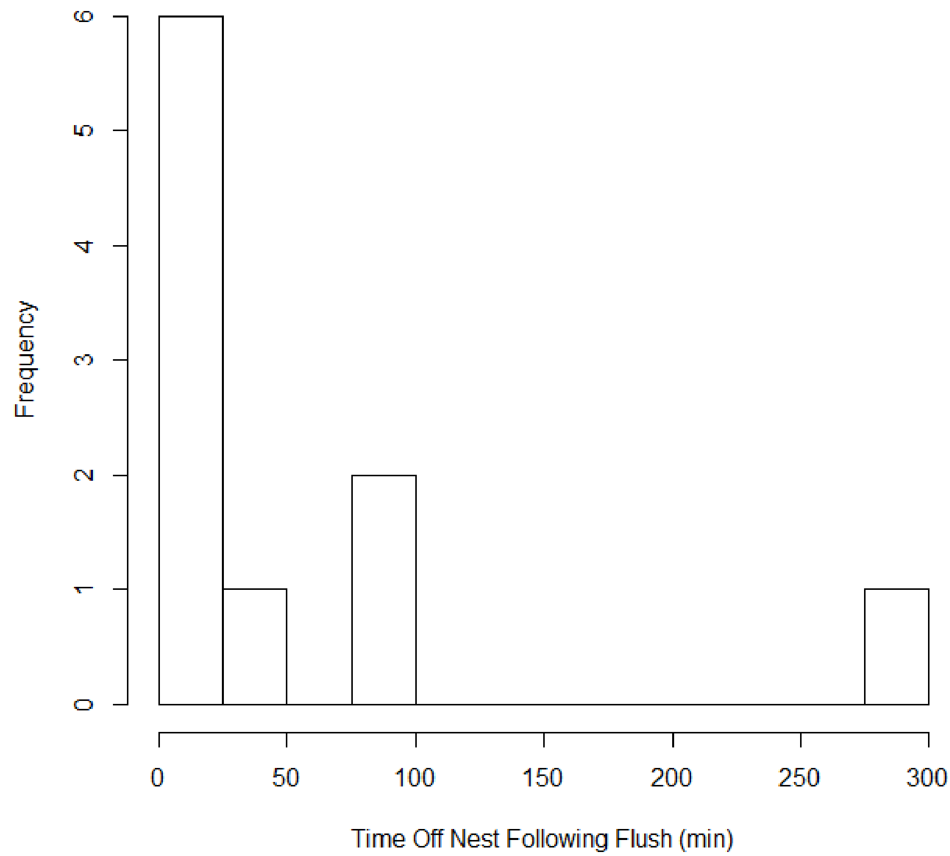

Figure 2.6. Histogram of Total Time Off the Nest, following a nest-associated flushing event (n=11).

APPENDIX

Methods of Statistical Analysis for Trail Camera Data Assessing Temporal Trends in Recreation Activity on Golden Eagle Territories in Southwestern Idaho

Introduction

Contained in this appendix are the methods of statistical analysis for trail camera data assessing temporal trends in recreation activity on golden eagle territories in southwestern Idaho. See the primary manuscript for a full description of field methods used for camera placement.

Statistical Analysis - Temporal Trends in Recreation Activity

Trail camera surveys lasted for $\bar{x}$ = 9.4 days (SD = 2.0, n = 221) and each territory was surveyed for $\bar{x}$ = 47.2 days (SD = 6.9, n = 44) per season between 15-Jan and 6-Jul. We removed the data from the first and last day of each survey from this analysis, so that all days would be full 24-hr records. We used generalized linear mixed models (GLMMs) in R 3.1.1 (R Core Team 2014), in package “lme4” (Bates et al. 2014), with a Poisson distribution, with territory as a random variable, to assess temporal variation in recreation volume across the entire breeding season. Trail camera survey days (n = 1861) were categorized into midweek (n = 1359 trail camera days) and weekend days (n = 502 trail camera days), and then assigned a Julian Week. We created separate models for recreation volume during midweek and weekend days. We assessed the influence of Julian Week and (Julian Week)2, on the volume of each recreation type and identified the best explanatory models using AICc model selection (Burnham and Anderson 2002), and assessed 85% confidence intervals on all parameters (Arnold 2010).

Results

Second order models, with a random variable for territory, with additive effects of Julian Week and (Julian Week)2, were the best predictors of recreation volume for all recreation types, on both midweek and weekend days (Tables A.1-A.8). Model estimates of OHV and road vehicle use (Figure A.1), pedestrian and non-motorized use (Figure A.2), are shown from 15 Jan to 15 Jul.

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Tables and Figures

Table A.1. AICc table showing the candidate models predicting OHVs per Weekend day per trail (n=502)[a]. Top model: *OHVs_day* = -7.605 (± .576) + *Julian_Week* * 0.499 (± 0.036) + $Week^2$ * -3.180 (± 0.229).

Model	***K***	**ΔAICc**	**Cum.w_i**
Week + $Week^2$*	4	0.00	1.00
$Week^2$	3	237.17	1.00
Intercept	2	239.38	1.00
Week	3	240.53	1.00

*AICc of top model = 2079.98

[a] All models included the random variable of Territory

Table A.2. AICc table showing the candidate models predicting OHVs per <u>Midweek</u> day per trail (n=1359)[a]. Top model: *OHVs_day* = -9.324 (± .828) + *Julian_Week* * 0.486 (± 0.052) + *Week*^{2} * -2.860 (± 0.316).

Model	***K***	**ΔAICc**	**Cum.w_i**
Week + Week^2*	4	0.00	1.00
Week	3	98.92	1.00
Intercept	2	105.92	1.00
Week^2	3	106.90	1.00

*AICc of top model = 1900.76

[a] All models included the random variable of Territory

Table A.3. AICc table showing the candidate models predicting Pedestrians per Weekend day per trail (n=502)[a]. Top model: *PEDs_day* = 1.165 (± .661) + *Julian_Week* * -0.260 (± 0.036) + $Week^2$ * 1.162 (± 0.262).

Model	***K***	**ΔAICc**	**Cum.w_i**
Week + $Week^2$*	4	0.00	1.00
Week	3	16.57	1.00
$Week^2$	3	48.12	1.00
Intercept	2	159.13	1.00

*AICc of top model = 1481.40

[a] All models included the random variable of Territory

Table A.4. AICc table showing the candidate models predicting Pedestrians per Midweek day per trail (n=1359)[a]. Top model: *PEDs_day* = -11.627 (± 1.342) + *Julian_Week* * 0.493 (± 0.079) + *Week*^{2} * -3.090 (± 0.499).

Model	***K***	**ΔAICc**	**Cum.w_i**
Week + Week^2*	4	0.00	1.00
Intercept	3	46.54	1.00
Week	2	46.54	1.00
Week^2	3	28.54	1.00

*AICc of top model = 1232.13
[a] All models included the random variable of Territory

Table A.5. AICc table showing the candidate models predicting Road Vehicles per <u>Weekend</u> day per trail (n=502)[a]. Top model: *Rd_Veh_day* = -3.658 (± .447) + *Julian_Week* * 0.209 (± 0.022) + $\boldsymbol{Week^2}$ * -1.397 (± 0.149).

Model	***K***	**ΔAICc**	**Cum.w_i**
Week + $Week^2$*	4	0.00	1.00
Intercept	2	92.12	1.00
Week	3	92.23	1.00
$Week^2$	3	93.53	1.00

*AICc of top model = 1934.55
[a] All models included the random variable of Territory

Table A.6. AICc table showing the candidate models predicting Road Vehicles per Midweek day per trail (n=1359)[a]. Top model: *Rd_Veh_day* = -3.912 (± .442) + *Julian_Week* * 0.160 (± 0.018) + *Week*^{2} * -1.136 (± 0.116).

Model	***K***	**ΔAICc**	**Cum.w_i**
Week + Week^2*	4	0.00	1.00
Week^2	3	87.17	1.00
Week	3	99.34	1.00
Intercept	2	100.19	1.00

*AICc of top model = 3513.91

[a] All models included the random variable of Territory

Table A.7. AICc table showing the candidate models predicting Non-Motorized riders per <u>Weekend</u> day per trail (n=502)[a]. Top model: *No_Motors_day* = -14.559 (± 1.794) + *Julian_Week* * 0.499 (± 0.064) + *Week*^{2} * -3.466 (± 0.456).

Model	*K*	ΔAICc	Cum.w_i
Week + Week^2*	4	0.00	1.00
Week^2	3	60.37	1.00
Week	3	73.83	1.00
Intercept	2	80.77	1.00

*AICc of top model = 823.30
[a] All models included the random variable of Territory

Table A.8. AICc table showing the candidate models predicting Non-Motorized riders per Midweek day per trail (n=1359)[a]. Top model: *No_Motors_day* = -8.982 (± 1.262) + *Julian_Week* * 0.339 (± 0.077) + *Week*^{2} * -2.270 (± 0.513).

Model	***K***	**ΔAICc**	**Cum.w_i**
Week + Week^{2}*	4	0.00	1.00
Intercept	2	19.80	1.00
Week^{2}	3	21.47	1.00
Week	3	21.61	1.00

*AICc of top model = 898.88

[a] All models included the random variable of Territory

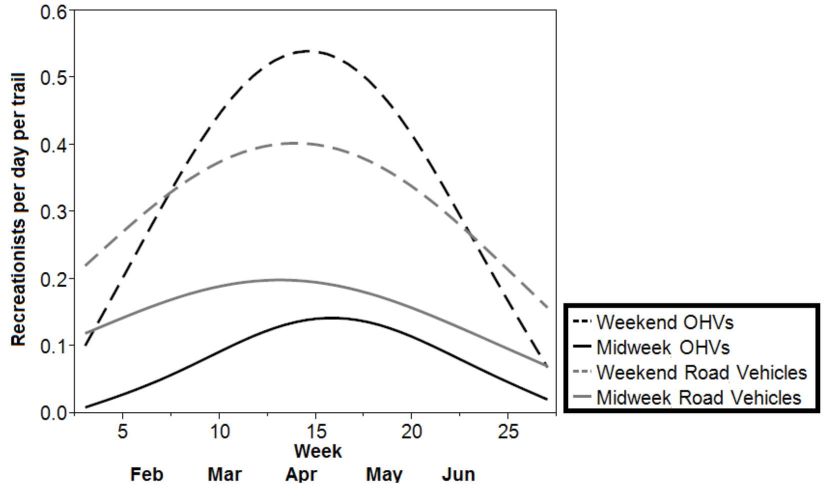

Figure A.1. Breeding season trends in motorized recreation traffic per day, per trail, across 23 Golden eagle territories. Data is predicted by generalized linear mixed models, with a random variable for Territory + Julian Week + (Julian Week)^2.

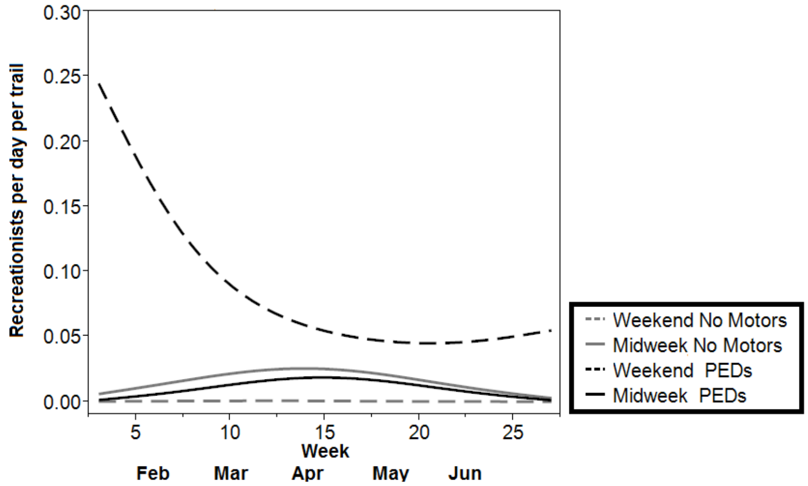

Figure A.2. Breeding season trends in Non-Motorized and Pedestrian recreation traffic per day, per trail, across 23 Golden eagle territories. Data is predicted by generalized linear mixed models, with a random variable for Territory + Julian Week + (Julian Week)^2.

Conclusion

When assessing human disturbance impacts to wildlife, it is best to examine a variety of spatial and temporal patterns of human activity and a wide breadth of potential responses in the study species. With this information, conservation biologists have an improved ability to determine the potential mechanisms of disturbance, and more completely understand the consequences of such activities. This research aimed to achieve these goals in a dynamic recreational use landscape, and successfully identified not only the consequences of recreation to breeding golden eagles, but also the behavioral mechanisms by which disturbance events occur. By monitoring eagle behavior, we have identified that eagle nest attendance is reduced in the presence of the unpredictable human form, separate from a motorized vehicle. By monitoring immediate eagle responses to passing recreationists, or lack thereof, we have identified that most trail based activities do not cause flush responses in eagles, and gained valuable insight into the distance at which recreation disturbance does occur. Furthermore, we have learned that nest site disturbance is not the only form of disturbance impacting eagles in this landscape, as perched eagles are significantly more likely to flush than those at the nest. This knowledge shows that further research into the foraging and habitat use of eagles in disturbed landscapes is needed. Research investigating habitat degradation in response to outdoor recreation and the consequences to eagle prey species is critical for a more complete understanding of the influence of outdoor recreation on eagles. Nonetheless, with a better understanding of the effects of direct disturbance, wildlife biologists in this study area, and in other similar systems, may be able to implement meaningful management strategies aimed towards eagle conservation.

While this research challenges common misconceptions that quiet, human-powered recreation is less detrimental to wildlife than is motorized recreation, it also supports a growing body of research that suggests the opposite may be true in some ecosystems (Reed and Merenlender 2008). By extending existing trail closures to include pedestrian and non-motorized users, eagle disturbance during nest initiation may be significantly reduced. By encouraging motorized users to continue riding when near eagle nests, eagle disturbance during incubation and brood-rearing stages may be reduced. Mounting controversy and an adversarial relationship between the public and federal land managers may be detrimental to the broader goals of habitat conservation on public lands. The public perception of implementing arbitrary trail closures on public lands may strain this relationship further. The use of no-stopping zones may offer a tractable compromise to this issue, whereby less spatially restricted recreation can still occur on public lands, and eagle breeding productivity can still be maintained. However, research into Flight Initiation Distance shows that there is a threshold to how close even predictable recreation activities can be before disturbance becomes very likely. With that in mind, minimum buffer zones around eagle nests, at which no recreational activity is allowed, would be beneficial to eagle productivity. Further education and outreach to broaden public understanding of anthropogenic disturbance to wildlife may reduce controversy associated with such management actions.

References

Reed, S.E. and A. M. Merenlender. 2008. Quiet, nonconsumptive recreation reduces protected area effectiveness. *Conservation Letters*. 1 : 146-154.