Adaptive Management Strategy for Science-Based Stewardship of Recreation to Maintain Wildlife Habitat Connectivity

A report to the Sonoma Land Trust

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Executive Summary

Non-consumptive human recreation activity negatively affects wildlife individuals, populations, and communities on every continent and in every major ecosystem (Larson et al. 2016). To effectively balance goals for outdoor recreation access and species conservation, protected land managers need robust and locally-relevant monitoring of recreation visitation rates, activity types, and wildlife impacts to guide decisions regarding public access, trail design, and permitted uses. The purpose of this report is to communicate an adaptive management strategy to minimize the negative effects of recreation on wildlife species and maintain the ecological function and permeability of the regionally significant Marin Coast to Blue Ridge Critical Linkage (Penrod et al. 2013). Our specific objectives were to: 1) review the scientific literature for evidence regarding quantitative thresholds and management guidelines for reducing or mitigating negative effects of recreation on wildlife; 2) map recreation infrastructure and monitor current visitation rates to three target properties (Glen Oaks Ranch, Sonoma Developmental Center, Santa Rosa Creek Headwaters) and six comparison properties in Sonoma Valley; 3) recommend guidelines for stewardship of recreation to maintain wildlife habitat connectivity at the target properties; 4) describe a monitoring approach to assess future changes in recreation activity and detect potential effects on wildlife; and 5) recommend future research and other information needed to balance the public access and species conservation goals of protected lands.

Although the publication rate on the effects of recreation on wildlife has increased exponentially (Larson et al. 2016), quantitative thresholds of recreation effects are lacking for many species, taxonomic groups, and sources of disturbance (Chapter 2). Given important gaps in available knowledge, we recommend a precautionary approach that adopts maximum threshold values observed for relevant taxonomic groups, while excluding extreme outliers. Specifically, we recommend minimum thresholds for distance to trails of 75 m for passerine birds (e.g., pygmy nuthatch), 200 m for ungulates (e.g., mule deer), 400 m for apex predators (e.g., mountain lions), and 600 m for birds of prey (e.g., golden eagles) (Chapter 4). We also recommend that land managers should allow dogs only on leash and consider restricting dogs from trails near sensitive habitats to create larger buffers for wildlife.

Recreation visitation rates to the three target properties varied from no recreation detected on Santa Rosa Creek Headwaters to >56 visitors per day at the Sonoma Developmental Center (Chapter 3). As expected, recreation activity in each target property was lower than in their comparison properties, with the exception of Jack London State Historic Park. Current visitation to Sonoma Developmental Center is likely at or above sustainable levels to maintain wildlife habitat connectivity, especially in the eastern half of the property (Chapter 4). We recommend that recreation management of the western portion of SDC should follow current management of JLSHP and include efforts to reduce trail density and revegetate duplicative and social trails. The area of greatest concern for wildlife movement appears to be the boundary between the northeastern portion of SDC and southeastern portion of Sonoma Valley Regional Park (SVRP), where recreation visitation rates are currently higher than in any other properties investigated. In this area, we recommend restricting access across the boundary between the two properties, closing and revegetating duplicative trails, increasing enforcement of dog leash laws, and limiting visitation as needed through seasonal closures or restricted dog access.

For Glen Oaks Ranch, we recommend that visitation should no more than double, no new trails should be added, and access should be minimized in areas near Stuart Creek. Trail planning for Santa Rosa Creek Headwaters should consider effect-distance thresholds for wildlife and minimize the creation of social trails. Monitoring should continue for all study properties, to document whether recreation activity levels and wildlife habitat use are changing, and to inform adaptive management decisions to maintain the ecological function of the Sonoma Valley Wildlife Corridor (Chapter 5).

We conclude with recommendations for future research and other information needs to balance public access with wildlife conservation, particularly on lands that are managed for habitat connectivity (Chapter 6). Specifically, we recommend that protected area managers: 1) complete accurate maps of official trail networks and recreation infrastructure, plus unofficial social trails; 2) monitor recreation visitation patterns, including overall numbers of visitors, activity types, spatial distribution, and timing of visits; 3) compare the effects of different recreation activities on wildlife, to address user conflicts and inform decisions regarding permitted uses; 4) include reference conditions or control sites (i.e., protected lands with no public access) in study designs to establish a baseline for detecting potential effects of recreation on wildlife; and 5) empirically test or simulate realistic management alternatives, to assess their effectiveness for reducing or mitigating negative effects of recreation on wildlife.

1. Introduction: Effects of Recreation on Wildlife

Beginning with the U.S. National Park Service Organic Act (1916), most protected areas operate under a dual or multiple-use mandate to provide public access for outdoor recreation and other human activities, while also protecting wildlife species, habitats, and other natural resources. As a result, the vast majority of protected areas—95% of protected land area in North America, and a similar percentage around the world—are open to public access (Dudley 2008). Although it is reasonable to assume that smaller proportion of protected land is currently used for outdoor recreation and nature-based tourism, just 5% is formally closed to future use.

Access for outdoor recreation plays an essential role in generating political support and revenue for land conservation and management, and it generates important human health and economic benefits for local communities. The dual mandate of public access and resource protection is echoed in government programs (e.g., Land and Water Conservation Fund; Walls 2009) and local referenda (e.g., open space tax or bond initiatives; Kroetz et al. 2014). Proximity to and visitation of natural open spaces is positively associated with people's physical, psychological, and social well-being (Shanahan et al. 2015), and outdoor recreation generates $887 billion in consumer spending annually, supporting 7.6 million jobs and $125 billion in federal, state, and local tax revenue (OIA 2017).

Globally, protected areas receive an estimated eight billion visits per year, and visitation is increasing rapidly (Balmford et al. 2015). In the United States, outdoor recreation activity (i.e., visitor-days to federal public lands) increased by 40% in the last decade (Cordell 2012), and visitation to developed recreation sites is projected to increase from 190 to 246 million participants per year by 2030 (White et al. 2014). Protected areas are the primary strategy for conservation of global biodiversity. Consequently, because recreation and conservation objectives have been combined in the missions, management, and funding of protected areas, conservation success depends on the assumption that public access and species protection are compatible goals for conserved lands.

Over the past four decades, a growing body of research has demonstrated that quiet, non-consumptive recreation activities (e.g., hiking, bicycling, and wildlife viewing) can impact the behavior, habitat use, reproduction, and ultimately survival of individual animals and persistence of wildlife populations. A recent global systematic review of the effects of recreation on wildlife documented widespread and broadly negative effects on a wide variety of animal species in many different environments around the world (Larson et al. 2016). Most (93%) published studies documented at least one statistically significant effect of recreation on wildlife, and nearly two-thirds (60%) of those effects were clearly negative. Negative effects included declines in species diversity (Miller et al. 2003), increased flight or stress responses (Jayakody et al. 2008; Maréchal et al. 2011; Deng et al. 2014), decreased survival and reproduction (Iverson et al. 2006; Baudains & Lloyd 2007; Uyarra & Côté 2007; Kerbiriou et al. 2009), and decreased population abundance (Miller et al. 1998; Bejder et al. 2006; Patthey et al. 2008; Zhou et al. 2013; Cowling et al. 2015). Many animal species react to human disturbance from recreation in a similar manner as predation risk, meaning that animals may exhibit increased stress hormones in their blood or reduce time spent on important behaviors such as foraging or caring for young (Frid & Dill 2002; Lenth et al. 2008).

All recreation activities included in the systematic review exhibited greater evidence for negative effects versus positive or unclear effects (Larson et al. 2016). However, one surprising result was that studies of hiking and other non-motorized recreation activities observed negative effects on wildlife more frequently than studies of motorized activities. Although this review may not fully capture the impacts of motorized recreation on other resources (e.g., soils or vegetation), it reveals that non-motorized activities have a similar if not greater potential to disrupt individual animals and wildlife populations as do motorized activities. A second intriguing result was that studies of snow sports observed negative effects on wildlife more frequently than studies of other terrestrial or aquatic recreation activities. However, relatively few studies have been conducted of snow sports, suggesting a need for more research to understand how animals respond to recreation in alpine environments or during sensitive winter seasons.

Although there are important knowledge gaps about several taxonomic groups and regions of the world, what is clear from the preponderance of articles reviewed by Larson et al. (2016) is that non-consumptive recreation is not simply a neutral form of human land use, but has wide ranging and at times profound effects on wildlife individuals, populations, and communities. Negative effects of recreation on wildlife have been observed on every continent and in major ecosystem on Earth, and these impacts are increasingly recognized as a threat to global biodiversity. However, findings vary widely among individual studies that focus on a single ecosystem, group of species, or type of impact, including some recent studies that have observed limited effects of recreation on animal communities (e.g., Kays et al. 2017; Reilly et al. 2017). Accordingly, questions remain about the consistency and magnitude of the effects of recreation across species and among different types of recreation activities.

To address this knowledge gap, Larson et al. (unpublished data) are currently conducting a meta-analysis to examine the magnitude of differences in vertebrate richness and abundance in response to variable levels of recreation use. Meta-analysis is increasingly popular in ecology and conservation as a tool to synthesize evidence across many individual studies and explore large-scale patterns (Stewart 2010; Haddaway 2015). Meta-analyses combine data from similar individual studies to determine an overall effect size, which can increase precision of existing estimates or detect previously undetected effects because of the larger sample size of the combined dataset (Stewart 2010). This can be particularly useful in situations where variability among studies is high and can help to identify trends that transcend geographic areas or species (e.g., Gardner et al. 2003).

Preliminary results of the meta-analysis indicate statistically significant and negative overall effects of recreation activity on vertebrate species richness and abundance (**Fig. 1.1**). Within taxonomic groups, significant negative effects of recreation were observed for bird species richness and mammal population abundance. Additionally, effect sizes were much larger for negative effects of recreation on vertebrate species richness in terrestrial (-0.86 ± 0.57) than in aquatic environments (-0.29 ± 0.78), and larger for negative effects of recreation on vertebrate abundance in terrestrial (-0.52 ± 0.38) than in aquatic environments (0.25 ± 0.86). These findings build upon a previous meta-analysis of the effects of winter recreation, which documented significant negative effects of recreation on species richness and diversity but not on abundance (Sato et al. 2013).

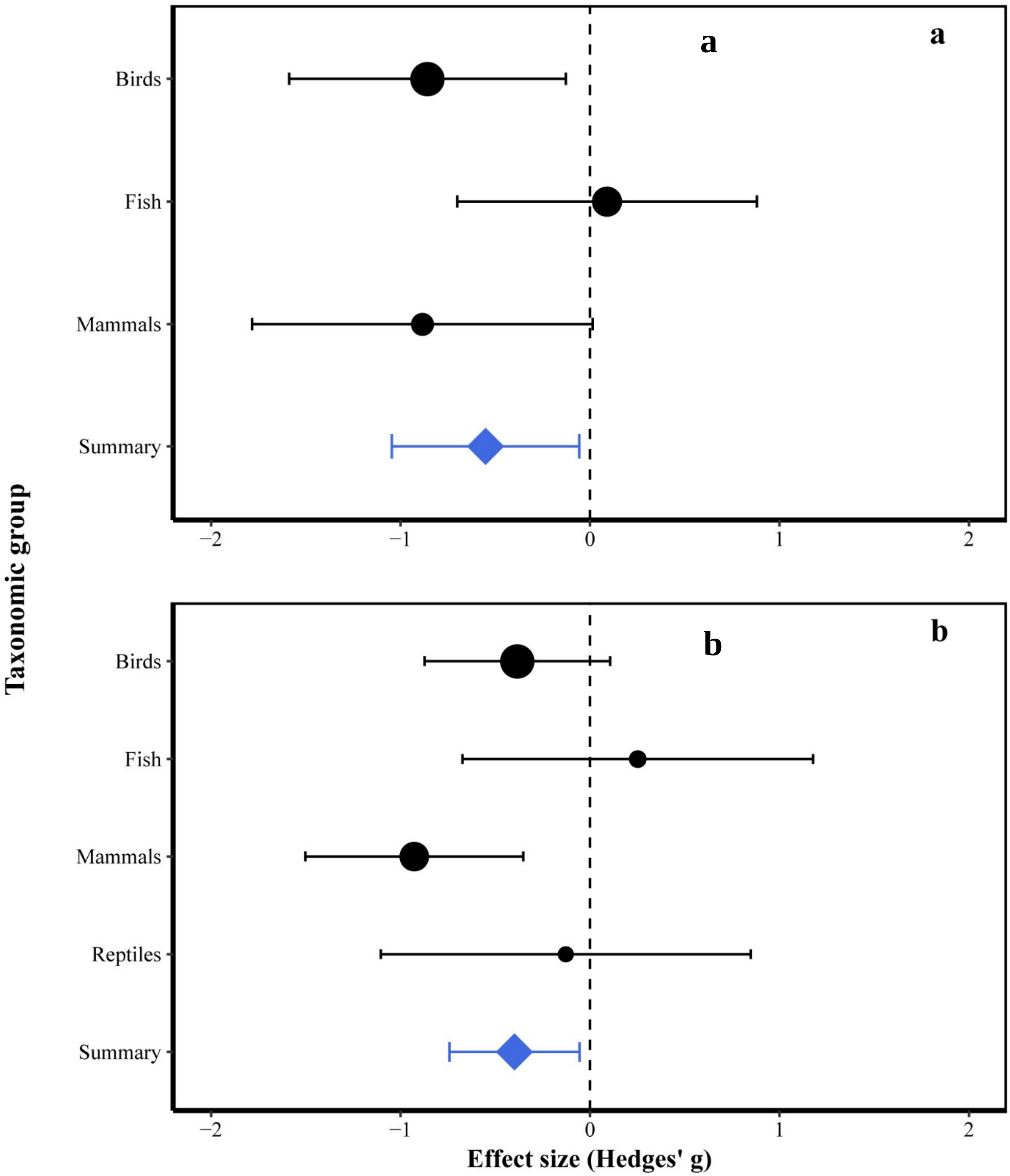


Figure 1.1 Effect sizes (Hedges' g ± 95% CI) of recreation on a) species richness of birds (n=7 studies), fish (n=8), mammals (n=3), and all vertebrates (n=18); and b) population abundance of birds (n=29), fish (n=12), mammals (n=29), reptiles (n=4), and all vertebrates (n=74).

To successfully balance the public access and species conservation goals of protected lands, landowners and managers need locally-relevant scientific information at appropriate spatial and temporal scales (Hadwen et al. 2007). This information is important to guide decisions regarding recreation access and permitted uses, and to increase support for and compliance with management decisions by recreationists. Understanding the frequency, timing, and location of visitors in protected lands can help managers to identify areas with high levels of use, establish thresholds for management, and monitor compliance with regulations (Cessford & Muhar 2003; Hadwen et al. 2007). Together with scientific expertise regarding the impacts of recreation on wildlife, this information can be used to minimize negative effects of recreation and improve the permeability of protected lands.

The purpose of this report is to communicate an adaptive management strategy to minimize the negative effects of recreation on wildlife species and maintain the ecological function and permeability of the regionally significant Marin Coast to Blue Ridge Critical Linkage (Penrod et al. 2013). In addition, the report provides a starting point for generating science-based recommendations for how to balance public access with wildlife conservation, particularly on lands that are managed for habitat connectivity. Results of the project will be communicated broadly to landowners, land trusts, and natural resource management agencies for application to protected lands within and outside of the study region.

2. Literature Review of Quantitative Thresholds

Introduction

Human disturbance to wildlife is widely recognized for its deleterious effects on the physiology, behavior, and demography of individual animals, wildlife populations, and communities (Steven & Castley 2013; Coetzee & Chown 2016). Sources of these impacts vary widely and include direct effects such as mortality from hunting and road kill (Scillitani et al. 2010) and indirect effects such as avoidance of hikers, dogs and boat traffic (Cowling et al. 2015; Tarjuelo et al. 2015). Whereas the direct effects of human disturbance on animal populations and communities are more apparent, indirect effects are less easily identified or separated from other environmental factors. An increasing body of research has focused on the indirect effects of human disturbance from outdoor recreation (Larson et al. 2016).

To avoid or mitigate the negative effects of recreation on wildlife, land managers require explicit recommendations for how to design trail systems and manage public access. Quantitative information about how wildlife respond to varying levels of recreation is especially important for land managers attempting to make decisions regarding the construction of recreation infrastructure or designation of permitted recreation uses (Braunisch et al. 2011; Rösner et al. 2014), which will affect the total number and spatial and temporal distributions of visitors to protected lands.

Studies of recreation activities can be used to estimate quantitative thresholds of negative effects on wildlife. Thresholds can be measured as effect distances (e.g., the distance at which wildlife species avoid trails or other infrastructure), trail densities (e.g., the density at which wildlife habitat use is altered), or visitation rates (e.g., the number of visitors per day at which wildlife abundance is reduced). However, detection of threshold effects, if present, can be constrained by the spatio-temporal extent and overall design of a study. For example, if the study design focuses on categorical differences between treatment effects or relies on too coarse a measure of wildlife response, threshold effects may not be detectable. In addition, the lower limit of the effect of human presence or infrastructure may be outside the boundaries of the study area or may be difficult to disentangle from correlated effects of other variables.

We conducted a review of the published scientific literature of human recreation effects on wildlife in terrestrial environments. We analyzed articles to determine if the authors detected a quantitative threshold or if the authors included management recommendations with thresholds drawn from the study's results. First, we summarize the findings descriptively, reviewing the species and ecosystems that have been studied, and identifying gaps in the available literature. Second, we highlight the findings of multiple articles on three frequently studied genera as case studies. Finally, we discuss how future research should consider study designs that explore the quantitative thresholds of systems as a means of providing the best recommendations for natural resource professionals.

Methods

We used a database of 274 articles from a recent systematic review of the effects of recreation on wildlife species with articles published from 1981 to 2015 (Larson et al. 2016). We supplemented this database with 24 additional articles published through February 2017 that matched the criteria of Larson et al. (2016), plus 30 articles on the effects of recreation infrastructure. The systematic review criteria identified articles that focused on non-consumptive human recreation activities (i.e., did not include hunting or fishing), studied one or more animal species, and assessed recreation effects using statistical tests. For our review of quantitative thresholds, we included only studies of terrestrial species or interactions that occurred while an animal was on land (e.g., marine mammals disturbed while on a beach). After excluding aquatic species, 268 articles remained in our database.

We defined a quantitative threshold as the point at which ≤ 10% individuals or observations of a wildlife population indicate a deleterious effect (e.g., flushing, reduced survival) in response to recreation disturbance. For example, we included papers if the results quantified the trail-effect distance where the upper 90% quantile of passerine habitat use occurred, or if logistic model results indicated a point at which ≤ 10% of deer were disturbed by human proximity. We chose this definition because of the frequency of articles that identified a threshold at or above the 90% value. We also recorded the value at which the least number of individuals were disturbed, including the value at which no wildlife individuals were disturbed. We did not include articles that reported only the mean effect or level of disturbance (e.g., mean flush distance, mean recreation group size, etc.), as this value does not represent the full distribution of disturbed animals (i.e., does not allow for estimation of the value at which the minimum effect occurs). We did include articles that presented figures or graphs that allowed for estimation of a threshold of effect, even if that threshold was not explicitly stated in the article's text.

We read all remaining articles to determine if the study results presented a quantitative threshold and/or if they stated a threshold management recommendation. We classified each article into one of seven different ecosystem classifications adapted from Larson et al. (2016): coast/shoreline, desert, forest, polar, rangeland, scrub/shrub, and wetland. Rangeland included grassland, alpine, tundra, and savanna ecosystems. In addition, we extracted details on the measure of recreation disturbance (e.g., number of visitors, distance to people, etc.), study type (e.g., observational or experimental), species of interest, and publication information (Larson et al. 2016).

Once a paper was determined to have identified a quantitative threshold, we recorded the details of the threshold including the measure of wildlife response, and the value at which the disturbance threshold was observed (e.g., < 14 visitors/day, <100 meter from people, etc.). Some articles recorded multiple threshold effects per species that varied by season or recreation type; therefore, several articles resulted in multiple database inputs.

We recorded whether an article both identified quantitative threshold(s) of recreation effects and recommended specific strategies for managing recreation. Management recommendations included suggested distances to separate people from animals and limits on visitor numbers. More general recommendations (e.g., people should be kept away from wildlife or a preserve area should be closed seasonally), were not included in our review if they did not specify an empirically-derived quantitative value (but see Larson et al. [2016] for a summary).

Results

We reviewed 268 full-text journal articles, of which 50 articles (18.7%) met our requirements for quantitative threshold effects and three articles (1.1%) included a quantitative management recommendation. Thus, we extracted data from a total of 53 articles.

Studies that identified threshold effects were conducted predominately in forest (45.3% of articles, n = 24), coastal/shoreline (28.3 %, n = 15), and/or rangeland ecosystems (26.4%, n = 14) (**Fig. 2.1**). There was limited representation of recreation studies in wetland (13.2 %, n = 7), scrub/shrub (5.7%, n = 3), polar (3.8%, n = 2) or desert (1.9%, n = 1) ecosystems.

The majority of the 53 articles focused on bird (58.2%, n = 30) or mammal (36.4%, n = 19) species, with little representation of invertebrates (3.6%, n = 2) or amphibians (1.8%, n = 1). We did not find a paper that identified thresholds for reptiles. Studies of birds focused primarily on species in the Orders Charadriiformes (e.g., wading birds and gulls; 26.9%), Accipitriformes (e.g., hawks, eagles, and vultures; 11.3%) and Passeriformes (i.e., perching birds; 11.3%) (**Fig. 2.2a**). Mammal

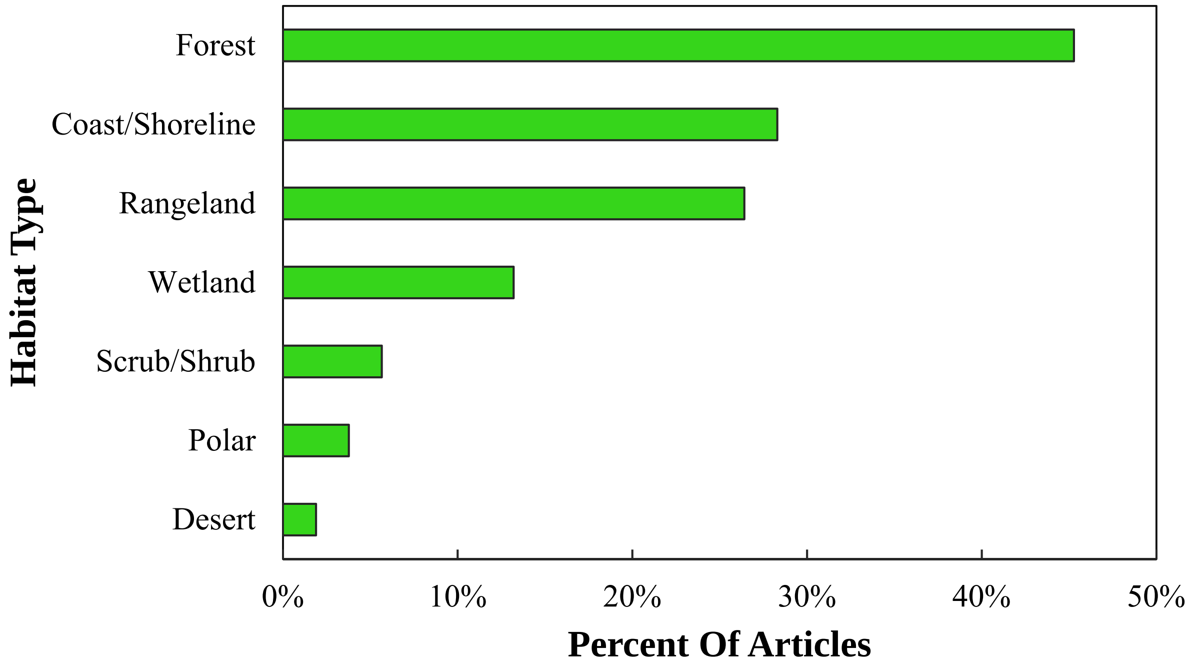
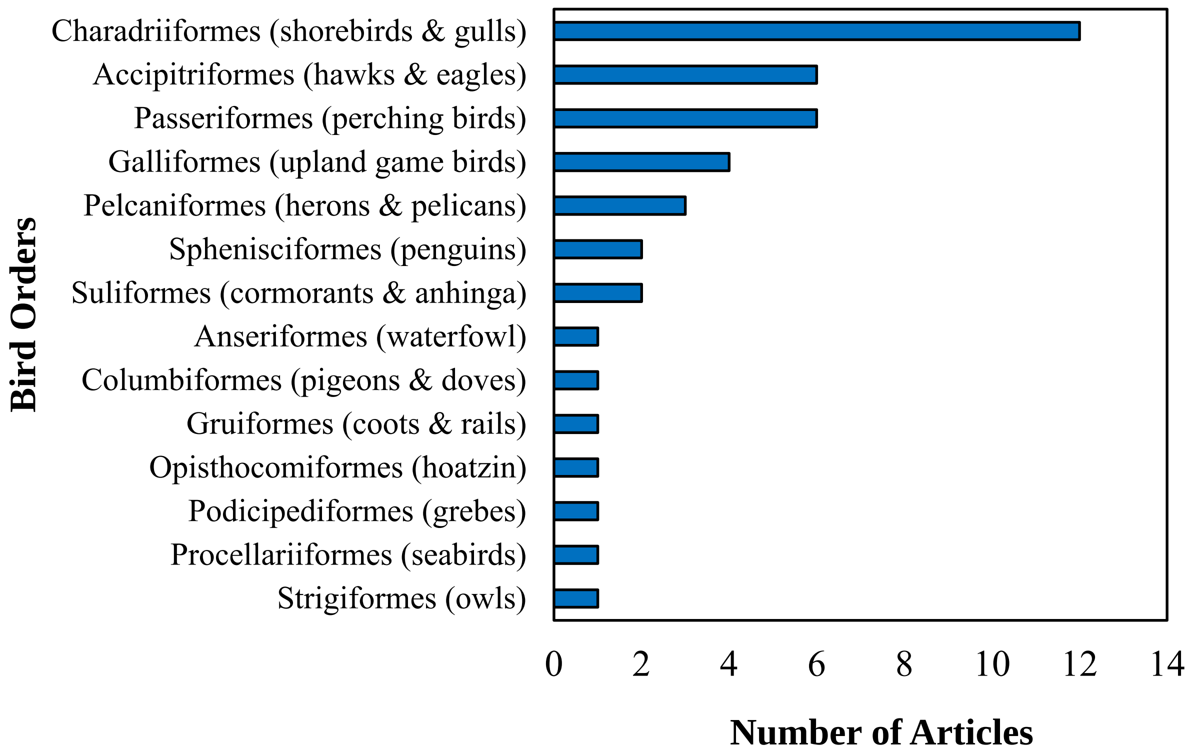


Figure 2.1. Summary of habitat types represented by papers that demsontrated threshold effects. Forest, rangeland, and coast/shoreline habitats made up the vast majority of studied ecosystems. Percentages sum to greater than 100% because some studies were conducted in more than one habitat type.

studies primarily focused on species in the Orders Artiodactyla (i.e., even-toed ungulates; 19.2%) and Carnivora (e.g., cats, bears, and seals; 11.3%) (**Fig. 2.2b**).

Hiking (30.0% of articles), wildlife viewing on land (11.3%), and dog-walking (11.3%), were the most commonly studied recreational activities (**Fig. 2.3**). Nearly half (45.3%) of the articles examined two or more recreation activities, most of which (73.9%) included hiking as one of the activities. Beach use (10% of articles) was typically associated with studies examining human disturbance to shorebirds.

a.



b.

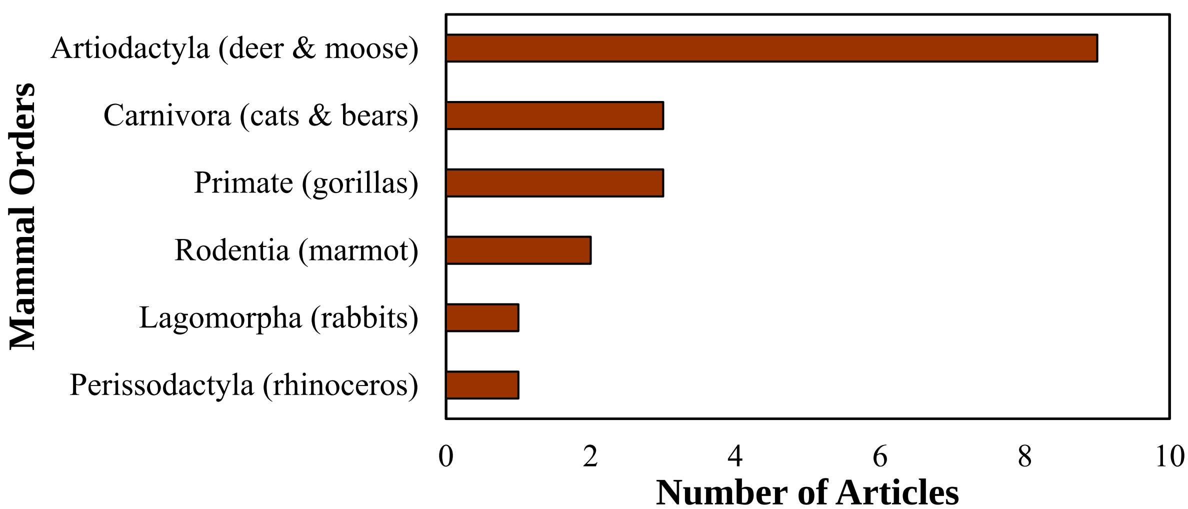


Figure 2.2. Orders of (a) bird and (b) mammal species studied in papers that identified an effect threshold. Several articles contained more than one order thus the total number of articles sums to more than all the threshold effects papers.

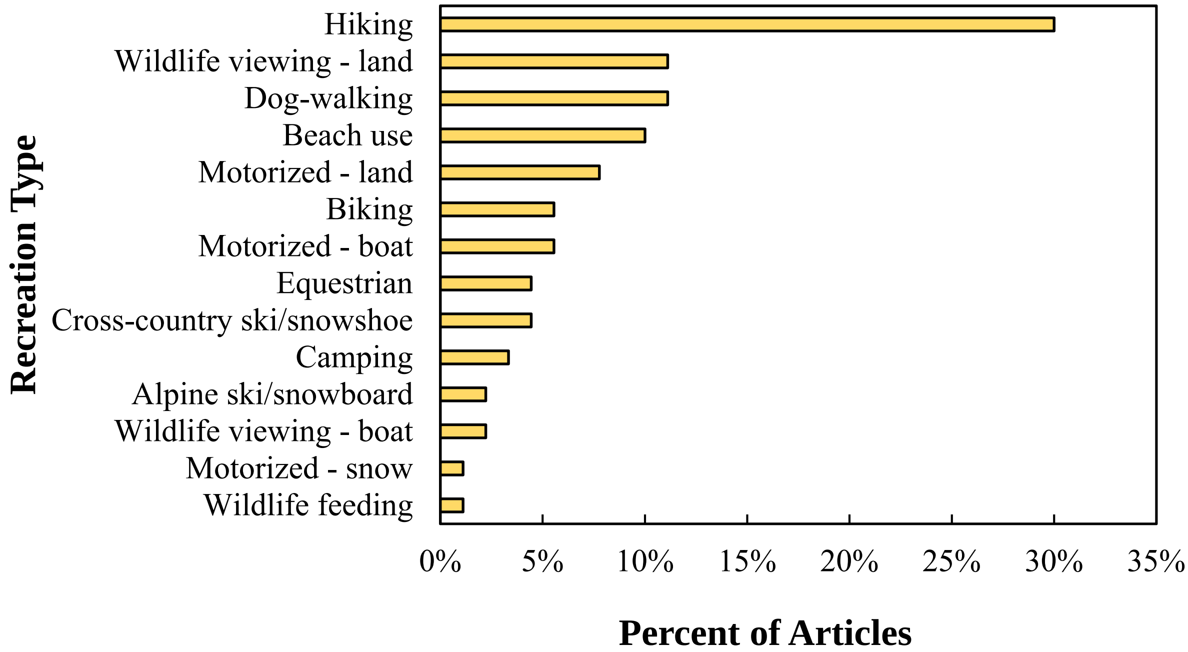


Figure 2.3. Forms of recreation across all articles that found a threshold effect. An article could measure multiple recreation types, therefore, the percent of articles sums to greater than 100%.

Quantitative thresholds were measured for a variety of recreation disturbance variables, including distance to people, distance to a trail or road, and number of people (**Fig. 2.4**). The greatest percentage of studies focused on measures of distance to the nearest people (66.0% of articles). Studies that focused on the distance to people included observational studies in coastal ecosystems where trails are less well defined (*n* = 10) and quasi-experimental studies in which researchers directly or adjacently approached an individual animal to measure alert and flight initiation distances (*n*=10).

Distance to trail was the second most frequently studied measure of recreation disturbance (22.6% of articles) (**Fig. 2.4**). Quantitative thresholds for distance to trail were identified in studies of birds (*n*=6), mammals (*n*=3), and invertebrates (*n*=1). Several studies were precluded from finding a threshold effect because the researchers focused on categorical differences between trail types or

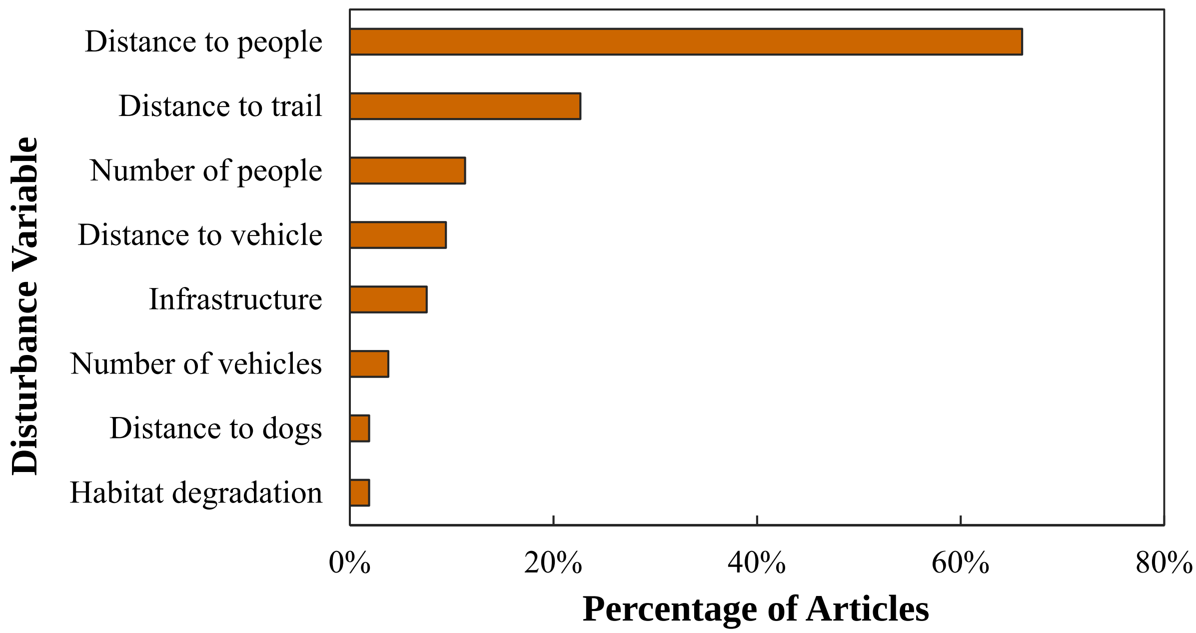


Figure 2.4. Disturbance variables for which threshold effects were measured in articles on impacts of recreation on wildlife species. Infrastructure refers to either distance (km) to human structures or density of human built structures. Distance to trail includes all forms of human recreation trails including motorized, non-motorized, dogs, and no dogs. Number of vehicles and number of people were measured daily or on a per survey time basis.

presented only mean distances of apparent trail effects. In addition, one study focused on the threshold distance of habitat degradation on the periphery of trails due to human traffic and its effects on the occurrence of a butterfly's host plant (Bennett et al. 2013).

Median threshold distances at which the presence of people, trails, or vehicles affected a target species was 80 m for birds and 90 m for mammals; maximum threshold distances exceeded 600 m for birds and 1000 m for mammals (**Fig. 2.5**). However, effect distances varied substantially among orders and species. Wading birds and passerines were generally affected at distances less than 100 m (Miller et al. 1998; Thomas et al. 2003; Lafferty et al. 2006), whereas larger-bodied species

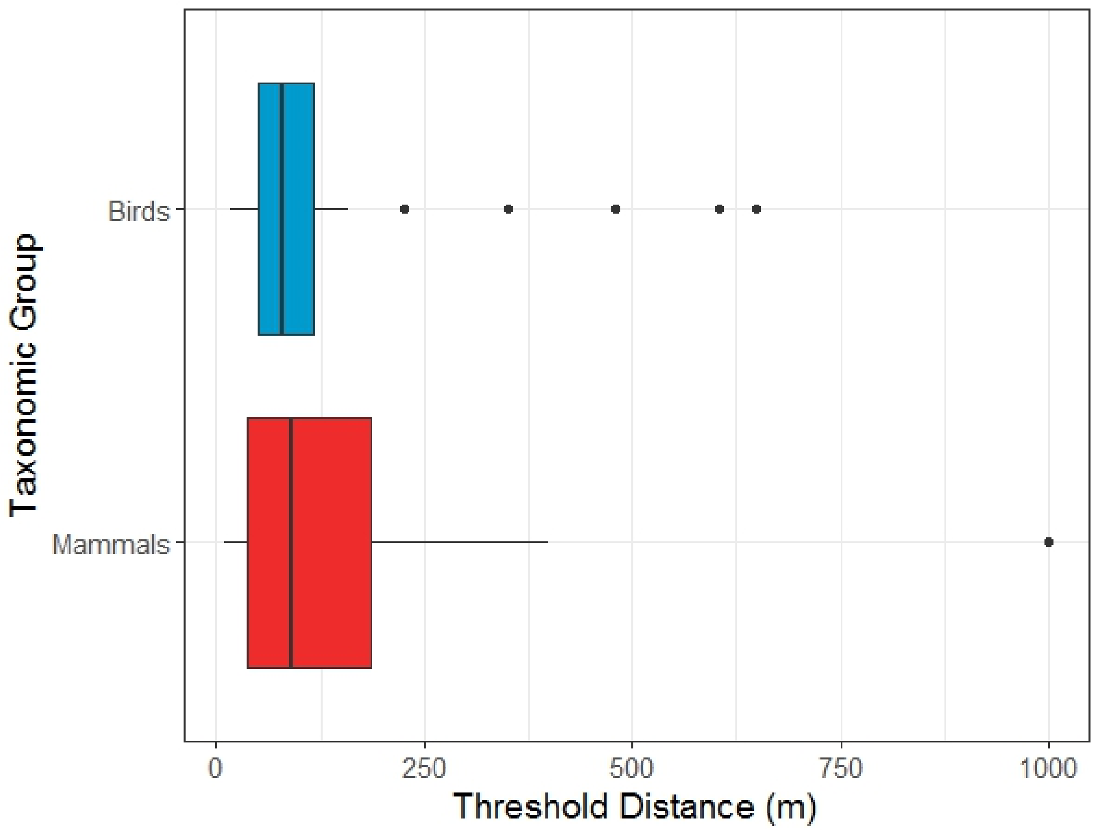


Figure 2.5. Minimum effect distance thresholds across all mammal (*n*=28) and bird (*n*=71) species studied for the impacts of recreation on wildlife. Thresholds included observed distances of direct human disturbance to wildlife and disturbance from recreation infrastructure. Outliers for mammals are effect distances for larger ungulates, including caribou and elk. Outliers for birds are effect distances for raptors, including hawks and eagles. The dark line through each box represents the median threshold distance, and the whisker lines correspond to 95% of the range of distance values.

such as hawks and eagles had threshold effect distances greater than 400 m (Zuberogoitia et al. 2008; Keeley & Bechard 2011) (**Fig. 2.5**). Regression analysis found evidence of a positive correlation between increasing bird body mass and effect distance (**Fig. 2.7a**).

Estimates of minimum effect distances for mammals were more variable, but appeared to follow a similar pattern to those of birds. Smaller rodent species avoided areas within 50-100 m of trails or people (e.g., Lenth et al. 2008), whereas some carnivores and ungulates had minimum effect

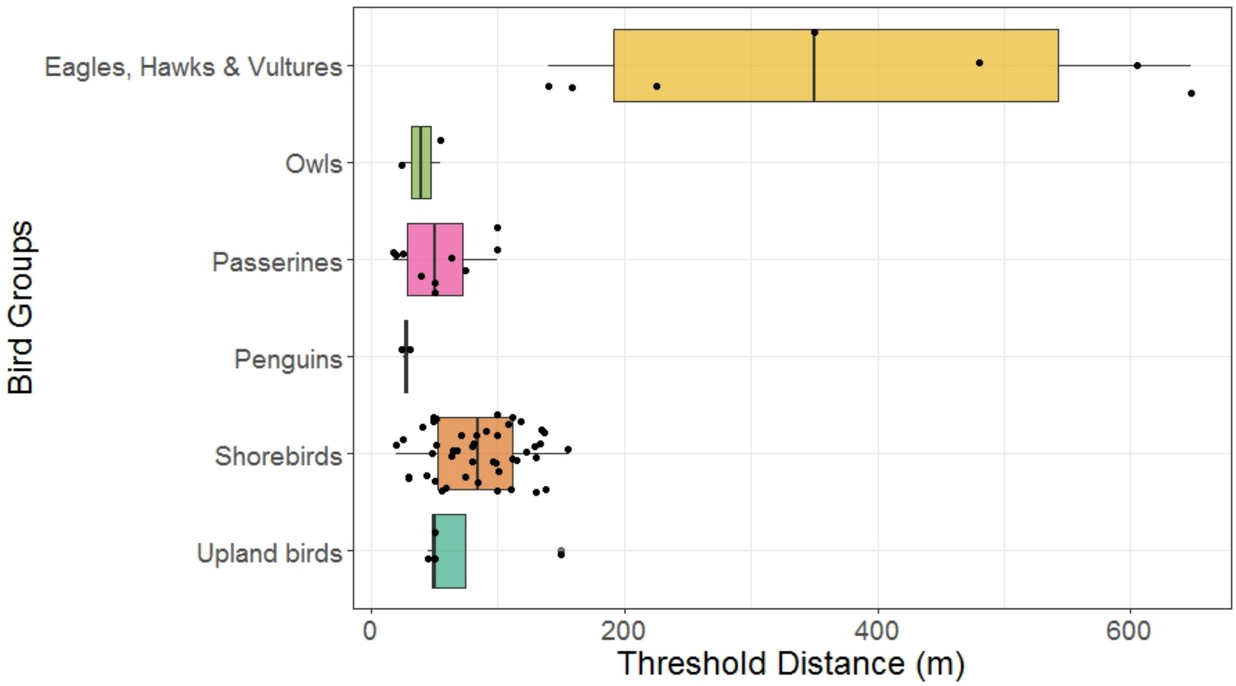
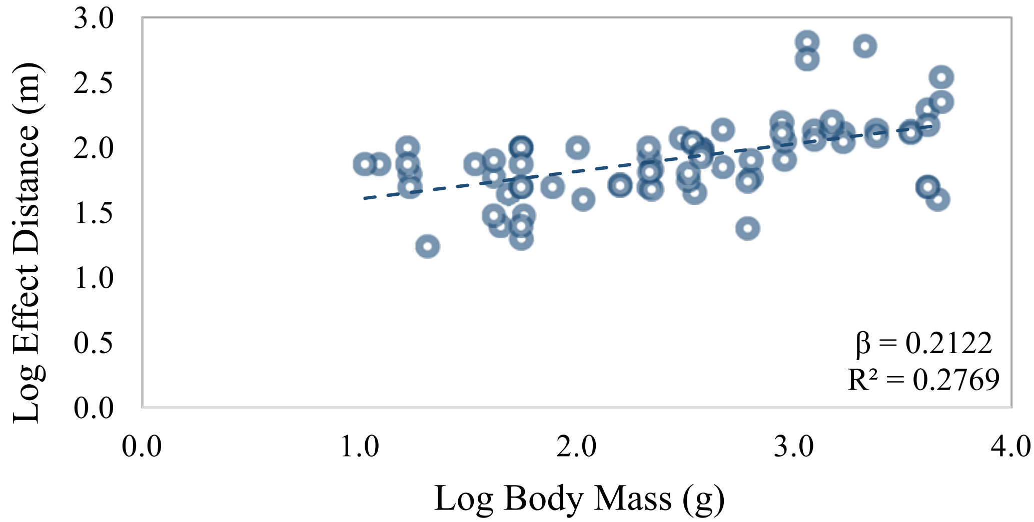


Figure 2.6. Threshold distances of different bird groups. Black dots represent individual data points that were used in estimating the box plot. Shorebirds had by far most threshold data, more than all other bird groups combined. Birds of prey, not including owls, had the highest variation in threshold distances and were impacted by recreation at much further distances.

distances up to 350-1000 m from trails and people (Preisler et al. 2006; Reimers et al. 2006; Coleman et al. 2013). However, regression analysis did not find evidence of a correlation between mammal body size and minimum effect distance (**Fig. 2.7b**).

Effect-distance thresholds also varied depending on the likely habituation of the species. Studies that examined western lowland gorilla (*Gorilla gorilla*) groups that had frequent tourist contact noted behavioral differences when humans approached within 10 meters (Blom et al. 2004; Klailova et al. 2010). A study of habituated Asian rhinoceros (*Rhinoceros unicornis*) recommended maintaining a buffer of greater than 15 m between tourists and rhinos, especially given the behavioral disturbance when people were within 10 m of an animal (Lott & McCoy 1995).

a. Birds



b. Mammals

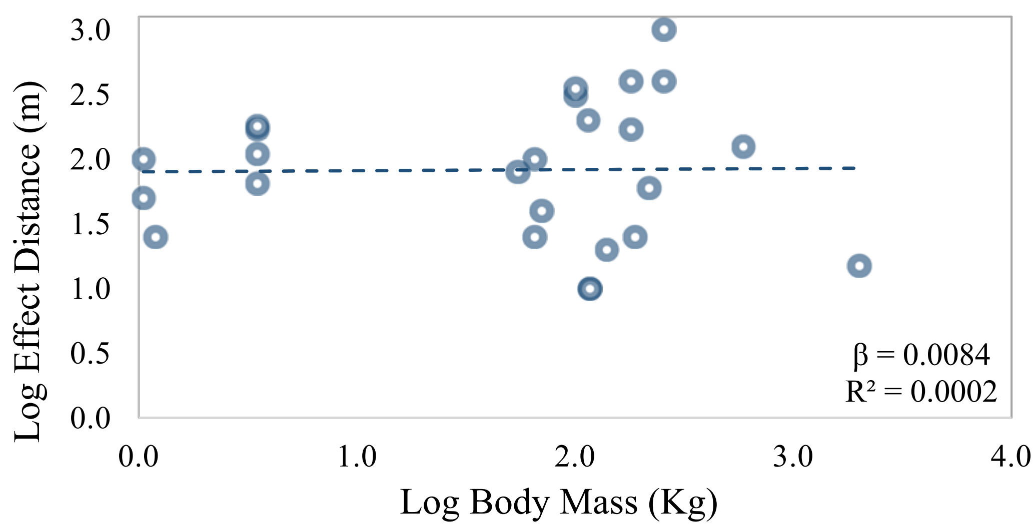


Figure 2.7. Correlation of animal body size versus threshold effect distance for (a) birds and (b) mammals. We excluded two flightless bird examples given differences in mass and life history compared to flying birds. Effect distances include distance to people, vehicle, and trails.

Articles examining thresholds of the number of people or vehicles per unit time were comparatively less well represented (11.3%, n = 6 articles) (**Fig. 2.4**). Thresholds on numbers of people included studies focused on human visitation effects on primate group behavior (n=2), decreasing wildlife sign or detection correlated with increasing magnitude of visitation (n=4), and behavioral disturbance to animals from tourist group visits to wildlife concentrations (n=3). Measurement units regarding the number of people present varied between studies; units included the number of people per day, people per month, people present at a survey, and people per km per visit.

Four articles (7.5%) found different threshold effects of recreation infrastructure (**Fig. 2.4**). The two articles concerning effects of human infrastructure other than trails (e.g., campgrounds, tourist buildings) demonstrated threshold effects an order of magnitude greater than effect distances to trails or people. Steller's jays (*Cyanocitta stelleri*) that supplemented their diet with human food from campgrounds used habitat up to 2 km from the campground infrastructure (i.e., the campground had a 2 km effect distance) (West et al. 2016). Interactive effects of human recreation and animal habituation led to significantly higher poaching of Barbary macaque *(Macaca sylvanus*) juveniles within 20 km of a tourist site (Ménard et al. 2014).

Discussion

There are numerous gaps in the scientific literature regarding quantitative thresholds of effects of recreation on wildlife. While the publication rate on this topic has increased exponentially, science-based recommendations for management of recreation are lacking (Larson et al. 2016). Further, certain taxonomic groups, including amphibian, reptile, and invertebrate communities, are substantially underrepresented in this body of research. In this review, amphibian and invertebrate species were each included in only one article, and no articles identified effect thresholds for reptile species. However, quantitative information about how wildlife respond to recreation activity and infrastructure, and management recommendations of researchers studying similar ecosystems or species of interest, can assist land managers to design trail systems and manage public access to avoid or mitigate the negative effects of recreation on wildlife.

Most studies were excluded from our review because they considered only categorical differences in recreation variables. Further, some of studies identified only means or medians of recreation effects, which precluded an estimation of the threshold value at which the minimum effect occurs. Although studies that identified means or medians did not meet our review's criteria, they can still contribute valuable insights for wildlife management. For example, studies such as Sibbald et al. (2011), which observed that GPS-collared red deer (*Cervus elaphus*) will stay an average of 371 meters from busy trails, or Mallord et al. (2007), which found that woodlarks (*Lullula arborea*) the probability of colonization was < 50% in areas with greater than eight human disturbance events per hour, both contribute useful information on the impacts of human presence on species behavior and habitat use. Including mean or median values is a common method for reporting such data; however, an average value does not indicate to a wildlife manager or researcher the level of human disturbance at which a negative effect actually begins. Moreover, depending on the distribution of disturbance values, an average result excludes a major portion of the sampled wildlife population.

We did find numerous examples of minimum effect thresholds from certain taxa, especially shorebirds and ungulates. Studies of plover species (genera *Charadrius* and *Pluvialis*) provided some of the clearest examples of minimum effect thresholds. Western snowy plovers (*Charadrius nivosus*) were rarely disturbed when humans were more than 30 m away (Lafferty 2001), whereas a study of piping plovers (*Charadrius melodus*) demonstrated that the minimum distance for flight initiation was greater for a person walking a dog (100 m) than for a person walking alone (50 m) (Jorgensen et al. 2016). Results for piping plovers aligned closely with those for Kentish plovers (*Charadrius alexandrinus*), which fled when humans were less than 80 m away (Martín et al. 2015), and for golden plovers (*Pluvialis apricaria*), which avoided areas within 50 m of a pedestrian trail (Finney et al. 2005). Separating humans and shorebirds by a minimum distance of 100 m appears to be the best practice to reduce potential negative effects of human disturbance on these species.

Ungulates of the order Artiodactyla (even-toed ungulates) were also well represented in this review. Estimates of minimum flight initiation distances for ungulates varied more broadly than those for birds. Studies found threshold distances of 25-60 m for species such as sika deer (*Cervus nippon*), sable antelope (*Hippotragus niger*), and greater kudu (*Tragelaphus strepsiceros*) in areas with high levels of human visitation (Borkowski 2001; Muposhi et al. 2016). Alternatively, reindeer (*Rangifer tarandus tarandus*) were disturbed up to 350 m from approaching humans (Reimers et al. 2006), and Rocky Mountain elk (*Cervus elaphus*) exhibited a flight response up to 1000 m from all-terrain vehicles (Preisler et al. 2006). Guanacos (*Lama guanaco*) had a similar flight initiation distance and reduced sightings by researchers with greater than 250 visitors per day to the study site (Malo et al. 2011). Given the wide variability of threshold estimates for species in this order, a precautionary recommendation for separating humans (excluding vehicles) and ungulates would be a minimum distance of 350 m to reduce potential negative effects of human disturbance.

Examples of recreation infrastructure thresholds, beyond those describing distance to trail, were lacking in our review. What appears from our low sample size is that infrastructure even at low levels can be a contributing factor to altering the habitat use of birds and mammals (Braunisch et al. 2011; Harris et al. 2014; Richard & Côté 2016). At a regional scale, recreation infrastructure may also further exacerbate underlying human-wildlife conflicts (Ménard et al. 2014). Better understanding of how building installations or the density of trails influences the behavior and survival of wildlife species is paramount for the creation of informed regulatory guidelines.

The availability of science-based management recommendations that include quantitative thresholds was lower than our initial expectations. We found relatively few accessible and practical recommendations for land and wildlife managers. Studies that focused on categorical variables (e.g., low and high recreation, hikers versus mountain bikers) to examine the potential effects of a recreation treatment rarely identified the threshold at which the recreation activity may begin to or no longer affects an animal species. Although researchers should not provide a quantitative recommendation that is not justified by their results, where possible, researchers should provide resource managers with clear guidance and conservative estimates to support science-based management decisions.

During the study design process, future researchers should consider how their design could support detection of a quantitative threshold. Rodríguez-Prieto & Fernández-Juricic (2005) provide a valuable example demonstrating how to estimate a quantitative threshold of the effect of recreation activity on the Iberian frog (*Rana iberica*). Their study design incorporated systematic exposure of the species of interest to human disturbance, which provided direct and measurable flight initiation distances of individual animals from humans. Their results clearly demonstrated that beyond 2 m, human approaches rarely result in the movement of frog individuals (**Fig. 2.8**). Although this study system is likely easier to control and observe than studies of large mammal species, it provides a useful example of implementing an experimental design to quantify a threshold effect of recreation disturbance.

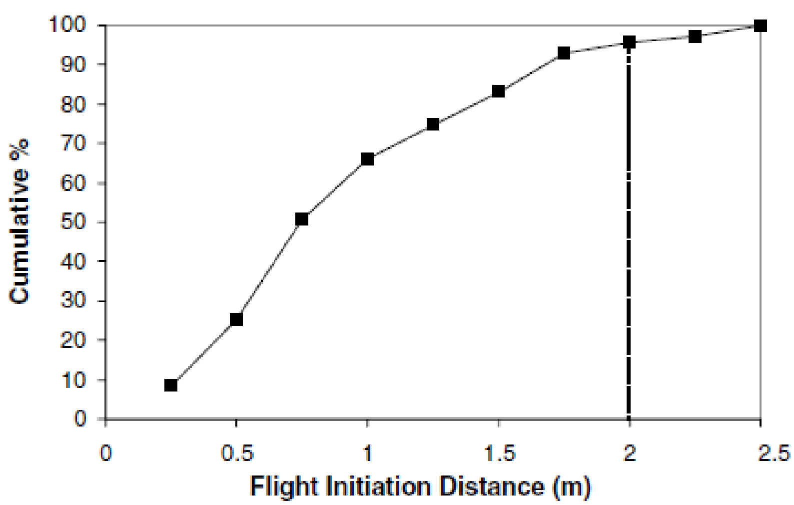


Figure 2.8. Example of estimate minimum effect distance taken from Rodríguez-Prieto & Fernández-Juricic (2005). The graph depicts the estimated of minimum approaching distance for Iberian frogs based on the relationship between the cumulative number of individuals fleeing from humans at different flight initiation distances.

While there remains a need to understand when and where recreation activities are affecting species negatively, to inform future designation and management of recreation use, researchers must move beyond simple hypothesis testing. Asking how and when a species is being disturbed, and measuring well beyond the spatial extent, temporal duration, or other value at which disturbance is expected to begin or end, will allow investigators to identify important thresholds of recreation disturbance. Ultimately, these thresholds allow for more informed and effective management decisions and a higher probability of conservation success.

3. Recreation Mapping and Monitoring in the Sonoma Valley Linkage

Introduction

Land management agencies are often mandated to allow human recreation access to parks, open spaces, and other protected lands, while also conserving natural resources. As demonstrated in the previous chapters, human recreation activity can have negative effects on a variety of wildlife species and in a variety of environments (Larson et al. 2016). However, quantitative measurement of recreation disturbances (e.g., visitation rates) is relatively uncommon and often limited by the staff and financial resources of a management agency (Cole & Wright 2004; Hadwen et al. 2007). With the increased recognition of human recreation impacts on wildlife, there is the need to accurately quantify spatial and temporal visitation patterns for different types of recreation activities.

Monitoring of visitation rates and types of recreation serves multiple purposes in the management of protected areas. Accurate information on visitor numbers and spatial patterns can assist in park planning decisions, such as the design of infrastructure and allocation of staff and resources (Cessford & Muhar 2003). In addition, it is difficult to assess potential human impacts without a complete and accurate map of the recreation infrastructure of a property; therefore, it is important to use remote-sensing and ground-truthing to inventory the locations of buildings, designated and undesignated trails, and any other recreation infrastructure. Although admissions data, if available, can be used as a proxy for visitation rates, it misses variation in spatial patterns of visitation and assumes no illicit use of the protected area. Utilizing expert opinion to define areas as categories of high or low use recreation does not provide detailed information of sufficient resolution to assess wildlife response to visitation magnitude; it also limits comparison of results among studies. Further, quantifying human recreation should go beyond simply counting people and include different types of recreation activities (e.g., hiking, cyclists, etc.). Considering different types of recreation across different properties and studying each factor independently allows researchers to correlate potential impacts of a recreation activity on wildlife. In summary, spatially detailed and temporally continuous visitation data is needed for researchers to study wildlife dynamics in response to varying types and magnitudes of recreation disturbance and identify thresholds of recreation effects.

The objective of our study was to quantify recreation on properties in California's Sonoma Valley that varied in type and intensity of human recreation activity. Sonoma Valley is a popular tourist destination for its long-established wine industry in addition to historic attractions such as author Jack London's homestead and the Sonoma Mexican Mission. Conservation of lands for wildlife habitat is therefore at a premium due to the extensive residential and urban development in the region and the extremely high land values. Undeveloped lands that provide connectivity for wildlife movement across the valley are restricted to one continuous linkage in the southeastern portion of the valley, the Sonoma Valley Wildlife Corridor (SVWC). With the changing management of some of these lands, including the potential for expanded access for human recreation, comes the concern for maintaining the permeability of the corridor.

We mapped existing recreation infrastructure and monitored recreation visitation patterns on nine properties in Sonoma Valley, to estimate baselines of current visitation levels to three target properties: Sonoma Developmental Center (SDC), Glen Oaks Ranch (GOR), and Santa Rosa Creek Headwaters (SRCH). We also monitored visitation at six nearby comparison properties, to quantify visitations levels that are similar to what could be expected for the three target properties in the future. We also analyzed two existing datasets to test for potential relationships between recreation visitation patterns and detections of wildlife species. These monitoring data and analyses will inform our recommendations for managing recreation access and permitted uses on properties within the

SVWC (Chapter 4), and for a monitoring design to assess future changes in recreation activity and potential effects on wildlife (Chapter 5).

Methods

Study Areas

Sonoma Valley is a north-south undulating valley 2-3 km wide situated between the Mayacamas and Sonoma Mountains in southeastern Sonoma County, California. Predominate land uses of the valley include vineyards and wineries, housing, and conserved open spaces. Study areas were dominated by open oak (*Quercus* spp.) woodlands with interspersed grasslands and Pacific madrone (*Arbutus menziesii*), and higher elevation areas with dense Douglas fir (*Pseudotsuga menziesii*), black oak (*Quercus kelloggii*), and coast redwood (*Sequoia sempervirens*) stands. The Sonoma Valley has a Mediterranean climate with warm, dry summers and mild, wet winters.

We monitored recreation activity from April to May 2017 on three target properties (SDC, GOR, and SRCH) and six nearby comparison properties (**Table 3.1**). The Sonoma Developmental Center (SDC) is a 380-ha State of California in-patient mental health facility comprised of an approximately 80 ha campus of buildings surrounded by approximately 300 ha of open oak woodlands and two reservoirs. We selected Jack London State Historical Park (JLSHP), which borders SDC to the west, and Sonoma Valley Regional Park (SVRP), which borders SDC to the northeast, as comparison properties of SDC given the proximity and contiguity of trails among the three properties; we also expected that JLSHP and SVRP would have similar levels of recreation visitation that could be anticipated for SDC in the future. Glen Oaks Ranch (GOR) is a 95-ha Sonoma Land Trust-owned property in the southeastern portion of the Sonoma Valley. Glen Oaks Ranch is closed to the public, but occasionally hosts school groups and philanthropic events, group and individual hikes, and receives frequent visitation by staff and volunteers. We chose Bouverie

Preserve (BP) and Fairfield Osborn Preserve (FOP) as comparison properties to GOR given their proximity and similar size, as well as similar management of public access and human recreation activity. We anticipated that both properties currently have higher visitation levels than GOR, but could be representative of GOR if visitation increases. Finally, Santa Rosa Creek Headwaters (SRCH) is a 66-ha new addition to Hood Mountain Regional Park that is not yet open for public

Table 3.1 Study areas in Sonoma Valley and their recreation restrictions. Dogs are permitted as on-leash only, but are often illicitly off-leash at many of these study areas.

Study Area	Code	Access	Area (ha)	Permitted Uses	Dog Access	Operator
Glen Oaks Ranch	GOR	Closed w/ access by appt.	94.7	Hikers	No Dogs	Sonoma Land Trust
Bouverie Preserve	BP	Closed w/ access by appt.	183.0	Hikers, school groups	No Dogs	Audubon Canyon Ranch
Fairfield Osborn	FOP	Closed w/ access by appt.	182.0	Hikers, students and research	No Dogs	Sonoma State University
Sonoma Developmental Center	SDC	Open	382.2	Hikers, Cyclists & Equestrians	Dogs	CA Dept. of Developmental Services
Jack London State Historical Park	JLSHP	Open	601.3	Hikers, Cyclists & Equestrians	Dogs (cultural areas only)	CA Dept. of Parks & Recreation
Sonoma Valley Regional Park	SVRP	Open	93.2	Hikers, Cyclists & Equestrians	Dogs	Sonoma County Regional Parks
Santa Rosa Creek Headwaters	SRCH	Closed	65.6	N/A	No Dogs	Sonoma County Regional Parks
Hood Mountain Regional Park and Open Space	HMRP	Open	786.0	Hikers, Cyclists & Equestrians	Dogs	Sonoma County Regional Parks
Sugarloaf Ridge State Park (McCormick)	SRSP	Open	374.4	Hikers, Cyclists & Equestrians	No Dogs	CA Dept. of Parks & Recreation

access. We chose Hood Mountain Regional Park (HMRP) and Sugarloaf Ridge State Park (SRSP), which directly border SRCH, as comparison properties to estimate potential visitation levels when SRCH is opened to recreation activity. Although it represents a snapshot of just one season of one year, the timing of recreation monitoring was chosen to capture an optimal time for recreation visitation in the Sonoma Valley, immediately following the rainy season and before the hot, dry summer, and during the school year to capture student group visits to several of the properties.

Mapping Recreation Infrastructure

We collected available geographic information system (GIS) data layers on the nine study areas including property boundaries, trails, and structures. We used satellite imagery displayed in ArcGIS and Google Earth to digitize property boundaries and trails for study areas in which we could not collect GIS layers. We ground-truthed digitized trails to check for accuracy of the remotely-sensed data.

Monitoring Design & Data Collection

We used remotely-triggered cameras ("camera traps") to measure the types and intensity of recreation use occurring at the study areas. In a prior study, we found that remotely triggered cameras were the most efficient and cost-effective technique currently available for counting visitors to recreation areas (Reed et al. 2014). We installed remotely triggered cameras (Bushnell TrophyCam with infrared flash) along the target trail and set them to record continuously day and night for a minimum of 14 days at each location. Camera traps were installed 0.5–1.0 m above the ground on trees (n=37) or fence posts (n=1) and positioned low enough to avoid capturing human facial images and maximize opportunistic detections of wildlife species. All camera traps were programmed to take two photos for each triggering event followed by a ten-second silent period to reduce multiple triggers from the same individual. We operated all camera traps from April to May 2017.

We selected camera trap locations by creating a spatially balanced-random design in ArcGIS (ArcGIS v10.5; Environmental Systems Research Institute, Redland, CA, USA), which creates a random but spatially distributed set of sampling locations across a study area. To ensure an adequate sample of all target and comparison properties, we created a unique sampling design using the trail shapefile for each study area. The number of cameras per study area was proportional to land area; we also increased the number of cameras located on the three target properties. We placed three cameras each at FOP and SRCH, four cameras at BP, GOR, SLSP, SVRP, five cameras at JLSHP and HMRP, and six cameras at SDC. All camera sites in SDC were in woodland hiking trails away from campus buildings, specifically located to avoid capturing images of resident clients.

Sampling locations were selected in the sequential order created by the ArcGIS spatially balanced points tool. If two sampling locations were generated on the same trail within 500 m of each other, we selected the lower numbered (i.e., higher-priority) point of the pair. When installing cameras in the field, if we determined that it was not logistically feasible to position a camera within 100 m of the generated point, then we would go to the next unselected sampling location in the list of generated points.

We analyzed the collected photos to obtain an estimate of visitation by recreation activity type. We subsampled the collected photos as needed to obtain a continuous 14-day sample at each study site, and we viewed each photo to count the number of individual hikers, cyclists, equestrians, and domestic dogs. We also noted whether dogs were leashed. We calculated separate estimates of total mean daily visitation and daily visitation by hikers, cyclists, equestrians, and dogs for each sampling location and summarized them by study area. We also recorded all mammal and bird detections for each sampling location. Given our single survey period and low sample size, we summarize the data as mean daily detections per sampling location and study area.

Existing Data

We analyzed two additional camera trap datasets for possible correlations between human recreation and wildlife detections. These data were collected in open spaces of Sonoma Valley prior to our data collection, and both used different study designs that were not focused on human recreation. The first dataset was provided by Sonoma Land Trust (SLT), which installed 44 cameras in a grid system throughout lands within the SVWC. These cameras were situated on average ~ 680 m apart and operated for 8 seasons or two years (Gray 2017). Duration of data collection varied among cameras; therefore, detection rates were normalized (detections/100 trap nights). The second dataset came from Sonoma County Regional Parks (SCRP), which used an array of eight camera traps in SCRP properties installed between June and December 2016. Four cameras were positioned at HMRP, three cameras were positioned at SDC/SVRP, and one camera at Taylor Mountain Regional Park, on the southeastern border of Santa Rosa, CA. All SLT and SCRP camera trap photos were identified to species, including domestic animals and humans. We analyzed deer and bobcat detections from both organizations since these were some of the most frequently detected species in both studies and correspond to the species that we analyzed with our monitoring data.

Analysis of Recreation and Wildlife Detections

We used simple linear regression to analyze correlations between the mean hikers detected at a camera location per day and the number of wildlife detections at a camera location across the sampling period. Mean detections of humans and total wildlife detections were log-transformed prior to regression analysis to meet assumptions of normality. We analyzed our data, SLT data, and SCRP data separately to determine if similar relationships held between studies for species with the largest detection sample sizes.

We used single-season occupancy models in Program MARK (White & Burnham 1999) to estimate the species richness of native mammals at our study sites. Detection histories were created for each camera location with the number of occasions equaling the number of plausibly detectable mammals in the Sonoma Valley (i.e., each column of the detection history is assigned to a species). If a species was detected at a camera location during any period of sampling it was recorded as a "1" in the detection history or if it was not detected as a "0." Species that were never detected during the study were still represented in the detection history as a column of zeros. Occupancy probabilities (ψ), the proportion of camera locations occupied, were fixed to one since at least one species was detected at each camera location. Detection probabilities (p), typically interpreted as the probability of detecting a species given that it is present, are rather interpreted as the proportion of potential mammal species present at a camera location. Therefore, all model variation was placed on the detection probability parameter. We constructed models that tested if species richness varied between study sites, target/comparison property groups, and by the intensity of recreation visitation. For this analysis, we used a list of 19 plausibly detectable mammal species across our study sites.

We ranked models using Akaike's Information Criterion adjusted for small sample size (AICc), an information theory metric for comparing the relative quality of a set of statistical models. Models with the lowest AICc value are considered the "best" model that neither under- or over-fit the data (i.e. the most parsimonious model). In addition, we used AICc weights, a measure of the relative likelihood of the model being closest to truth in comparison to other models, to gage the uncertainty in model selection.

Results

Recreation Activity

We established 38 camera locations from April to May 2017 at nine study areas. One camera failed to work after installation and two cameras did not operate for the full two weeks. Camera traps collected approximately 30,000 photos and detected human recreation activity at 33 of 37 functioning camera trap locations (**Appendix I**). Sonoma Valley Regional Park had three times more hiker, dog, and cyclist detections than any other study area. Human recreation was highest at sampling locations on the paved Valley of the Moon trail in SVRP, along Orchard Road and around Suttonfield Lake within SDC, and near the start of the JLSHP hiking trails. We did not detect human recreation at SRCH or along the GOR southern border. On and off-leash dogs were detected with hikers on four of the nine properties, including JLSHP and SRSP where dogs are not permitted. In addition, dogs were detected on GOR and BOUP, although these animals appeared to be a feral pack of three dogs (**Table 3.2**).

Detection of cyclists and equestrians were relatively low on all nine properties. Sonoma Valley Regional Park had the highest number of cyclists per day, predominately concentrated on the Valley of the Moon trail. Jack London State Historic Park had by far the most equestrians, which is likely attributable to the equestrian outfitters located in the park taking visitors on several of the wider hiking trails. Sonoma Developmental Center was moderately popular for both cyclists and equestrians, with cyclist detections being highest on the paved Orchard Road and equestrian detections occurring predominately to the east of Suttonfield Lake (**Appendix I**).

Table 3.2: Mean daily detections of human recreation activity per study area. Study areas (rows) are listed by target property followed by its two comparison properties.

Study Area	Code	Hikers	On-Leash Dogs	Off-Leash Dogs	Cyclists	Equestrians
Glen Oaks Ranch	GOR	2.78	0.00	0.01*	0.00	0.00
Bouverie	BP	14.41	0.00	0.35*	0.00	0.00
Fairfield Osborn	FOP	5.50	0.00	0.00	0.00	0.00
Sonoma Developmental Center	SDC	55.35	9.93	6.85	0.80	0.28
Jack London	JLSHP	45.41	0.23	0.45	0.65	4.02
Sonoma Valley	SVRP	171.03	38.94	5.31	2.01	0.90
Santa Rosa Creek Headwaters	SRCH	0.00	0.00	0.00	0.00	0.00
Hood Mountain	HMRP	49.38	6.22	3.21	0.45	0.35
Sugarloaf Ridge	SRSP	4.68	0.09	0.37	0.12	0.03

* Appeared to be a feral pack of three dogs

Wildlife Detections

We detected 11 mammal species during our sampling (**Table 3.3**). Black-tailed deer (*Odocoileus hemionus columbianus*) constituted the greatest number of mammalian detections, and they were particularly prevalent on properties closed to the public and with lower human use. We detected four mesopredators: bobcat (*Lynx rufus*), gray fox (*Urocyon cinereoargenteus*), coyote (*Canis latrans*), striped skunk (*Mephitis mephitis*) and two apex predators: black bear (*Ursus americanus*) and mountain lion (*Puma concolor*). Bobcat and gray fox were the only carnivore species which we had more than ten unique detections. In addition, we detected domestic cats (*Felis catus*) at HMRP and SVRP at camera locations that were on trails within 200 m of houses.

We captured only two detections of mountain lions, one detection at GOR to the north of Stuart Creek (Fire Road) and one detection on the eastern portion of the Valley of the Moon Trail in SVRP. The detections were 1.25 hours apart, images were of a collared lion, and in the first

Table 3.3. Mean wildlife detections per sampling location at nine study areas. Study areas (columns) are listed by target property followed by its two comparison properties.

Species	GOR	FOP	BOUP	SDC	JLSHP	SVRP	SRCH	HMRP	SRSP
Black-tailed deer	10.75	4.00	8.50	6.33	2.40	2.00	17.00	1.60	10.00
Wild turkey	6.75	0.33	13.75	7.17	2.80	0.00	0.00	0.40	6.25
Bobcat	0.00	0.33	1.50	1.67	3.60	0.67	0.00	1.40	0.75
Western gray squirrel	0.50	0.00	3.00	0.17	2.60	0.00	0.67	2.20	0.25
Gray fox	0.00	0.00	1.75	0.17	0.00	1.00	0.00	2.00	0.50
Virginia opossum	1.50	0.00	0.25	0.33	2.00	0.00	0.67	0.20	0.00
Black-tailed Jackrabbit	0.25	0.00	0.75	1.83	1.00	0.00	0.00	0.20	0.00
Domestic cat	0.00	0.00	0.00	0.00	0.00	3.00	0.00	0.40	0.00
Coyote	0.50	0.00	0.25	0.33	0.00	0.00	0.00	0.40	1.00
Striped skunk	0.75	0.00	0.00	0.33	0.00	0.00	0.00	0.20	0.25
Black bear	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.20	0.25
Mountain lion	0.25	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00

detection the lion was moving in the direction of the second detection location. If these photos were of the same individual mountain lion, it may have been captured in the process of using the wildlife corridor to cross Highway 12 and the valley.

Further analysis of our most detected species black-tailed deer, wild turkey (*Meleagris gallopavo*) and bobcat detections per day by camera location and by study area exhibited mixed results. At the sampling point level, hiker and deer detections were negatively correlated (R^2=0.225, p<0.005) (**Fig. 3.1a**). We did not observe correlations between hiker and bobcat detections (p=0.136) or between hiker and wild turkey detections (p=0.920) at the sampling point level (**Figs. 3.1b,c**). At the study area level, hiker and bobcat detections were positively, but uncertainly correlated (R^2=0.371, p=0.082) (**Fig. 3.2c**). We did not observe correlations between hiker and deer detections (p=0.783) or between hiker and wild turkey detections (p=0.985) at the study area level (**Figs. 3.2a,b**).

Species richness analysis found the highest support for the null model p(.) Psi =1 and models that contained one of the two dog covariates (e.g., p(Off Leash) Psi =1). We found a weak negative correlation between species richness of native mammals and off-leash dogs/day (β=- 0.029, SE 0.027) and on-leash dogs/day (β=- 0.006, SE 0.008); however, there is substantial overlap of zero with these beta estimates indicating a non-statistically significant result. We did not find differences in species richness between study sites or when we compared the three target properties with comparison property groups. Due to model uncertainty, we model-averaged our estimate of species richness across all models. Model averaged estimates found a low proportion of mammal species richness across all sites (p=0.163, SE 0.015) compared to the available pool of mammal species.

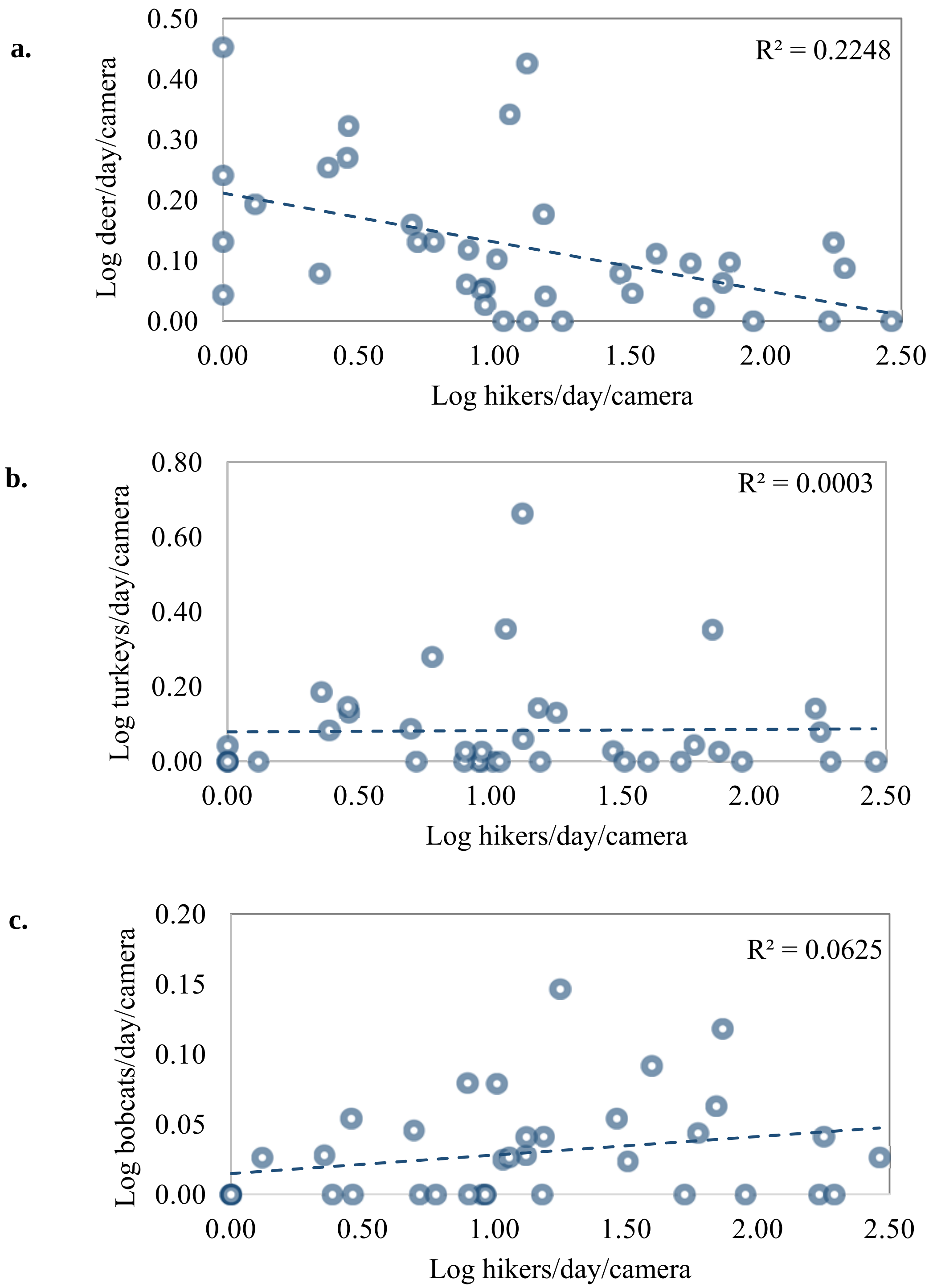
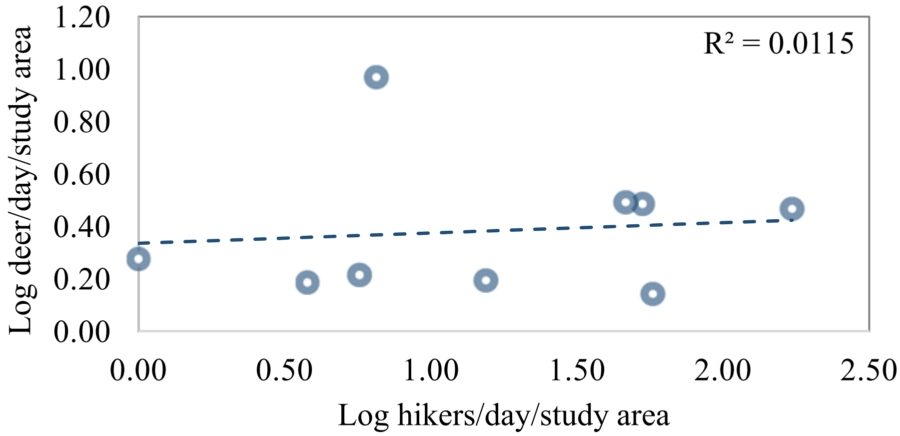
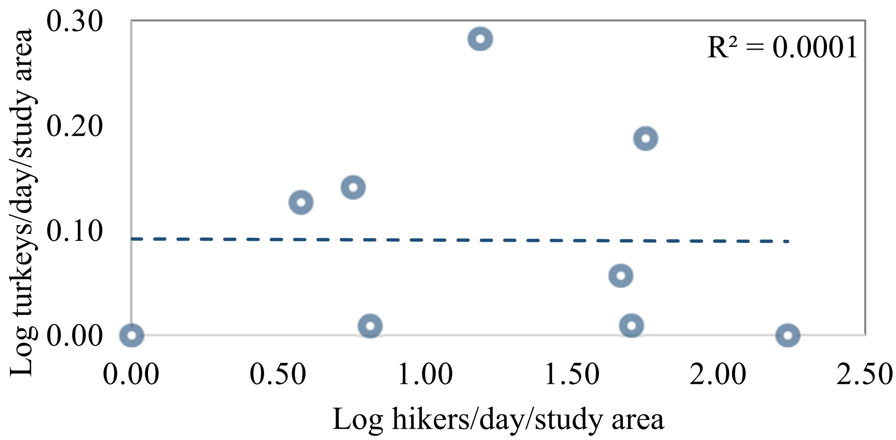


Figure 3.1. Linear regression of **(a)** deer, **(b)** wild turkey, and **(c)** bobcat detections versus hikers per day at the sampling point level. Deer detections were correlated negatively with increasing detections of hikers. Wild turkey and bobcat detections were not correlated with hiker detections. All data points were log(x+1) transformed to meet the assumption of normality.

a.



b.



c.

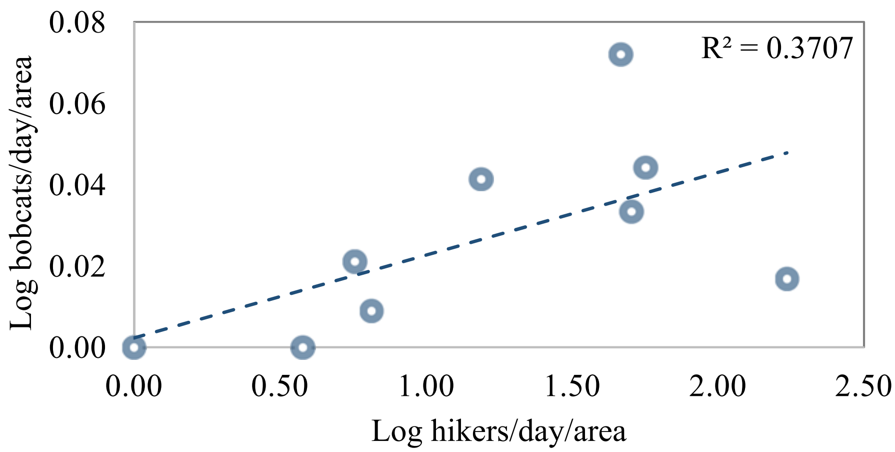


Figure 3.2. Linear regression of the mean **(a)** deer, **(b)** wild turkey, and **(c)** bobcat detections versus the mean hikers per day at the study area level. Deer and wild turkey detections were not correlated with hiker detections. Bobcat detections were correlated positively with hiker detections. All data points were log(x+1) transformed to meet the assumption of normality.

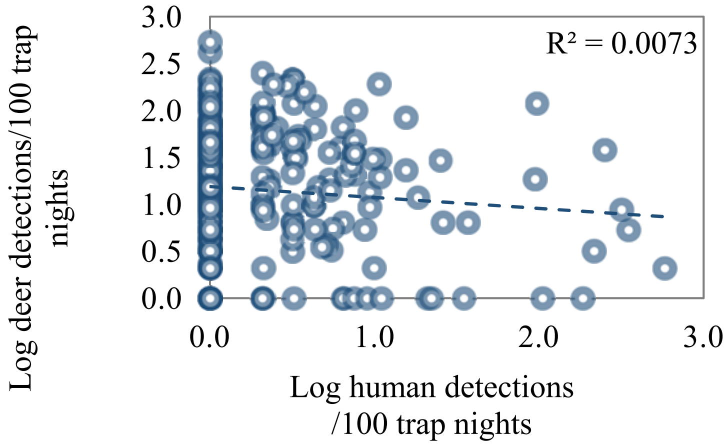
Table 3.4. Model results of species richness analysis for all study sites in the Sonoma Valley. The null model found the most support with some support for a weak negative correlation between the rate of dogs off or on leash and species richness.

Model	Δ AICc	AICc Weights	*K*
p(.) Psi=1	0.000	0.335	1
p(OffLeash) Psi=1	0.912	0.212	2
p(OnLeash) Psi=1	1.706	0.143	2
p(Hikers) Psi=1	2.133	0.115	2
p(Cyclists) Psi=1	2.228	0.110	2
p(SuperGroup) Psi=1	4.096	0.043	3
p(SuperGroup+OffLeash) Psi=1	4.493	0.035	4
p(SuperGroup+Hikers) Psi=1	6.271	0.015	4
p(Group) Psi=1	13.818	0.000	9

Existing Data

Analysis of existing data did not find strong correlations between the human detections and wildlife detections. It is important to note that these prior studies were focused on maximizing detections of wildlife, and they were not designed to capture human detections. We analyzed SLT and SCRP data for correlations between human and wildlife detections per 100 trap nights. We did not observe correlations between human and deer detections (p=0.111) or between human and bobcat detections (p=0.455) in the SLT dataset (**Fig. 3.3**). However, the data for bobcats were zero-inflated; there were > 170 sampling occasions where neither bobcats nor humans were detected, a potential contributing factor to the lack of correlation in the simple regression. We also did not observe correlations between human and deer detections (p=0.724) or between human and bobcat detections (p=0.599) in the SCRP dataset (**Fig. 3.4**). However, the number of cameras was very low (n=8); therefore, possible inference from these findings is limited.

a.



b.

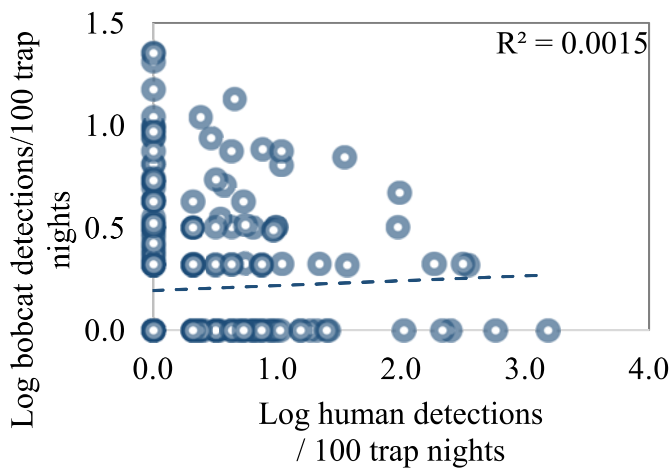
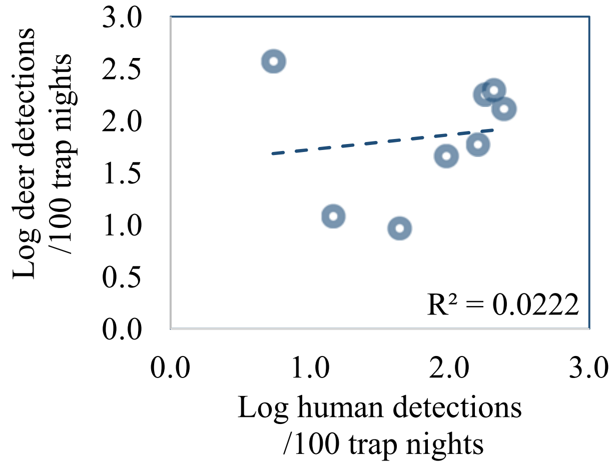


Figure 3.3. Sonoma Land Trust data of (**a**) deer and (**b**) bobcat detections versus human detections per 100 trap nights. Deer and bobcat detections were not correlated with detections of humans. All data was log (x+1) transformed to meet the assumption of normality.

a.



b.

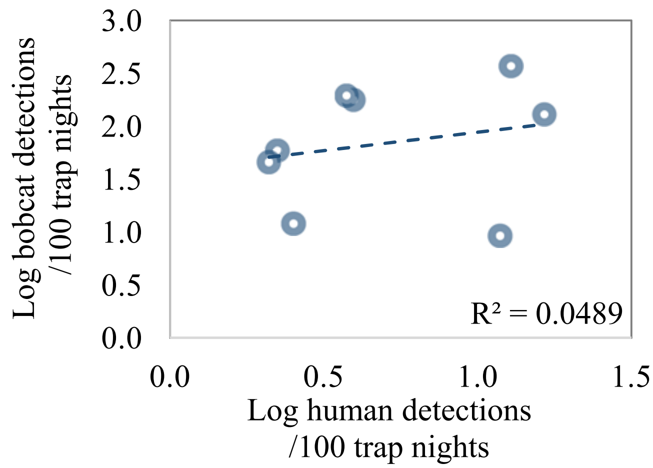


Figure 3.4. Sonoma County Regional Parks data of (**a**) deer and (**b**) bobcat detections versus human detections per 100 trap nights. Deer and bobcat detections were not correlated with detections of humans. All data was log (x+1) transformed to meet the assumption of normality.

Discussion

We sought to monitor human recreation and detect wildlife species on nine properties within the Sonoma Valley. As we expected, Sonoma Developmental Center and its two comparison properties (JLSHP and SVRP) had the highest current levels of human recreation activity, whereas GOR and SRCH had the lowest levels. Our use of passive camera traps created a visual record of human presence, including illicit activity such as off-leash dogs and park use during restricted hours.

However, it is important to note that we sampled a very narrow window of 14 days within one season. This sampling effort achieved our goal of estimating visitation levels on these properties during a period that we predicted would have some of the highest annual rates of human recreation activity, but it limits inference to other seasons (e.g., fall or rainy seasons).

Human recreation activity in each target property was lower than their comparison properties, apart from SDC and JLSHP. Recreational use of SVRP was much higher than all other properties, and is concerning as a barrier of recreation disturbance within the SVWC and for potential impacts on the eastern section of SDC. Glen Oaks and SRCH are both facing pressures of increased recreation, which, given our results and if they follow patterns of their comparison properties, could negatively influence mammal occupancy and corridor movement.

Camera traps captured detections of 11 mammal species at three different trophic levels. Analysis of our data and existing data showed mixed results between rates of wildlife and human detections. Detections of deer appeared to be negatively correlated with higher rates of human detections at the sampling point level (**Fig. 3.1a**); however, this relationship did not hold at the study area level, possibly because deer adjusted their habitat use to avoid busier trails within a study area. A recent study pre- and post-opening of a recreation trail in the North Sonoma Mountain Regional Park did find declines in deer detections following opening of the trail (Townsend et al. 2017), which is consistent with our findings.

We detected bobcat in seven of nine study areas, but analysis of these data and the SLT and SRP data found no correlations between the rates of human and bobcat detections. This is potentially due to bobcats' ability to increase use in areas where apex predator use is diminished (i.e., mesopredator release). It could also be attributable to our narrow sampling window, which may have resulted in few detections of higher trophic level, low-density, and elusive species.

Gray (2017) conducted a more thorough occupancy analysis using the same SLT dataset. This analysis found that human and dog detections were not an important covariate related to the occupancy of any mammal species; rather habitat covariates and proximity to human population densities were the most important drivers of species occupancy (Gray 2017). Although the SLT study was not designed to investigate effects of human recreation, these results are consistent with those of another recent study in the San Francisco Bay Area (Reilly et al. 2017), which found that environmental covariates such as land cover, precipitation, and elevation were more strongly associated with mammal occupancy than recreation activity levels. However, both studies contrast with earlier research in the ecosystem, which recorded more than five times fewer detections of native carnivores in protected lands open to recreation access (Reed & Merenlender 2008) and observed decreasing detections of native carnivores with increasing levels of human and dog visitation (Reed & Merenlender 2011).

There are several possible explanations for the contrasting results of these prior studies; these explanations may also be useful for interpreting relationships between recreation activity and wildlife detections and planning for future monitoring efforts in Sonoma Valley. In addition to differences in field research methods (i.e., transect-based scat surveys vs. point-based camera traps) and statistical analyses (i.e., paired-sample t-tests vs. occupancy models), the studies also differed in several fundamental aspects of research design. First, Reed and Merenlender (2008) compared recreation paired sites selected to be similar in habitat characteristics and landscape context, whereas Reilly et al. (2017) studied recreation across a gradient of sites encompassing multiple habitat types and land uses. Second, Reed and Merenlender (2008, 2011) modeled effects of recreation at the reserve level, using individual survey transects as replicates, whereas Reilly et al. (2017) modeled effects of recreation for individual camera stations assumed to be independent of one another. Third, Reed and Merenlender (2008) collected data during only one season of one year, whereas

Reilly et al. (2017) surveyed their sites once each over a period of three years. All of these differences may have contributed to the greater variability observed by the Reilly et al. (2017) study. Strong variability in other factors that are well-known to influence mammal distributions (e.g., habitat type, human development, or seasonal effects) make it difficult to conclude whether the potential effects of recreation on the target species were truly absent or simply undetected. As a result, we recommend that future researchers consider carefully how to design studies to assess possible effects of recreation activity at appropriate spatial and temporal scales and to isolate measures of recreation disturbance from other confounding factors (Chapter 6).

In conclusion, using camera traps to monitor humans and wildlife, land managers and researchers can estimate the levels of human recreation, the types of recreation activities, and how recreation varies spatio-temporally across the landscape. We have shown that even with narrow sampling windows researchers can capture general estimates of recreation rates and types, while also detecting a majority of the mammal species in a region. With the growing popularity of and greater ease in acquiring camera traps, more land managers and researchers can gather an informative dataset on the recreational use of protected lands.

4. Guidelines for Stewardship of Recreation and Wildlife at Target Properties

Management for both recreation and wildlife conservation is challenging given the multiple-use mandates of protected areas and the varying responses of species to different types and intensities of recreation activity. Hundreds of research articles have demonstrated that human recreation has a myriad of negative impacts on wildlife individuals and populations (Larson et al. 2016). When considering the impacts of recreation, managers must focus on different possible sources of disturbance, including infrastructure (e.g., trails, campgrounds, lights), the number of people participating in different activities, their spatial and temporal distribution, and the presence of human-commensal animals (e.g., dogs, cats, horses). Considering empirical evidence for effects of these disturbances on one or more focal species or taxonomic groups, although not ideal because it does not represent the full wildlife community, can provide the most straightforward answers for decisions such as where to place a trail or how to regulate domestic dogs.

Recommendations for quantitative thresholds of recreation effects are lacking for many species, taxonomic groups, and sources of disturbance (Chapter 2). Thresholds for apex predators and mesopredators are especially lacking (**Table 4.1**); this is likely attributable to the difficulty of observing these species and the broad spatiotemporal scale at which they interact with their environment. Information regarding impacts of trail density is also noticeably deficient. Future studies that focus on apex predators and mesopredators, especially in relation to trail density or visitor numbers, would be particularly useful for infrastructure development and protected area management in northern California and worldwide.

Given these important gaps in our knowledge, we recommend a precautionary approach that adopts maximum values of quantitative thresholds observed for relevant taxonomic groups, while excluding extreme outliers. Specifically, we recommend minimum thresholds for distance to trails of 75 m for passerine birds (e.g., pygmy nuthatch), 200 m for ungulates (e.g., mule deer), 400 m for

Table 4.1 Recommended thresholds of three measures of recreation disturbance for five taxonomic groups. Threshold values are maximum observed thresholds, excluding extreme outliers. Data is sparse for threshold effects for most taxonomic groups, especially mammalian and avian predators, and many recommendations are derived from a small number (*n*) of studies. A dash (—) indicates insufficient information to recommend a threshold.

Taxonomic Group	**Distance to trails**	**Visitation level**	**Distance to dogs**
Apex predator (e.g., mt. lion)	400 m (n = 2)	—	—
Mesopredator (e.g., bobcat)	—	—	—
Ungulate (e.g., mule deer)	Hikers: 100 - 200 m (n = 6) ATVs: 400 m (n = 1)	250 visitors/day (n = 1)	100 - 150 m (n = 2)
Bird of prey (e.g., eagles)	400 - 600 m (n = 4)	1 ORV/day; < 20 groups of people/day (n = 2)	—
Passerine bird (e.g., pygmy nuthatch)	75 m (n = 4)	< 800 visitors/day (n = 1)	100 m (n = 1)

apex predators (e.g., mountain lions), and 600 m for birds of prey (e.g., golden eagles). Based on our review, threshold distances appear to increase with increasing trophic level and body size for birds, with smaller avian species having threshold distances an order of magnitude lower than distances for larger species (**Table 4.1**). The ability for some mammal species to habituate to human presence may explain why we did not observe similar trophic level or body size relationships for mammals (**Fig. 2.6**).

Research examining the effects of total recreation trail system length or density on wildlife population dynamics and habitat use is lacking. Harris et al. (2014) provides one of the clearest examples of trail density thresholds on wildlife. They observed decreased habitat use by moose (*Alces alces*) in areas of >5% snowmobile tracks covering; however, it is important to note that off-trail snowmobile use is different from other recreation activities, which occur along defined trails. Beyond this one study's estimate, guidance for trail system design can be derived from the numerous studies examining effects of distance to trail on wildlife habitat use and behavior. For example, a land manager could use GIS software to generate buffers around all trails in a park or protected area using the recommended threshold distances (**Table 4.1**). These maps can be used to identify areas were recreation effects are likely to be minimized (i.e., beyond threshold distances) for a species or taxonomic group of concern. If buffers are widespread throughout the park or protected area, then the maps can be used to explore opportunities to close or reroute trails to allow adequate areas for wildlife habitat use and movement. For example, applying the recommended threshold distances to buffer existing trails at SDC shows that there are few areas within the property where there are likely to be minimal effects of recreation on perching birds, ungulates, or apex predators (**Fig. 4.1**).

Finally, the presence of dogs is a well-known disturbance for both wildlife and other recreational visitors (Lenth and Knight 2008; Ettema 2015). Estimates for the distance from or number of dogs at which predators will avoid dogs is lacking, but research has shown that habitat use of ungulates decreases near trails where dogs are present, and off-leash dogs have a greater potential to disturb wildlife than on-leash dogs (Lenth and Knight 2008). There is evidence that passerine birds are impacted by the presence of dogs (Banks and Bryant 2007); however, quantitative thresholds regarding the number of dogs or the distance from dogs are lacking. From a precautionary perspective, we recommend that land managers should allow dogs only on leash and consider restricting dogs from trails near sensitive habitats to create larger buffers for wildlife, and because human visitation rates are higher in protected areas that allow dogs (Reed and Merenlender 2011).

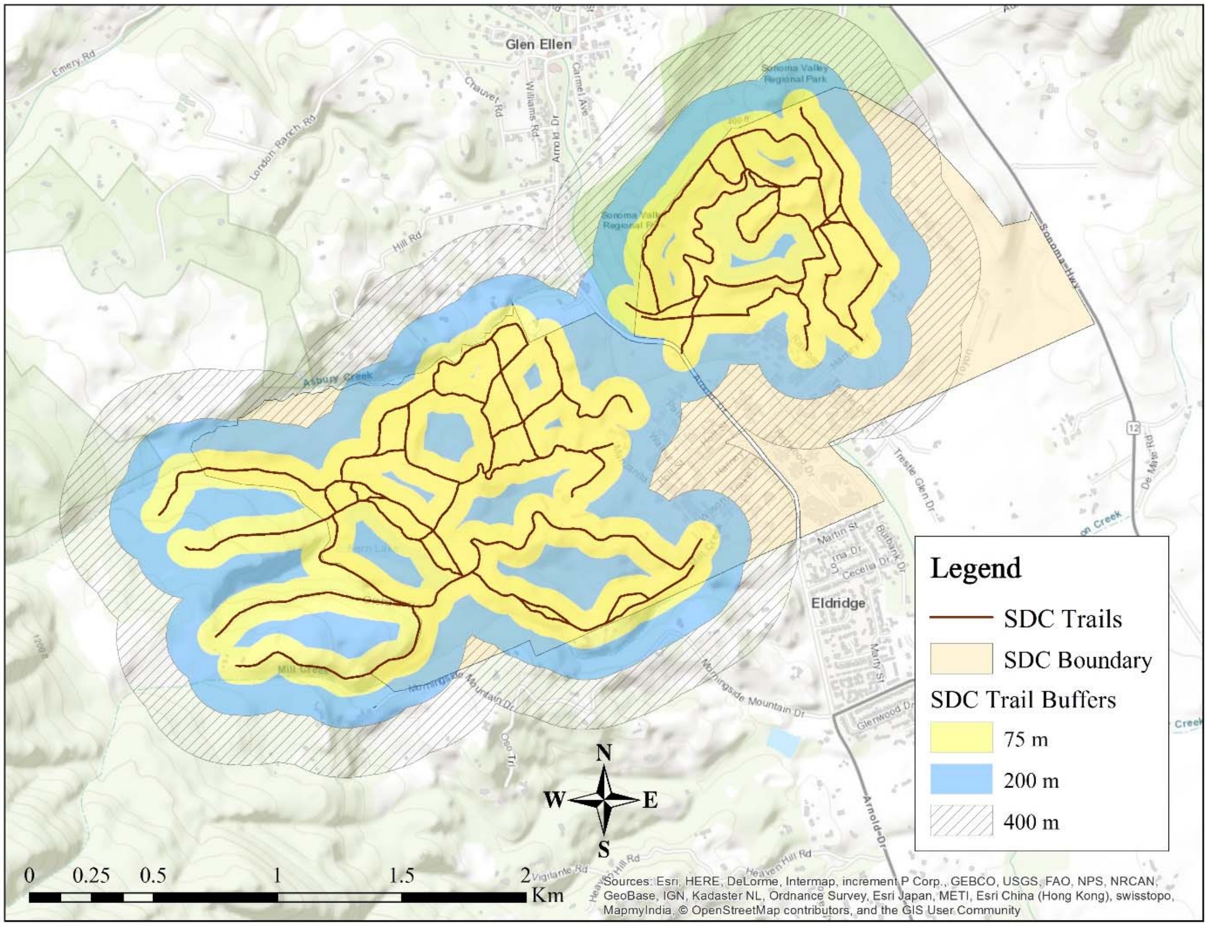


Figure 4.1. Threshold buffers for perching birds (75 m), ungulates (200 m) and apex predators (400 m) applied to recreation trails of the Sonoma Developmental Center and eastern Jack London State Historical Park. Trail buffers overlap most of the property resulting in no contiguous areas across the property free from potential recreation effects. This map only takes into consideration the effects of recreation and does not include the effects of human presence in Glen Ellen, Eldridge and other surrounding properties.

Sonoma Developmental Center

The Sonoma Developmental Center (SDC) is a key pinch point in the wildlife corridor that connects Jack London State Historic Park (JLSHP) and Sonoma Mountain with the eastern face of the Sonoma Valley. Recreation use of SDC is already relatively high in comparison to the other two target properties (Glen Oaks Ranch and Santa Rosa Creek Headwaters; **Fig. 4.2**). Jack London State Historic Park, which is less developed and at slightly higher elevation than SDC, had marginally fewer hikers, whereas SVRP had three times the total visitors as the other two properties. SDC and

JLSHP had comparable levels of mammal species detections (**Table 3.3**), with more detections of deer and wild turkey on SDC and more detections of bobcat on JLSHP. In comparison, SVRP had substantially fewer detections of all mammal species except domestic cats. With a limited sample size and a lack of pre-disturbance data, it is difficult to state definitively that the much lower level of mammal detections on SVRP is attributable to the high levels of recreation activity; however, the proximity of the three properties and the strong reduction in wildlife detections suggests a possible relationship between human recreation and wildlife activity.

Sonoma Developmental Center is divided easily into western and eastern halves, due to the positions of the campus buildings and Arnold Drive bisecting the property. In addition, human recreation activity on the two sides of the property has different sources. In the western half of SDC most of the recreation appears to be cyclists and hikers venturing to Fern Lake or into JLSHP. In the eastern half of SDC recreation pressure is a result of Suttonfield Lake and the proximity to SVRP. Social trails, unofficial trails created by visitors walking off established trails, are present across both halves of the property and appear to be used heavily by cyclists and hikers.

Heavy use of Orchard Road, in the western section of SDC, already exists and creates seamless trail connections between SDC and JLSHP. There were numerous repeat visitors of the main road within the two-week sampling period. It is unknown whether these visitors were employees of SDC; however, SDC administrators did inform us that employees often walk some of the trails during breaks or after work. Therefore, hiker volumes from this group of people may reduce after SDC's planned closure. For the easiest transition, management of the natural resources of the western portion of SDC should follow the current recreation management of JLSHP. Efforts should be made to reduce the trail density and revegetate social and duplicative trails (trails within 200-400 m of each other) throughout the western section (**Fig. 4.1**). Permanent barricades with

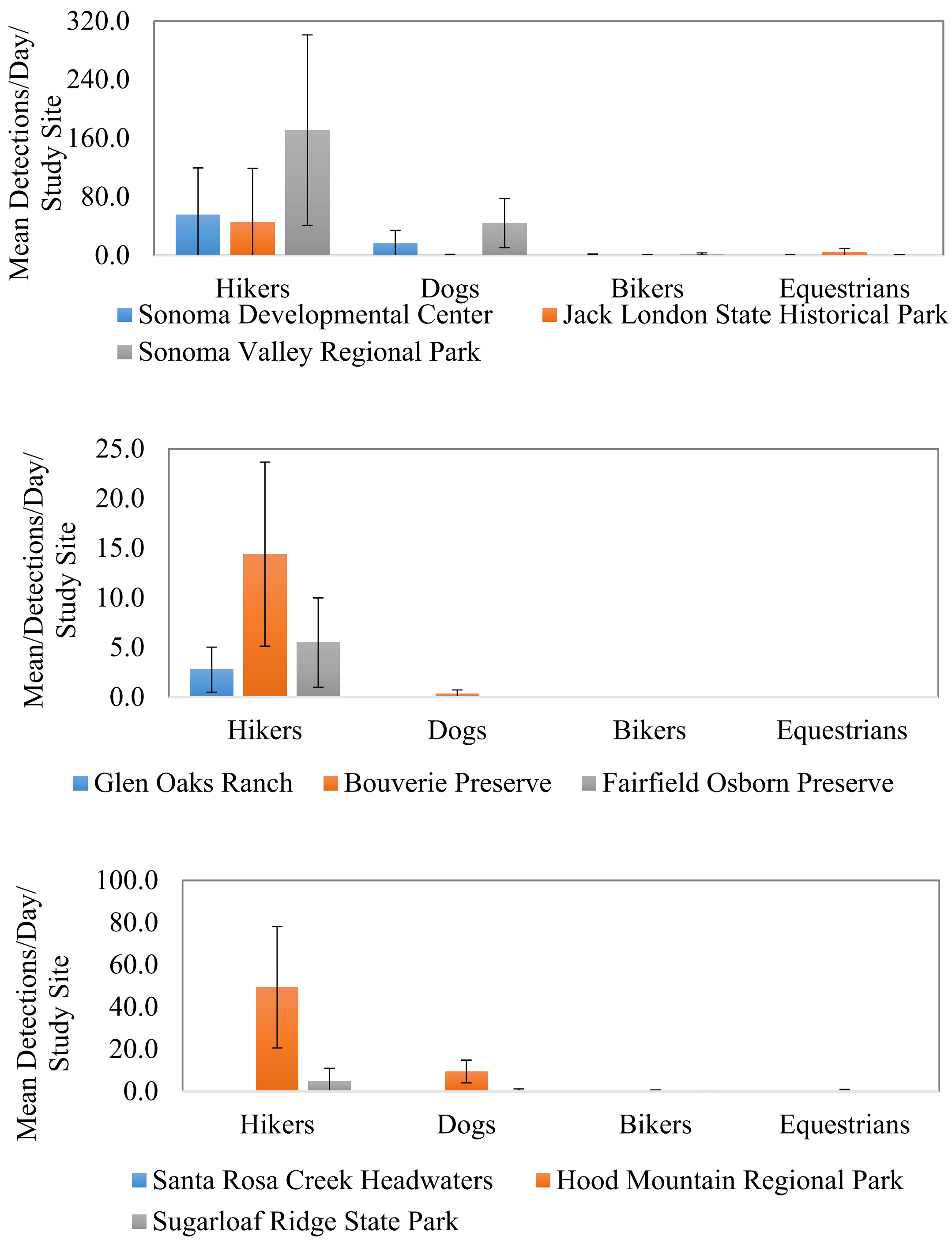


Figure 4.2. Mean (± 95% CI) detections per day across study sites for the Sonoma Developmental Center, Glen Oaks Ranch, and Santa Rosa Creek Headwaters property and their associated comparison properties. Hiking was substantially higher than any other recreation activity. Note that y-axes scales are different.

messaging concerning trail closures should be positioned in front of all trails that are being closed (Lawhon et al. 2016).

The eastern section of SDC currently has higher levels of recreation activity than the western section. A porous boundary between SVRP and eastern SDC allows for easy movement between the two properties. There are at minimum six spots where fencing does not exist (e.g., fencing holes and gaps) and/or where trails move continuously across the boundary. However, despite these existing connections, we do not recommend transitioning the eastern half of SDC to management similar to SVRP, given concerns previously stated regarding high recreation levels and low wildlife detections.

The pinch point and area of greatest concern for movement of wildlife appears to be the northern and northeastern portions of SDC and the south and southeastern portions of SVRP. Recreation levels are higher in these areas than any other properties that we investigated and they are among the narrowest swaths of contiguous natural lands for animal movement within the entire corridor. Higher recreation in the eastern section of SDC could create a barrier for some wildlife attempting to travel through the corridor. In this area, we recommend restoring natural vegetation, limiting visitation of these areas, increasing enforcement of dog leash laws, and closing and revegetating duplicative trails in the eastern section of SDC to reduce human impacts on wildlife (**Fig. 4.1**). If recreation were to increase to levels similar to SVRP, then we would recommend seasonal closures of some trails and restricted dog access. Finally, the boundary between SDC and SVRP should be enforced, allowing only human movement at the far western and eastern ends of the common boundary. This should reduce the impact area for wildlife and minimize disturbance to animals moving through the area.

Glen Oaks Ranch

Glen Oaks Ranch is a SLT-owned preserve consisting primarily of open oak woodland and scrubland with a small area of human infrastructure near Highway 12. As anticipated, we detected low recreational use of GOR (**Table 3.2**). The two comparison properties, BP and FOP, had 2–6 times more detections of hikers per day (**Fig. 4.2**). We did not find a relationship between higher levels of visitation by hikers on BP and reduced mammalian detections or species richness compared with GOR. Conversely, FOP had lower detections and species richness of mammals. Fairfield Osborn is on the western slope of the Sonoma Mountains, whereas BP is directly adjacent to GOR within the Sonoma Valley; the greater separation between the properties and associated habitat differences could be a partial explanation for the differences in mammal detections. We also had a lower sampling effort of three cameras at FOP, which could contribute to greater variability in wildlife detections.

Given our findings from BP, a modest increase in hiker use (≤ 2x) on GOR is likely sustainable for the purposes of the property acting as a key linkage in the wildlife corridor. Extrapolating from the daily visitor numbers that we detected, this means that SLT should allow fewer than 200 visitors to GOR per month. However, we recommend that no new trails should be added to GOR, and increases in hikers or other forms of recreation (e.g., mountain biking) on GOR and BP should continue to be closely monitored and restricted (Chapter 4), especially given the narrow width of woodland cover connecting the west side of Highway 12 to GOR and BP via Stuart Creek. In addition, the high density of GOR and BP trails along the narrow corridor surrounding Stuart Creek is a concern for mammals and perching birds, given the quantitative thresholds of 75-400 m derived from our literature review (**Table 4.1**). Three trails and one road are located <70 m from Stuart Creek, well within the threshold effect-distances documented for ungulates and passerines. Therefore, if visitation by hikers were to increase, it should be concentrated on trails to the north of Stuart Creek and avoided on the Phyllis Ellman Trail (**Fig. A.3**).

Santa Rosa Creek Headwaters

The Santa Rosa Creek Headwaters (SRCH) property is a unique inholding within HMRP that is currently closed to the public. We did not detect any human recreation activity on SRCH. Hood Mountain Regional Park (HMRP) had recreation activity levels similar to those of SDC (**Table 3.2**), but visitation was concentrated on the southern trails of the park, and specifically on routes leading to the summit of Hood Mountain. Sugarloaf Ridge State Park (SRSP) McCormick Addition had much lower levels of human recreation activity than HMRP (**Table 3.2**), potentially due to the more remote access to the property. If SRCH were to be opened to the public, trail use would likely be lower than on the southern trails of HMRP, but potentially higher than SRSP, given the attractiveness of a backpacking campsite. Addition of a trail that connected either the Summit Trail or the Hood Mountain Trail to the Headwaters Trail via SRCH would likely require a tightly switch-backing route exacerbating the recreation effect-zone across the property (i.e., more area within an 80 m buffer of the trail) (**Fig. 4.3**).

Wildlife detections on SRCH were unexpectedly low given detection rates on HMRP and SRSP (**Table 3.3**). This could be attributable in part to the small size of the property and lower sampling effort on SRCH. Deer detections were much higher on SRCH, slightly lower on SRSP, and lowest on HMRP, which would follow the overall patterns that we observed, and results of the North Sonoma Mountain Regional Park study (Townsend et al. 2017). The proposed camping and hiking infrastructure on SRCH will likely decrease wildlife detections and richness levels as compared to eastern sections of SRSP.

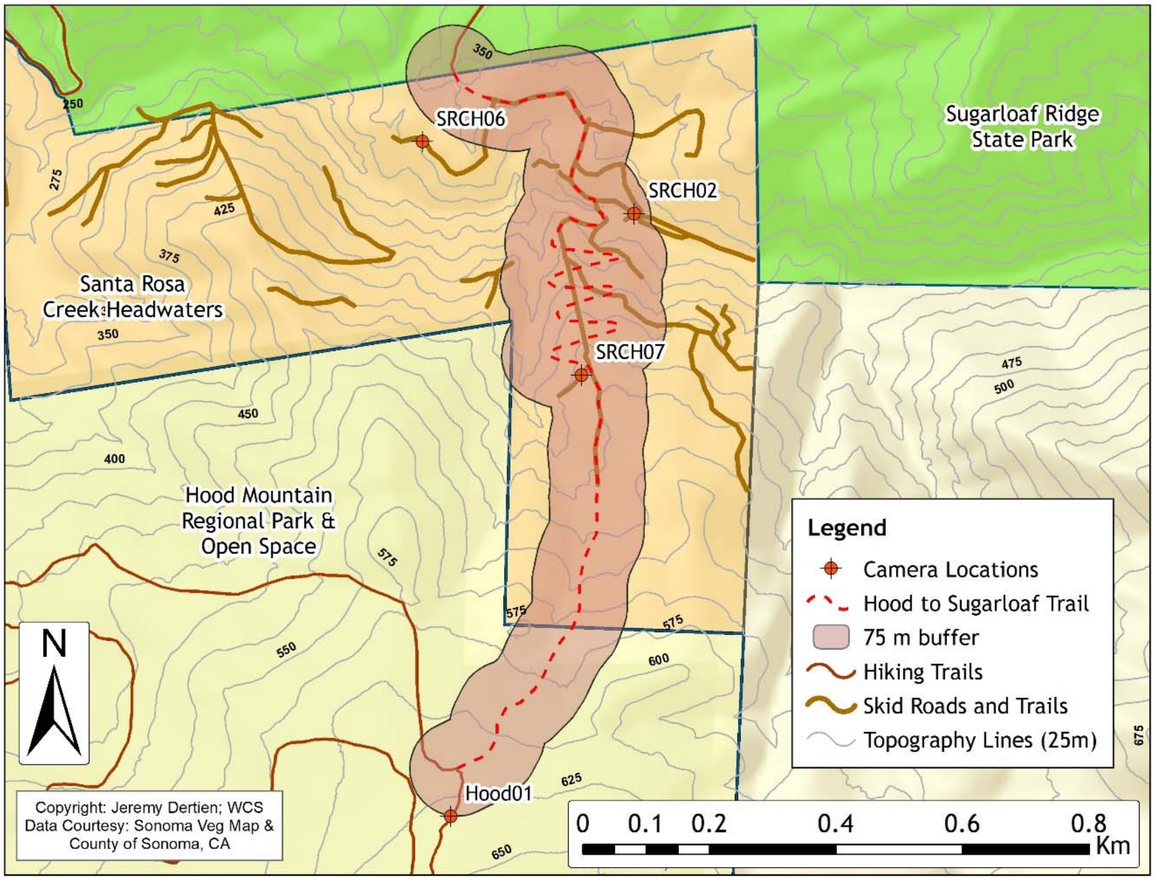


Figure 4.3. Potential route of a trail to connect the Summit Trail in Hood Mountain Regional Park and Open Space with the Headwaters Trail in Sugarloaf Ridge State Park via the Santa Rosa Creek Headwaters property. The 75 m buffer is representative of the recommended effect-distance threshold for perching birds.

Reducing the creation of social trails is an important consideration for the construction of this and any trail system. Social trails expand the negative effects of human recreation on the flora and fauna of any conserved land (e.g., wildlife avoidance, soil erosion) (Bay & Ebersole 2006; Wimpey & Marion 2010; Monteiro 2015). A potential connection trail through SRCH would likely intersect historic logging skid roads that are distributed sporadically across the southern woodlands of the SRCH property (**Fig. 4.3**). At these intersections, permanent barriers should block access from the constructed trail to skid roads. In addition, skid roads should be revegetated in areas that are easily accessible and visible from the constructed trail to dissuade visitors from leaving the official trail. Minimizing social trails would also reduce the risk of falls and other accidents in the rugged and steep areas of the property.

Keeping SRCH closed to the public would obviously maintain the lowest impacts of human recreation. As this may not be feasible, recreation activity should be restricted to hiker use only to minimize possible effects of recreation on wildlife. As stated, we would anticipate relatively low recreational use of the property given our observations on surrounding properties. However, it is difficult to predict the attractiveness to hikers, cyclists, and equestrians to campsites and a new large loop trail extending across HMRP, SLSP, and SRCH, but potentially significant increases in visitation may occur and possible wildlife responses should be closely monitored and managed if these infrastructure developments occur (Chapter 4). If recreation levels were to elevate to magnitudes similar to those of HMRP (**Table 3.2**), then additional restrictions should be considered such as seasonal hiking closures, increased enforcement of dog leash regulations, or the closure of the property to dogs entirely.

5. Monitoring to Assess Future Changes in Recreation and Wildlife

Continued monitoring of human recreation activity and wildlife habitat use is vital for the long-term management of the Sonoma Valley Wildlife Corridor (SVWC). With our study design, we were able gather a snapshot of the relative levels of human recreation on properties in the Sonoma Valley. However, our data encompasses only a brief survey period during one season in one year, prior to anticipated changes in recreation access and management. Thus, it is important to continue to collect data to ensure that human recreation levels are measured accurately and managed effectively to ensure the continued function of the wildlife corridor. A longer time series of data would be needed to document whether wildlife detections, habitat use, or species richness are changing in correlation with increasing or decreasing human recreation and to inform adaptive management decisions.

Sampling Strategy

Since our project has established a baseline for recreation levels, camera traps should be deployed in the same spatial configuration as the original design. This will make comparisons across seasons and years easier to interpret. We conducted our sampling near the beginning of the dry season (April-May), when we hypothesized that conditions would be optimal for outdoor recreation in the Sonoma Valley. However, it is important to gather data across multiple seasons to understand seasonal fluctuations in recreation activity and wildlife habitat use. Therefore, camera traps should initially be deployed year-round to fully track the highs and lows of recreation levels and to increase detections of mammal species. Increased wildlife detections should ultimately produce more accurate estimates of habitat use (i.e., occupancy) probability. Recreation monitoring could then be restricted to narrower sampling windows to save time and funding if distinct seasons of recreation use are detected, but sampling should be conducted for ≥ two weeks per sampling site.

Properties within the Sonoma Valley Wildlife Corridor should be sampled first if all study areas are unable to be sampled each year, since the focus of this monitoring protocol concerns the wildlife corridor. Ideally, all nine properties in this study design, plus North Sonoma Mountain Regional Park, will be sampled each year. As additional properties are acquired in Sonoma Valley, or opened to public access for recreation, similar methods could be used to incorporate more study areas into the monitoring design.

Guidelines for Camera Traps

Field implementation of camera traps to monitor human recreation activity will vary depending on the region and ecosystem of interest. Depending on the recreation activity, placement of the camera trap set back slightly from the trail will be important to avoid missing detections, or detections of individuals in a group. For example, if sampling a multi-use trail with hikers and cyclists, the camera should be placed at least 2 - 3 meters from the trail or positioned at an angle to the trail, and not perpendicular to the trail. If the camera is too close to the trail, it will be activated by a cyclist, but will not take the picture quickly enough to capture an image of the cyclist. Continued research into the effectiveness of camera traps and suggestions on camera trap placement will provide valuable insight for recreation and natural resource managers (Miller et al. 2017).

In open spaces with high levels of human recreation activity or in regions where there is wariness towards cameras, efforts may be made to avoid capturing facial images. Identification of individual humans is rarely necessary, unless the managing agency is concerned about positively identifying people engaging in illicit behavior. Positioning cameras low to the ground can reduce facial images, but this could increase the chance of false triggers from ground vegetation and cyclists may not trigger the thermal detector on a camera due to the lack of heat coming from the bike.

Off-trail camera traps may not be as useful as on-trail camera traps because wildlife movement can be diffuse and harder to predict. Wildlife habitat use may be higher away from humans or recreation trails, but wildlife detection rates at off-trail sampling locations are typically lower than on-trail sampling locations (Dertien et al. 2017). Low detection rates off trail can lead to the erroneous conclusion that wildlife use is higher in human areas, when in fact the detection probability is much lower off trail. Further, if the data is being collected for occupancy analysis, there is the concern that low detection probabilities ($p < 0.20$) can produce biased occupancy estimates (MacKenzie et al. 2002). Off-trail camera traps can be useful for asking questions about threshold distances to human disturbance, but researchers and managers need to consider the potential differences in detection rates in the analysis of such data.

Leveraging Other Data

Beyond the continued use of camera traps to monitor levels of recreation activity, and collect opportunistic detections of wildlife species, external data should be leveraged to better estimate and monitor possible changes in wildlife habitat use. Multiple organizations within Sonoma County, including Sonoma County Regional Parks and Audubon Canyon Ranch (ACR) collect recreation and wildlife data. Combining camera trap data from these different entities may help to elucidate broader-scale or longer-term trends in wildlife habitat use, or provide further evidence to justify the need for changes in recreation management. In addition, leveraging mountain lion GPS collar data from ACR in combination with camera data from the monitoring protocol and others could help to evaluate the effectiveness of recreation management in maintaining the permeability of the wildlife corridor.

Adaptive Action

The obvious concern with the introduction of more recreation into the Sonoma Valley is the potential for disturbance to wildlife, especially within the narrow SVWC. Monitoring will continue to provide estimates of human recreation activity, but they are not useful if action is not taken before recreation visitation reaches unsustainable levels (i.e., current levels at SVRP). If recreation activity levels increase rapidly, especially on the target properties and properties with restricted access, management actions should be taken to decrease either the number of visitors, types of recreation activities, or spatial footprint of recreation trails and infrastructure.

If rapid changes occur on properties with restricted access (i.e., those properties that are open only by appointment), the number of people allowed on site should be decreased, or tours and public events should be concentrated to certain days or times of year. Parks and open spaces that are open to the public should first consider reducing access by cyclists or dogs, then potentially increasing admissions fees to create economic disincentives. Closure of duplicative and social trails on all protected lands will also decrease the disturbance potential across the landscape. It is too late to wait until wildlife detections or estimates of habitat use decrease, since we can anticipate from other studies that some species will be affected (Larson et al. 2016).

Post-fire Monitoring

The expansive Sonoma County fires of October 2017 will undoubtedly impact the human recreation activity in open spaces and preserves. Protected areas that were partially or completely burned within this study including BOUP, GOR, HMRP, SDC and SVRP will be indefinitely closed or have reduced recreation activity. Monitoring human recreation will continue to be important as these protected areas reopen and recreators return. Continued camera trap monitoring post-fire will track trends in mammalian detections and human use. This will be an important time to ensure that only official trails are being used and that social trails are being revegetated.

6. Research and Other Information Needs

1. Complete trail maps

More accurate conclusions will be derived from a study that considers the full spatial footprint of human recreation activity on the landscape. It is easier than ever to access maps of parks and open space trails. Visitors can download maps online, pick up a paper map at a trailhead, or take a digital picture of a large map display. However, trail databases are often inconsistent or incomplete. Therefore, prior to creating a study design, it is important to conduct heads-up digitizing of aerial photos, validated by on-the-ground mapping, of all designated recreation trails and undesignated social or informal trails (Wimpey & Marion 2011). It may also be important to map game trails, especially those that cross designated recreation trails and that could be used mistakenly used by visitors. Conclusions regarding human impacts on flora and fauna of protected lands may be flawed if there is a network of unmapped social trails not considered in a study's design.

2. Monitor human recreation patterns

As increasing research correlates non-consumptive recreation activities, such as hiking and biking, to negative effects on wildlife populations, there is a growing need for robust data on human recreation activity in protected lands. Few protected land managers collect reliable information on how many visitors enter protected areas (Newsome et al. 2013), or when they visit, where they go within reserves, or which activities they participate in during their visit (Hadwen et al. 2007). In addition, most (>80%) studies of recreation impacts measure recreation as a categorical variable; for example, researchers compare sites with and without recreation, or compare sites with low versus high levels of recreation activity (Larson et al. 2016). Instead, by measuring recreation as a continuous variable, scientists can specify response relationships and identify thresholds of recreation disturbance, in terms of the number of visitors, their spatial distribution, or the timing of their visits (Monz et al. 2013). These relationships can then be translated into appropriate management thresholds.

Monitoring of wildlife habitat use via camera traps is prevalent and increasingly popular among researchers, conservation organizations, and even private citizens. The collection of these data often includes detections of human visitors to protected lands that may be ignored in favor of wildlife detections. However, these data on human activity provide an important covariate to correlate with wildlife habitat use, especially when analyzed within a mark-recapture or occupancy framework. Beyond camera traps, the use of on-the-ground technicians directly observing human recreation activity, social surveys of visitors, or expert opinion surveys of land managers can provide valuable information to guide future management decisions.

3. Compare recreation activities

Types of permitted human recreation activities often vary among parks and open spaces, and these different activities may have variable effects on target wildlife species. Relatively few studies to date have directly compared the effects of different activities at the same time, in the same place, and on the same target species (e.g., Taylor and Knight 2003). Understanding the relative effects of different types of recreation activities is an important research need, especially as recreation preferences among reserve managers change, or as new types of recreation activities emerge (e.g., nighttime endurance events).

Therefore, it is important to fully map the different combinations of permitted recreation for each open space or trail before creating a study design. It is also important to create a study design that incorporates the full range of permitted recreation activities, and different combinations of those activities, so that a researcher or manager can study if recreation activities vary in effect on wildlife habitat use or survival and to monitor for non-permitted or illegal activities. These comparisons will be useful for resolving conflicts among user groups and creating a plan that balances visitor preferences with wildlife conservation.

4. Include reference conditions

It is important to include a reference condition or treatment in a study design to establish a baseline to detect potential effects of human recreation activity. For a study of the effects of recreation in general, a reference condition would be protected lands with no public access. For a study of the effects of dog management policy, a reference condition would be protected lands that do not permit dogs.

In addition to reference conditions, it is important to isolate the effects of different permitted recreation activities (or other management provisions) within a factorial design, which is a study design that incorporates all possible combinations of factors. This allows a researcher to isolate the effect of individual factors (e.g., cyclists) on the target wildlife species, as well as possible interactions among factors. However, researchers should be wary of attempting to study too many recreation activities within the same study design, since the addition of each activity will reduce statistical power to detect a difference among treatments.

5. Assess management options

The fundamental question of interest to land managers seeking to balance public access for outdoor recreation with wildlife conservation is: What are the management options for avoiding or reducing the negative effects of recreation on wildlife, and are they effective? Very few published studies address this question, for example, by manipulating management activities or creating an experimental design that simulates realistic management alternatives (Larson et al. 2016). Yet, these are the studies that will be most useful for resolving management challenges and providing rigorous scientific evidence to support decisions to permit recreation uses or restrict public access.

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Appendix I. Maps

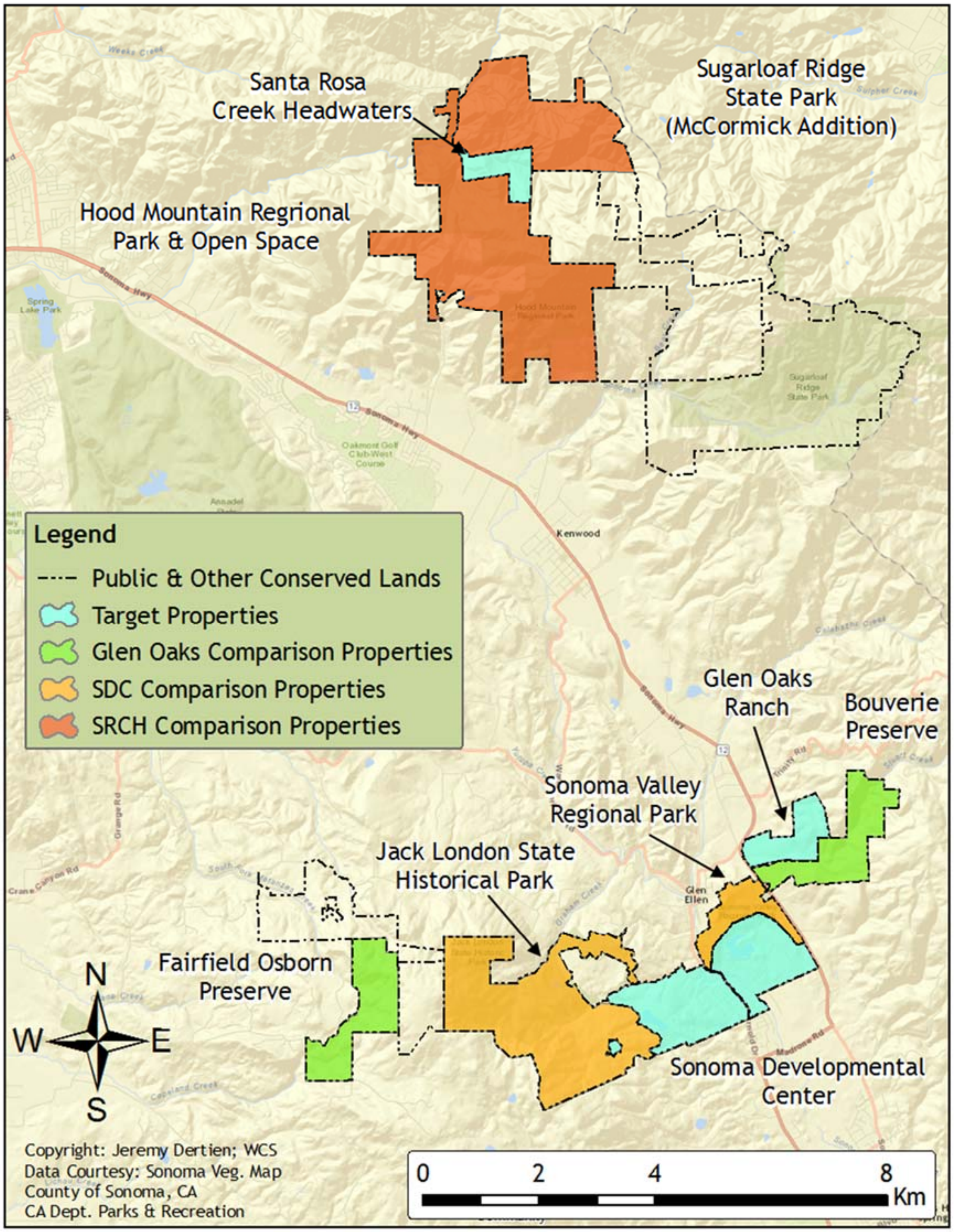

Figure A.1. All nine study areas across Sonoma Valley. Target properties are depicted in light blue with paired comparison properties in similar color groupings.

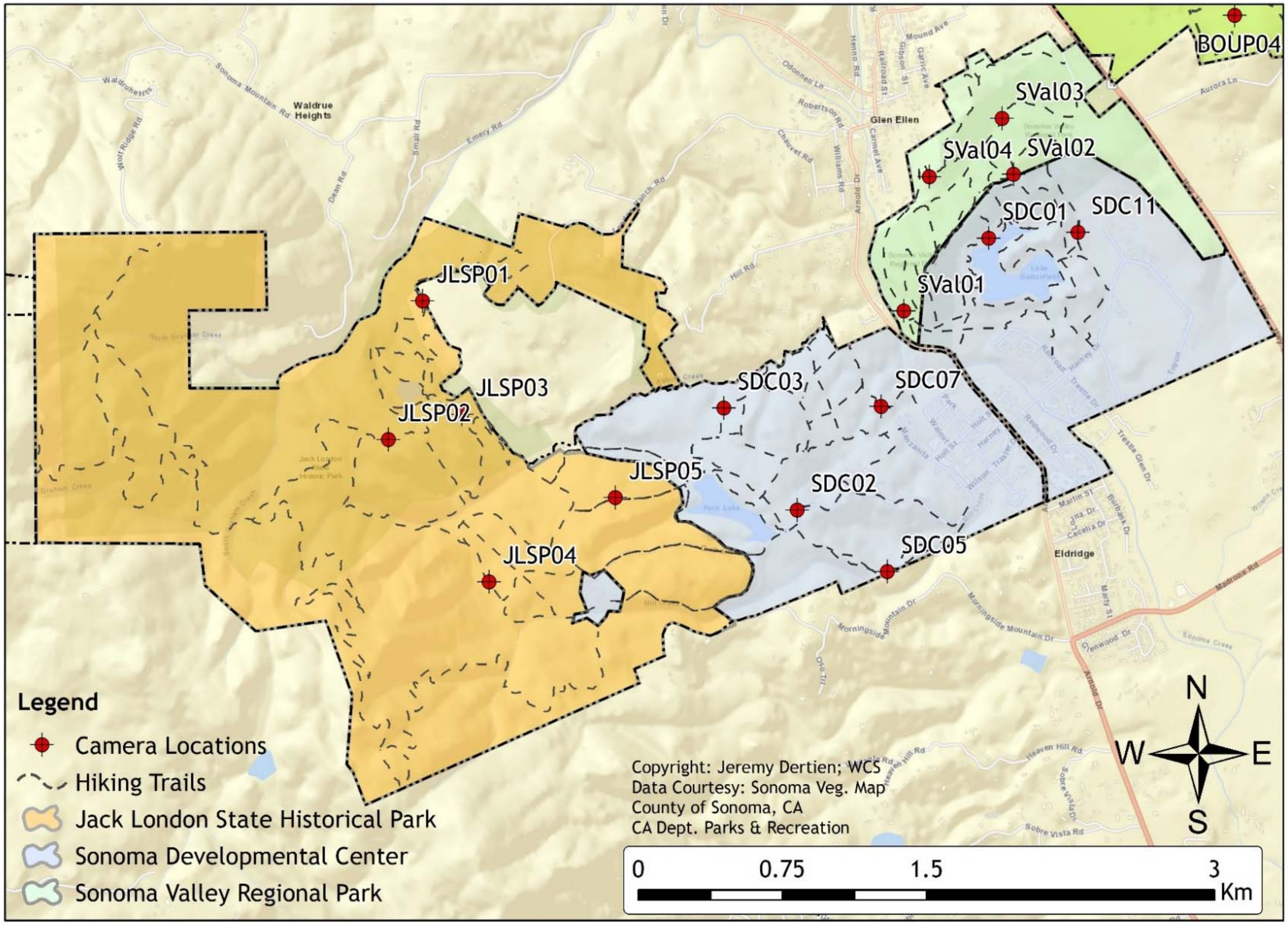

Figure A.2. Jack London State Historical Park, Sonoma Developmental Center and Sonoma Valley Regional Park are in south Sonoma Valley and constitute some of the narrowest portions of the Sonoma Valley Wildlife Corridor. Bouverie Preserve appears in the top right corner of the map.

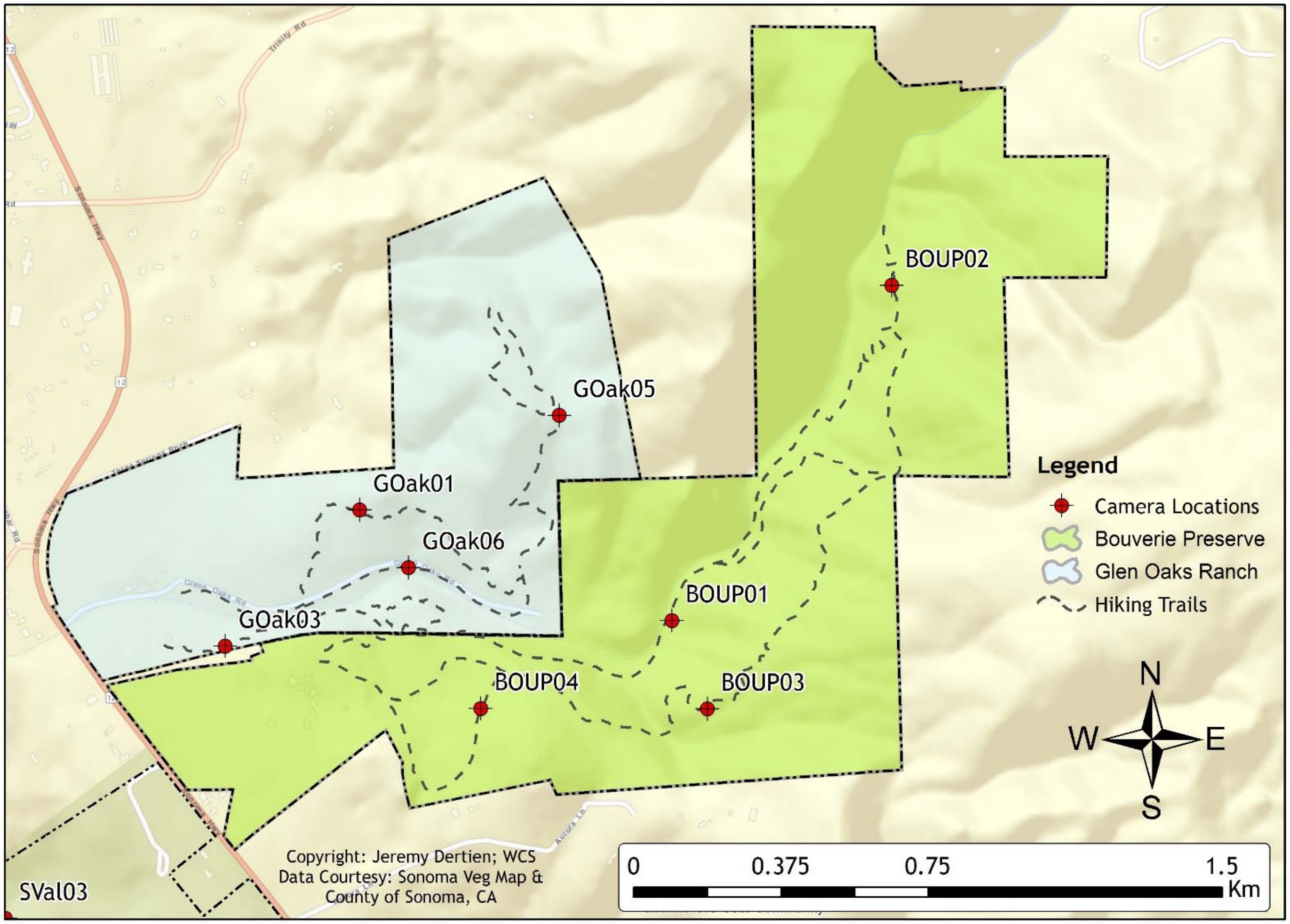

Figure A.3. Glen Oaks Ranch and Bouverie Preserve are located in southern Sonoma Valley to the east of Sonoma Valley Regional Park and Sonoma Developmental Center. Glen Oaks Ranch's Phyllis Ellman trail is located on the southern boundary of Glen Oaks Ranch in especially concentrated area of human disturbance.

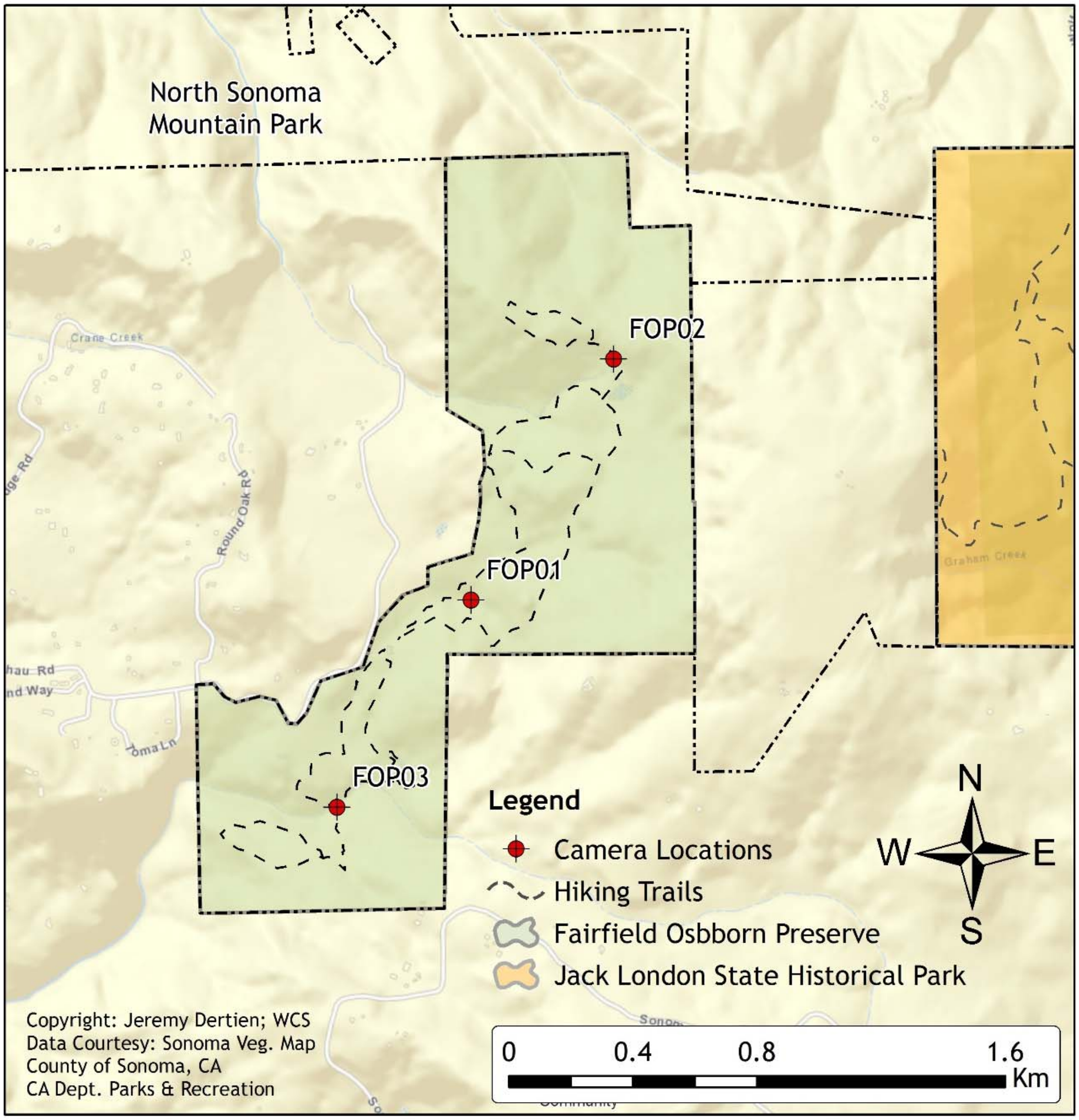

Figure A.4. Fairfield Osborn Preserve to the west of Jack London State Historical Park and Sonoma Mountain. It was studied as a paired comparison to Glen Oaks Ranch in the Sonoma Valley.

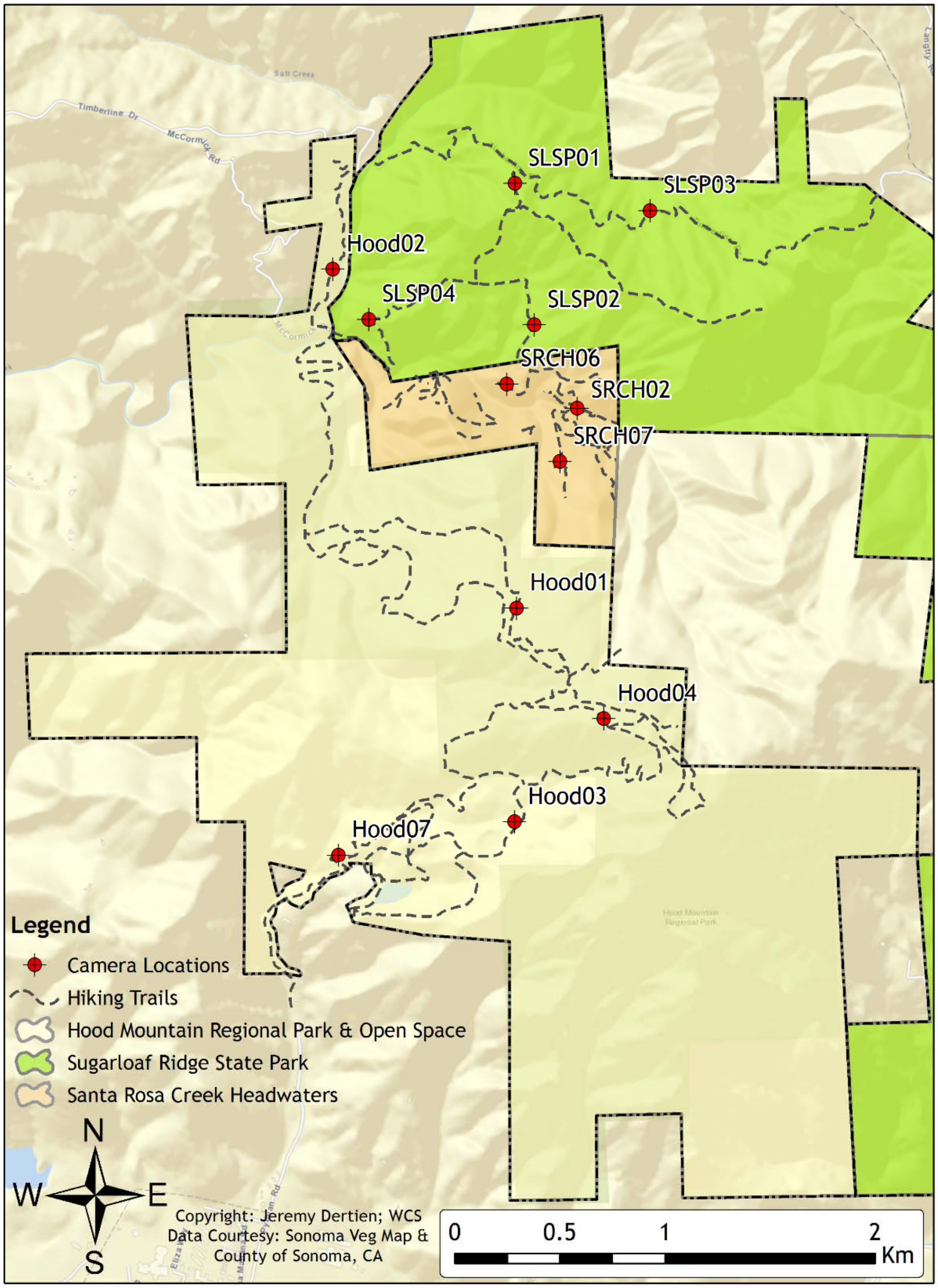

Figure A.5. Study areas of northern Sonoma Valley. Santa Rosa Creek Headwaters property is situated between Sugarloaf Ridge State Park and Hood Mountain Regional Park and Open Space.

Appendix II. Recreation Monitoring Results

Trail Name	Location Name	Hikers/ Day	OnLDogs/ Day	OffLDogs/ Day	Cyclists/ Day	Equestrians/ Day
Canyon	BOUP01	28.07	0.00	0.86	0.00	0.00
Waterfall Overlook	BOUP02	8.20	0.00	0.13	0.00	0.00
Rim	BOUP03	9.20	0.00	0.40	0.00	0.00
Woodland	BOUP04	12.15	0.00	0.00	0.00	0.00
Madrone Spur	FOP01	0.31	0.00	0.00	0.00	0.00
Ridge Loop	FOP02	7.96	0.00	0.00	0.00	0.00
Creek Trail	FOP03	8.23	0.00	0.00	0.00	0.00
George Ellman	GOak01	1.90	0.00	0.00	0.00	0.00
Phyllis Ellman	GOak03	0.00	0.00	0.00	0.00	0.00
Manzanita Loop	GOak05	4.22	0.00	0.00	0.00	0.00
Fire Road	GOak06	4.99	0.00	0.00	0.00	0.00
Summit Trail	Hood01	9.80	0.65	1.18	0.00	0.00
Hood Mountain (North)	Hood02	58.11	8.39	3.93	0.27	0.00
Pond	Hood03*	51.69	6.80	4.08	0.62	0.00
Hood Mountain (South)	Hood04	38.55	3.11	3.59	0.71	0.47
Lower Johnson Ridge	Hood07	88.74	12.15	3.29	0.65	1.29
Lake	JLSP01	176.83	0.10	0.25	1.65	13.71
Mountain	JLSP02	14.37	0.00	0.00	0.00	1.50
Quarry	JLSP03	12.22	0.00	0.00	0.05	3.28
Apple Tree	JLSP04	6.90	0.45	0.50	0.40	0.60
Fern Lake	JLSP05	16.75	0.60	1.50	1.15	1.00
N. Suttonfield	SDC01*	169.95	20.08	27.42	0.77	0.00

Orchard Road	SDC02	73.38	20.73	0.75	2.82	0.06
N. Boundary	SDC03	7.01	0.69	3.13	0.06	0.00
Eldridge	SDC05	10.41	2.08	2.08	0.69	0.00
Wagner	SDC07	3.96	0.67	2.45	0.11	0.00
E. Suttonfield	SDC11	68.38	15.32	5.24	0.31	1.64
Headwaters (North)	SLSP01	1.86	0.07	0.13	0.27	0.00
Headwaters (South)	SLSP02	1.43	0.00	0.05	0.00	0.00
Maple Glen	SLSP03	1.27	0.00	0.13	0.00	0.00
Quercus	SLSP04	14.16	0.28	1.18	0.22	0.11
Riparian Road	SRCH02	0.00	0.00	0.00	0.00	0.00
Overlook Road	SRCH06	0.00	0.00	0.00	0.00	0.00
Logging Skid Road	SRCH07	0.00	0.00	0.00	0.00	0.00
Valley of the Moon (West)	SVal01	193.59	41.26	6.76	1.90	1.28
Woodland Star	SVal02*	.	.	.	.	.
Valley of the Moon (East)	SVal03	288.32	69.95	5.59	3.58	0.69
Black Canyon Creek	SVal04	31.17	5.60	3.58	0.56	0.73

Appendix III: Data Products

Sonoma Developmental Center hiking trails

(SDC_FinalTrailMerge.shp)

- This dataset includes hiking trails within the boundaries of the Sonoma Developmental Center (SDC) outside of the SDC building campus and those trails that connect to eastern Jack London State Historical Park. Except for portions of the Northern Boundary trail, all presented trails were ground-truthed.
- Metadata
    - ID: Unique identification number assigned for each trail.
    - Shape: Type of feature class.
    - Name: Route name used on previous maps or a trail name created by the author.
    - Hist_Name: Yes = name used on previous maps; No = name generated by dataset author as an identifying placeholder.
    - Shape_Leng: Length of each trail in kilometers.

Hiking trails of all study areas

(FullTrailMerge.shp)

- This dataset includes all hiking trails within the nine parks and protected areas studied for this report. Trail names were assigned by the managing organization of each park or protected area, except for the aforementioned SDC trail names assigned by the dataset author.
- Metadata:
    - FID: Unique identification number assigned for each trail.
    - Shape: Type of feature class.

    - Name: Route name created and assigned by the managing organization of each park or protected area.
    - StudyArea: Full name of the park or protected area where the trail is located.
    - Shape_Leng: Length of each trail in kilometers.

<u>Hiking trails of all study areas with freely accessible trail data</u>

(OpenSourceTrailMerge.shp)

- This dataset includes all hiking trails within the six parks or protected areas that have remotely sensed data freely available on the internet. This dataset does not include trail data on Bouverie Preserve, Glen Oaks Ranch, or Santa Rosa Creek Headwaters.
- Metadata:
    - FID: Unique identification number assigned for each trail.
    - Shape: Type of feature class.
    - Name: Route name created and assigned by the managing organization of each park or protected area.
    - StudyArea: Full name of the park or protected area where the trail is located.
    - Shape_Leng: Length of each trail in kilometers.