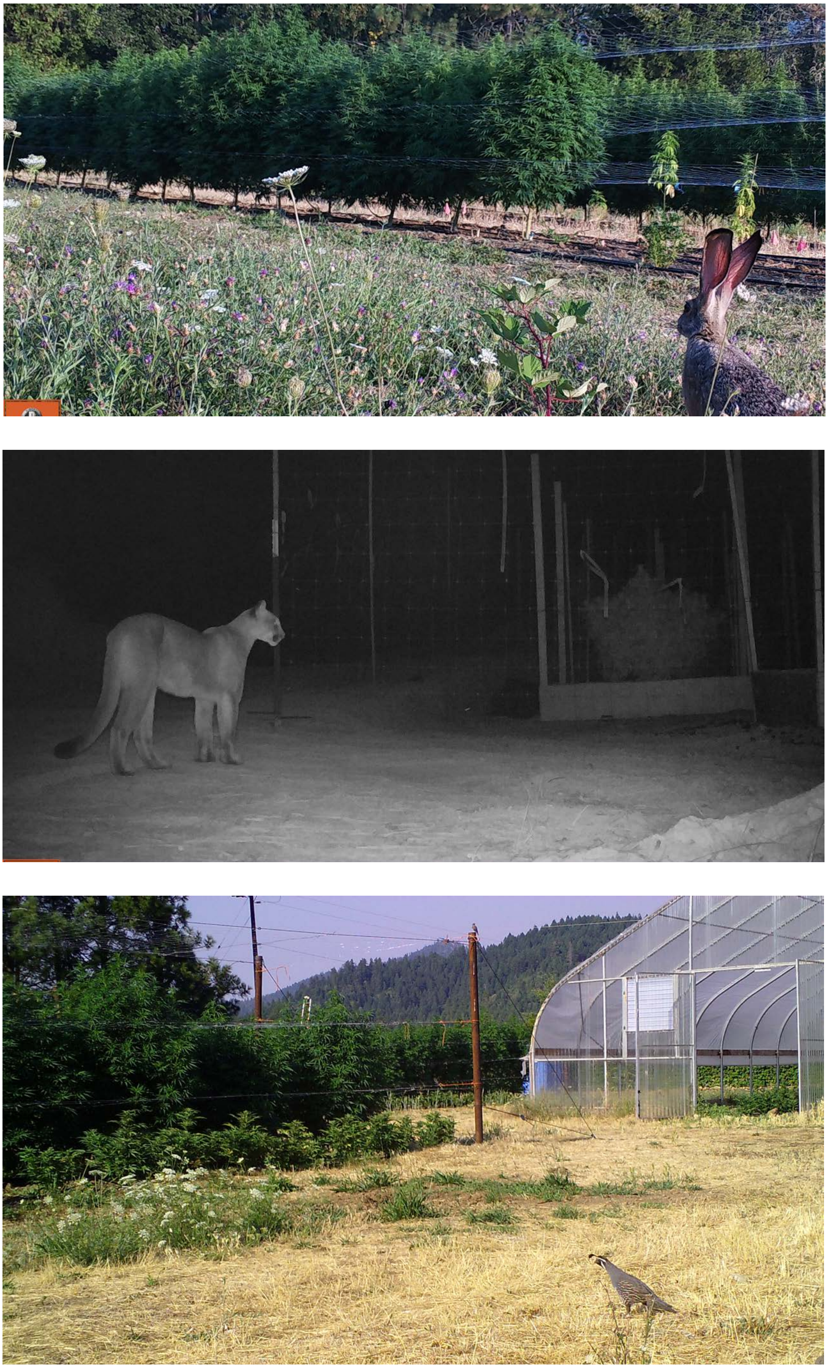

Examples of wildlife on cannabis cultivation sites in the Klamath-Siskiyou Ecoregion of southern Oregon [in order from top to bottom: black-tailed jackrabbit (*Lepus californicus*), mountain lion (*Puma concolor*), and California quail (*Callipepla californica*)]. Photo credit: Phoebe Parker-Shames, UC-Berkeley.

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# Coexisting with cannabis: wildlife response to marijuana cultivation in the Klamath-Siskiyou Ecoregion

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The recent expansion of cannabis agriculture in rural areas of the western United States provides an ideal opportunity to study the outcomes of policy change for land use and wildlife. Small scale (<1 acre), private-land cannabis cultivation has the ability to coexist with or alter surrounding wildlife communities. To date, there has been little to no formal research on wildlife response to this form of cannabis cultivation. This study examines local wildlife community dynamics on and nearby active private-land cannabis farms. Using camera data collected between 2018–2019, we summarized the frequency of occurrence of 11 wildlife species and 3 domestic animals on and adjacent to (within 500 m) eight cannabis farms within the Klamath-Siskiyou Ecoregion in southern Oregon. We also assessed how cannabis production influenced the occupancy (defined here as space use) of black-tailed deer (*Odocoileus hemionus columbianus*), lagomorphs, and gray fox (*Urocyon cinereoargenteus*) in our study area. We found that cannabis farms were generally occupied by smaller-bodied wildlife species, and had a higher proportion of domestic dog (*Canis familiaris*), cat (*Felis catus*), and human activity compared to nearby comparison sites. The presence of a cannabis farm helped explain detection probabilities of deer and gray fox, but did not affect lagomorphs. Farms also helped predict gray fox occupancy, but were not selected in lagomorph or deer models. These results suggest species-specific responses to cannabis cultivation, and highlight the need for further research on site-level production practices and their influence on surrounding ecological communities.

**Key words:** agricultural frontier, anthropogenic disturbance, camera traps, cannabis cultivation, occupancy and detection, rural development, terrestrial mammals

Cannabis agriculture is a quickly-expanding industry in the western United States, and represents a new opportunity to study the ecological outcomes of a policy change that has induced rapid rural land development (Carah et al. 2015; Butsic et al. 2018). Cannabis has been cultivated in the western United States for decades, but as a federally illegal drug it was confined to surreptitious farms, often in remote areas (Corva 2014; Butsic and Brenner 2016). Illegal production on public lands in the West have long elicited concerns about their potential environmental impact via habitat destruction, toxicant use, and poaching (Gabriel et al. 2012; Levy 2014; Carah et al. 2015). However, over the past few years, recreational legalization of cannabis in several states, including California and Oregon, has led to the expansion of production on private land, potentially supplanting much of the production on public lands (Arcview Market Research 2016; Butsic et al. 2018; Klassen and Anthony 2019). This expansion raises new questions about how the evolving cannabis industry may interface with and potentially alter surrounding wildlife communities and their habitats (Carah et al. 2015; Butsic et al. 2018).

While a robust body of literature on wildlife-agriculture interactions may help predict outcomes associated with the growth of cannabis agriculture, cannabis production has several unusual factors that differ from most other crops: 1) remoteness, 2) small individual farm size, and 3) unique spatial pattern on a landscape. Influenced by its illicit history, cannabis is often grown in remote, biodiverse regions with minimal other non-timber agriculture (Corva 2014; Butsic and Brenner 2016; Butsic et al. 2018). Regardless of individual legal status, private land cannabis farms are typically smaller than those of other commercial crops, and are clustered in space, creating a unique land use pattern of small points of development surrounded by less developed land (Butsic and Brenner 2016; Wang et al. 2017; Butsic et al. 2018). This pattern of development in rural areas, particularly in the West, makes cannabis agriculture a frontier industry—one that often occurs at the wilderness boundary—a somewhat rare characteristic for agriculture in the United States (Butsic et al. 2018).

Cannabis production practices vary widely depending on legality and land ownership, which influence the severity and type of environmental impacts from cultivation (Carah et al. 2015; Wilson et al. 2019). It is unclear how many of the environmental concerns associated with public land cultivation can be generalized to private land, but it is likely that many production practices differ. For example, reports and studies on illegal public land cannabis production list the following impacts from these sites: use of anticoagulant rodenticides and other toxicants that can bioaccumulate across food chains, poaching, habitat alteration, illegal water withdrawals, and potential water contamination (Gabriel et al. 2012; Levy 2014; Thompson et al. 2014; Carah et al. 2015; Gabriel et al. 2018). Yet, surveys of licensed and unlicensed cannabis producers in California suggest that toxicant use, poaching, and water contamination may be less prevalent with private land producers (Wilson et al. 2019). In addition, on many private land farms, both licensed and unlicensed, the use of high-powered grow lights, drying fans, and visual barrier fencing may create potential wildlife disturbance (Rich, Baker, et al this issue.; Rich, Ferguson, et al. this issue). Such practices are less common on public land. Given that regulated cannabis agriculture is an emerging industry that has prioritized sustainable cultivation, research on how private land cannabis farms may impact wildlife is conspicuously scant.

Here, we examine how private land cannabis cultivation may interface with wildlife communities on and surrounding outdoor cannabis farms (both licensed and unlicensed). Individual species may respond to different cues on cannabis farms (e.g., lighting, fences, human activity), and so we expected species would exhibit a range of responses including being deterred by, attracted to, or indifferent to cannabis production. For example, larger animals, such as black-tailed deer (*Odocoileus hemionus columbianus*), may be less likely to use cannabis farms due to fencing and increased human presence (Brashares 2010; Fischer et al. 2012). Alternatively, cannabis farms could attract species such as behaviorally flexible omnivores or foragers through the creation of novel food sources or new edge habitat (Gabriel and Wengert 2019). These individual responses may offer insights into broader community level responses.

The goal of this study was to understand local wildlife community composition on and nearby small, private cannabis farms. We used data from remotely triggered camera surveys (hereafter cameras) to determine whether cannabis cultivation influenced the local distributions of terrestrial mammals (>0.5 kg). To achieve this goal, our objectives were to use camera detections to: 1) describe species composition on and near cannabis farms, and 2) compare individual species habitat-use responses to cannabis production (using occupancy modeling where "occupancy" is redefined as "use" as in Latif et al. 2016). Ultimately, this research is intended to support efforts to predict and mitigate potential outcomes of cannabis development on terrestrial wildlife communities.

## METHODS

### Study area

Our study area was situated within the Oregon portion of the Klamath-Siskiyou Ecoregion and consisted of farms spread across three sub-watersheds (Slate Creek, Lower Deer Creek, and Lower East Fork Illinois River; defined by USGS hydrologic unit code 12) in Josephine County, southwestern Oregon (42.168, -123.647; Figure 1). We set cameras at 1,240 m to 1,910 m above sea level. The study area included a mix of vegetation types, including open pasture, serpentine meadows, oak woodland, and mixed conifer forest. Rainfall in this region varies seasonally and by elevation, with an average of 82.7 cm annually (Borine 1983). Mean temperatures ranged between 3.9-20.6°C in 2018–2019 (NOAA https://www.ncdc.noaa.gov/cdo-web/).

The Klamath-Siskiyou Ecoregion is one of the most biodiverse temperate forest regions on Earth, in an area that straddles the Oregon-California border and contains several regions identified as critical climate change refugia (Olson et al. 2006; Olson et al. 2012). Several species of concern are present in the county, including native salmonids, threatened Humboldt martens (*Martes caurina humboldtensis*), Pacific fishers (*Pekania pennanti*), and spotted owls (*Strix occidentalis*), all of which are hypothesized to be directly or indirectly affected by cannabis agriculture (Gabriel et al. 2012; Thompson et al. 2014; Carah et al. 2015; Gabriel et al. 2015; Butsic et al. 2018).

Southern Oregon, and Josephine County in particular, have a long history of illicit and medical cannabis cultivation, as well as an active presence in the growing legal industry in Oregon (Klassen and Anthony 2019; Smith et al. 2019). Southern Oregon has become known as a prime destination for outdoor cannabis production, and Josephine County has the highest number of licensed producers relative to population size in the state (Oregon Liquor Control Commission 2019; Smith et al. 2019). Production in the county accelerated after recreational legalization in 2014 (Parker-Shames, unpublished data), and takes a similar form to cultivation occurring across the border in northern California, with clusters of small farms surrounded by undeveloped or less developed rural land (Butsic and Brenner 2016; Wang et al. 2017; Butsic et al. 2018; Smith et al. 2019).

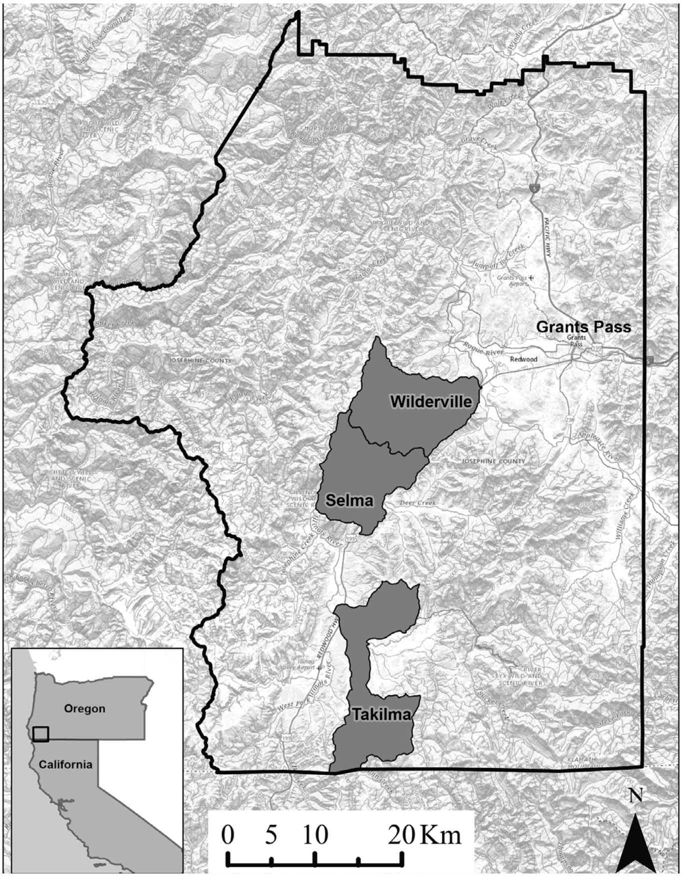

**Figure 1.** Map of study area with local population centers identified. The study sites are indicated as USGS hydrologic unit code 12 sub watersheds within Josephine County, southern Oregon. All study farms were contained within these three watersheds, and are summarized at this scale to anonymize specific farm locations. From the top down, the sub watersheds are: Slate Creek, Lower Deer Creek, and Lower East Fork Illinois River.

Cannabis farms for this study included one licensed recreational production site, one medically licensed (though non-compliant) production site, and six unlicensed sites. All farms were producing cannabis for sale, though in different markets depending on their access to licensed markets. We selected these eight farms because they (1) were representative of the size and style of cultivation predominant in Josephine County in the years immediately following recreational legalization in 2015 (Parker-Shames, unpublished data), (2) were all established after recreational legalization except for the medical farm, (3) did not replace other plant-based agriculture, and (4) granted us permission to set up cameras on site. Our sampled farms were small (typically < 1 acre), had conducted some form of clearing for production space, and three had constructed some form of fence or barrier around their crop. Nonetheless, specific land use practices and production philosophies differed between farms (e.g., pesticide use, type of fencing, presence of dogs, number of people working on the site, attitudes towards conservation, etc.). We cannot disclose farm locations, as per our research agreement for access.

## Camera surveys

Monitored farms were clustered within each watershed: one farm in Slate Creek, five in Lower Deer Creek, and two in Lower East Fork Illinois River. We placed un-baited motion sensitive cameras (Bushnell E3, Bushnell Aggressor, or Moultriecam models) on and surrounding cannabis farm clusters as well as in random locations up to 1.5 km from the farms. To guide the placement of cameras, we overlaid the area surrounding each cannabis farm cluster with a 50 x 50 m grid and then selected a random sample of at least one-quarter of grid cells (a minimum of 45 locations in each watershed), stratified by vegetation openness and distance to cannabis farm. We rotated 15-20 cameras through the sampled grid cells, ensuring each camera was deployed for a minimum of two weeks. As a result of sampling across two years, we likely violated the model's assumption of geographic and demographic closure (Mackenzie et al. 2006), but given our interest was in space use associations and not estimates of occupancy, we believe this is a minimal issue. For this analysis, we restricted our data to a subset of cameras on cannabis farms ("cannabis sites") and cameras in 500 m proximity to farms ("comparison sites") active during the same camera rotation (n = 8 farms, 17 rotations, 2-5 cameras/rotation). Because of rotations and field constraints, all cannabis sites were not monitored at the same time or for the same length of time (one to six rounds). Each cannabis site had at least one, and up to three comparison cameras within 500 m during each of its active rounds. Because of farm clustering, some comparison cameras were within 500 m of more than one farm. Half the cameras on farms (n = 4) were monitored for more than one round, but the comparison camera(s) were not always the same for all rounds due to rotations.

## Statistical analyses

We summarized species observations at cannabis farms and created detection histories (i.e., matrices where a "1" indicated the species was photographed at a given camera station during the respective 24-hr time interval, a "0" that it was not, and an NA if the camera was inactive) using the package CamtrapR (CamtrapR v.1.2.3, https://cran.r-project.org/web/packages/camtrapR/index.html, accessed 11 December 2019) in program R (R v.3.6.2, www.r-project.org, accessed 18 December 2019). We used a 24-hr time interval because our focus was on estimating space use associations instead of occupancy, and a short interval reduced the likelihood of the same individual animal being detected on both the farm and comparison camera (Latif et al. 2016; Steenweg et al. 2018). We used the detection matrix to summarize detection rates per 100 operation nights for species found on cannabis sites and comparison sites. We then modeled the occupancy probabilities of the three most commonly detected wild species, which included black-tailed deer, lagomorphs (including brush rabbit *Sylvilagus bachmani* and black-tailed jackrabbit *Lepus californicus*), and common gray foxes (*Urocyon cinereoargenteus*), using the UNMARKED package in Program R (unmarked v.0.13-1, https://cran.r-project.org/web/packages/unmarked/index.html, accessed 11 December 2019). We combined lagomorphs due to uncertainties in distinguishing individual species in photographs.

We used single-species occupancy models to assess factors influencing the likelihood that a species used the area around each camera station (interpreting the "occupancy" parameter as "use" in that it is influenced by both occupancy and availability) and the probability that the species would be detected given they were present (i.e., "detection probability", as influenced by both availability and perceptibility) (Latif et al. 2016). In this case, detection can also be influenced by fine scale activity and/or habitat use patterns (Latif et al. 2016; Moreira-Arce et al. 2016)

We hypothesized that cannabis cultivation, elevation, water access, and vegetation type would influence species' spatial relationships, and therefore included them as predictors of occupancy (i.e., space use) in the model. We predicted that cannabis cultivation would have a negative influence on a species' probability of using an area. We included a binary, categorical variable in the models to characterize whether detection occurred on a cannabis site (1) or a nearby comparison site (0). This variable reflected and distilled the on-site practices that are common across farms, including increased human activity and fencing. We expected regional elevation to influence species' vegetation use, and therefore used the average elevation within a 1 km buffer of each camera location, from the 30 m National Elevation Dataset (State of Oregon Geospatial Enterprise Office, U.S. Geological Survey, www.gis.oregon.gov). Water access is frequently an important predictor for wildlife occupancy (Rich et al. 2019), especially during dry periods such as during our study years, so we included distance to streams as a predictor of occupancy (NOAA Intrinsic Potential Streams, https://archive.fisheries.noaa.gov/wcr/maps_data/maps_and_gis_data.html). To represent vegetation, we used the percent evergreen forest, as determined via the National Land Cover Database (NLCD 2016, www.mrlc.gov) within a 1 km buffer of each camera site as a vegetation predictor variable. Finally, to distinguish general biogeographic variation between regions, we used watershed as a categorical predictor for occupancy (we assigned cameras as Slate Creek = 1, Lower Deer Creek = 0, and Lower East Fork Illinois River = -1).

For modeling detection, we hypothesized that cannabis production sites would negatively influence the probability that a species was photographed given they were available in the general area, due to both physical barriers to wildlife accessing these sites, and to behavioral shifts, such as animals moving less or moving more cautiously around areas of higher human activity (Smith et al. 2017; Jakes et al. 2018; Tucker et al. 2018). We used distance to road (Josephine County GIS Department 2018) as a proxy for human activity separate from cannabis production that might also negatively influence detection probability. Although cannabis cultivation can be associated with the creation of new roads (Carah et al. 2015), the roads used in these analyses were not those created or used exclusively by cultivators. Finally, we included year as a categorical variable to account for potential inter-annual variation in detection ability.

We standardized covariates to have a mean of zero and a standard deviation of one. We used Akaike's Information Criterion (AIC) (Burnham and Anderson 2002) to compare model fits. We modeled all of the detection covariates first, and then kept our top ranked model for detection constant before modeling our occupancy (use) covariates. We used our top ranked model to assess covariate relationships and determine which variables influenced species use and probabilities of being photographed.

## RESULTS

We analyzed over 5,000 animal detections over 957 operation nights (with an average of 31 operation nights per camera). We found that the communities of wildlife present on cannabis farms were qualitatively different from the surrounding, uncultivated areas

(Figure 2). Wildlife on cannabis farms were often smaller-bodied species, and co-occurred with higher human and domestic dog (*Canis familiaris*) activity. There were 18 different species recorded on cannabis farms, and 24 on comparison cameras. Wild predators were predominantly detected on comparison cameras rather than cannabis farms. For example, gray foxes had 18.5 detections per 100 operation nights on cannabis sites compared to a detection rate of 31.6 on comparison sites, while black bears (*Ursus americanus*) had a detection rate of 2.5 on cannabis sites compared to 4.9 on comparison sites, and coyotes (*Canis latrans*) had a rate of 1.9 on cannabis sites and 6.1 on comparison sites. By contrast, domestic predators such as cats (*Felis catus*) and dogs, had a detection rate twice as high on cannabis production sites than comparison sites (Figure 2). It is also worth noting detections of two rarer carnivores: we detected mountain lions (*Puma concolor*) seven times on a cannabis farm and once on a comparison site, and bobcats (*Lynx rufus*) two times on each.

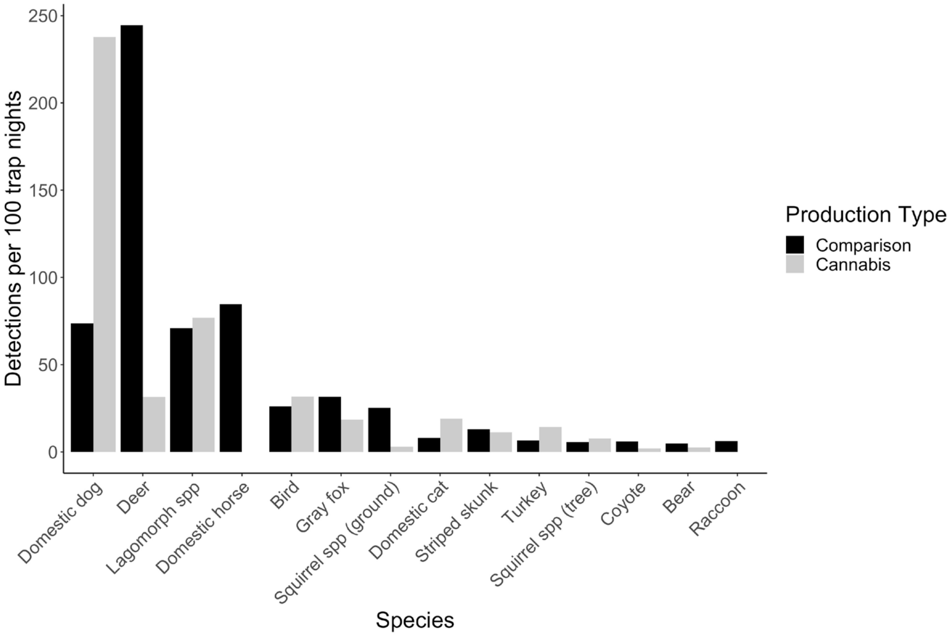

**Figure 2**. Top animal species present at cannabis (8) versus comparison (24) sites, by detection rate (number of detections per 100 sampling occasions). Excludes any species detected less than a total of 10 times at all sites combined. Excludes humans, which were the most frequently detected presence on both cannabis and comparison sites (detection rate of 1306.6 on cannabis sites and 478.7 on comparison sites).

For the single species occupancy models, detection variables varied by species. The top models for deer and gray foxes included a negative association with cannabis production for detection, while the top model for lagomorphs did not have similar associations (Table 1). Distance to roads was retained in all models for detection, and was positively associated with detection for all species, such that detection increased with increasing distance from roads.

For occupancy, here defined as use, cannabis production had a weak negative association with gray fox occupancy, and was not a top occupancy variable for any of the other species (Table 1). Because watershed and forest cover were correlated ($R^2 = 0.86$), we only used the variable with the highest univariate effect size for each species. For instance, watershed had a higher univariate effect size than forest cover for deer and gray fox occupancy, so we used watershed for candidate selection in those models, and forest cover for lagomorphs. No single variable was consistently selected as a predictor of occupancy across all species.

**Table 1.** Results from the top space use models for each species, including occupancy (defined in this case as use) and detection (influenced by both availability and perceptibility) variable beta estimates and 95% confidence intervals in parentheses. Stars are on confidence intervals that don't overlap zero.

| | Occupancy Variables | | | | |
|---|---|---|---|---|---|
| Species | Cannabis Production | Watershed | Elevation | Forest within 1 km | Distance to Streams |
| Black-tailed deer | | -2.82<br>(-5.37– -0.27)* | | | |
| Gray fox | 11.17<br>(-102.4–124.7) | | -1.18<br>(-2.61–0.25) | | |
| Lagomorphs | | | | -0.99<br>(-2.29–0.30) | -0.73<br>(-2.32–0.86) |

| | Detection Variables | | | |
|---|---|---|---|---|
| Species | Cannabis Production | Year 2018 | Year 2019 | Distance to Roads |
| Black-tailed deer | -1.71<br>(-2.26–<br>-1.16)* | -0.485<br>(-1.02–0.05) | 0.519<br>(-0.01–1.05) | 0.522<br>(0.30–0.74)* |
| Gray fox | -1.81<br>(-2.33–<br>-1.29)* | | | 1.81<br>(1.21–2.41)* |
| Lagomorphs | | 0.45<br>(-0.021–0.92) | 4.25<br>(2.85–5.66)* | 0.77<br>(0.45–1.09)* |

## DISCUSSION

This study represents a first step to quantify patterns of wildlife avoidance and coexistence on and surrounding active small-scale cannabis farms on private land. Our observational monitoring data suggest that wildlife species may be affected by these locations and may be altering their use of these environments. Specifically, our results suggest that 1) wildlife are consistently present on and around cannabis farms, 2) private land cannabis production may influence the local space use of some species more than others, and 3) cannabis farms may deter larger-bodied wildlife species in particular. Although limited by a small dataset, these results offer valuable insights into the ecological outcomes of the emerging cannabis industry.

The assessment of wildlife detection rates suggest that many wildlife species are consistently present at cannabis production sites (Figure 2, Figure 3). Whereas some species detected on cannabis farms are ones that have been recorded in the western United States as more tolerant to agriculture or disturbance (e.g. striped skunk, raccoon, deer), others are species that tend to avoid human activity (e.g. mountain lion, bobcat) (Crooks 2002; Gehring and Swihart 2003; Hilty and Merenlender 2004; VerCauteren et al. 2006). While we did detect some relatively rare species (mountain lion, bobcat), we did not detect others such as fishers or ringtails (*Bassariscus astutus*), and cannot assess whether this is due

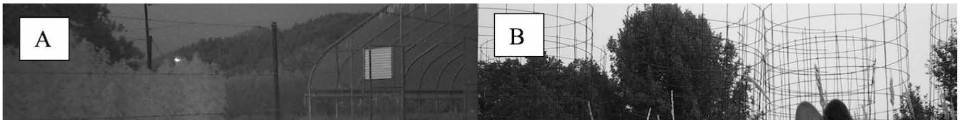

**Figure 3.** Examples of photos from cameras at cannabis sites demonstrating varied space use by wildlife at cannabis farms. A) Two black tailed jackrabbits (*Lepus californicus*) resting and foraging. B) A coyote (*Canis latrans*) passing through a cannabis farm with a prey item in its mouth. C) A squirrel (*Sciurus* sp.) passing in front of the camera carrying an unknown food item. D) A black-tailed deer (*Odocoileus hemionus columbianus*) appearing to forage at the base of a cannabis planter (the wooden box holding the cannabis plant in the photo).

to true absence or simply short study duration. We infer detection of wildlife on cannabis farms implies a potential for these species to move through these areas. In addition, some photos revealed foraging or resting behavior (Figure 3), which may indicate that cannabis agriculture could maintain biodiversity as other small scale agricultural crops have in other systems (Mendenhall et al. 2016). However, understanding long term impacts of cannabis production would require information on farm-level land use practices. For example, if animals on private land cannabis farms suffer fitness consequences similar to the toxicant exposure occurring on public land production, then coexistence on these sites may be detrimental in the long term (Levy 2014; Thompson et al. 2014; Carah et al. 2015; Gabriel et al. 2015; Gabriel et al. 2018).

Modeled use and detection probability results indicate that despite a general wildlife presence at cannabis farms, some animals may be more affected by these areas than others. For detection, both deer and gray fox were influenced by cannabis farms (Table 1). Distance to roads was positively associated with all species detection, suggesting that animals are consistently avoiding roads, but no other variable was consistent across all species for either detection or use. For occupancy (i.e. space use), cannabis farms were not selected for deer or lagomorph models (Table 1), but we suspect this could have been due to our close proximity of cannabis and comparison locations. It is possible that these species would move >500m within a 24-hour period, making it difficult to distinguish space use. Additionally, because we pooled lagomorph species, it is possible that either brush rabbits or black tailed jackrabbits individually might have responded differently to cannabis production. Nonetheless, cannabis farms influencing detection probabilities for deer and gray foxes may imply an influence on repeated visits over our time period, and potentially a behavioral adjustment near cannabis farms.

There are many possible explanations for why deer and gray fox space use might be more influenced by cannabis farms than lagomorphs. These generally have to do with characteristics on the farms themselves. Wildlife may be interacting with the increased presence of domestic cats and dogs on cannabis farms (Figure 2), for instance, for deer as potential or perceived prey, or gray foxes as competitors (Zapata-Ríos and Branch 2016; Reilly et al. 2017; Twardek et al. 2017). Alternatively, deer and gray foxes may be responding to behavioral cues from increased human presence and activity on cannabis farms (Berger 2007; Tucker et al. 2018). Lagomorphs may be responding to these same cues, but via different response mechanisms. It is possible that lagomorphs are more behaviorally flexible than deer and gray foxes and can avoid altering their spatial patterns by instead shifting their temporal activity patterns, for instance, becoming more nocturnal (Gaynor et al. 2018). More research is needed to disentangle these potential mechanisms.

Both detection rate summaries and model results suggest that cannabis farms appeared to disproportionately influence the space use of larger wildlife species. Black bears had a higher detection rate on comparison sites compared to cannabis farms (Figure 2) and the model results indicate that larger black-tailed deer and gray foxes might avoid cannabis farms, while smaller animals such as lagomorphs appear to be unaffected. This result is expected, as large bodied animals such as deer may be unable to access space on the farms if they are physically blocked by fencing, while smaller species are still able to move through these barriers (Brashares 2010; Jakes et al. 2018).

Despite variation in which species responded to cannabis farms, we did not find evidence from either detection rate summaries or model results to suggest that predators were attracted to these sites. Other studies have shown predators tend to avoid agricultural development, and our results seem to support the same trend (Gehring and Swihart 2003; Hilty and Merenlender 2004). By contrast, there has been recent suggestion that cannabis production on public lands may serve as an "ecological trap" by attracting carnivores to production areas that then expose individuals to deadly toxicants (Gabriel and Wengert 2019). Our results, at least in the short-term, suggest that this dynamic may be less likely to occur on small-scale private land cannabis farms. This highlights the different potential ecological threats and processes playing out on public versus private land cannabis production sites. Not only do private land cannabis farms seem to use fewer toxicants (Wilson et al. 2019), but they may also have higher human activity levels on site compared to public land production located in more remote areas. Wildlife may in turn tend to avoid this human presence rather than being attracted (Smith et al. 2017).

This study begins the discussion regarding a glaring shortage of data on animal space use on cannabis sites, but there are many further avenues for future research. For example, the relative importance of cannabis farms in their influence on animal space use should be analyzed in the surrounding landscape context. The influence of roads on the modeled detection results implies that cannabis cultivation, despite occurring in a rural area in this case, was not the only form of human disturbance to which animals were responding. It may therefore be useful to compare cannabis and other forms of rural land use. In addition, it is necessary to conduct further study at broader spatial and temporal scales in order to examine long term wildlife community response to cannabis and unravel the complicated set of potential contributing factors.

### Management and conservation implications

Wildlife are likely to have species-specific responses to small-scale outdoor cannabis farms, and, thus, the specific land use practices occurring at a site may be influential for biodiversity conservation in these communities. Future studies should examine the role of fencing, timing of human activity, presence of domestic dogs and cats, and other site level practices that may influence wildlife use. Many small-scale cannabis farms are not part of a licensed production system (such as most included in this study), and therefore cannot be regulated for their production practices (Polson 2015; Short Gianotti et al. 2017). For these producers, a mix of educational resources on wildlife friendly growing practices, grower-enforced community standards or expectations, and law enforcement efforts to reduce noncompliance, may play an important role in increasing or maintaining biodiversity. For species deterred from cannabis farms, such as was implied by our deer and gray fox results, further research is needed to understand the mechanism for this avoidance. If, for example, fencing, artificial lighting, or sound are identified as major causes of this deterrence, then careful consideration should be given to the regulations on these practices at cannabis farms and their relation to critical habitat features such as water sources or animal migration routes.

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**Author Contributions**

Conceived and designed the study: PPS, advised by JB, and with consultation from LR
Collected the data: PPS
Performed the analysis of the data: PPS and WX, with guidance from LR
Authored the manuscript: PPS
Provided critical revision of the manuscript: PPS, WX, LR, and JB

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