HABITAT SELECTION AND HABITAT USE OF GRAY FOXES (*UROCYON CINEREOARGENTEUS*) ON TRESPASS CANNABIS GROWS

By

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A Thesis Presented to

The Faculty of California State Polytechnic University, Humboldt

In Partial Fulfillment of the Requirements for the Degree

Master of Science in Natural Resources: Wildlife

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May 2023

ABSTRACT

HABITAT SELECTION AND HABITAT USE OF GRAY FOXES (*UROCYON CINEREOARGENTEUS*) ON TRESPASS CANNABIS GROW SITES

Haley-Marie Rahm Jones

Trespass cannabis grow sites, otherwise known as illegal cultivation sites on public lands, are extremely hazardous to the environment and can severely impact wildlife movement and behavior. Trespass grow sites are dangerous to wildlife as they negatively impact the quality of habitat and wildlife behavior through habitat modification, pesticide use, discarding of trash, and poaching on national forests. I researched gray fox habitat selection and habitat use at six different grow sites in the Klamath National Forest and Shasta-Trinity National Forest in northwestern California. I deployed GPS collars on three gray foxes at two of those grow sites and three gray foxes at two reference sites between September 2020 and April 2021. I used autocorrelated kernel density estimates and resource-selection functions, using generalized linear models, to evaluate gray fox habitat selection and found that two of the three gray foxes selected trespass grow sites when grow sites were found within their home ranges. I evaluated the combined data of all six collared foxes in regard to environmental characteristics and found that foxes prefer areas with a greater aspect, specifically those facing south, southwest, and west. I deployed eighty-eight game cameras across six trespass grow sites to collect photo and video media for 22 months. I used the Shapiro Wilks Normality test and the Mann

Whitney *U* test to compare gray fox behavior across different grow site features. There were a higher number of detections of gray foxes at process areas, camp sites, toxicant piles, and trash pits. Locomotion behavior was observed at similar levels across all site features. Vigilant behaviors were most observed at toxicant piles, camp sites, trails, and cultivation plots. Marking behaviors were most common at process areas, trash pits, and toxicant piles. The most recorded behavior was locomotion, followed by vigilance, scent marking, and then feeding, with no documented behaviors of resting. Proportionally more foxes were recorded at camp sites, toxicant piles, trash pits, and process areas than in cultivation plots or along trails, which signifies that gray foxes utilize areas hypothesized as more attractive within the grow site. This research shows that foxes use trespass grows, though future researchers are encouraged to include a larger sample size collared gray foxes and of the cultivation plot and trail locations. Resource agencies must prioritize elimination and reclamation of these sites. Otherwise, wildlife will continue to suffer direct and indirect effects as they utilize the trespass grow sites present in their home ranges.

ACKNOWLEDGEMENTS

I would like to thank the Integral Ecology Research Center (IERC), which provided me with the funds, equipment, permit assistance, and access to trespass grow study sites. Within IERC, I'd like to thank my coworkers, Trish Figueroa, Chloe Burt, Kevin Smith, Simon Boycott, Antoine Chery, and Ivan Medel, for assisting me in my fieldwork, data management and data analysis efforts. I would like to especially thank Dr. Vitek Jirinec of IERC, who provided guidance in my resource selection function analysis. I am deeply grateful to IERC's Executive Director, Dr. Greta Wengert, who became my advisor, gave me access to this unique study system, and helped make me a better field researcher.

I am grateful to Dr. Richard Brown of Cal Poly Humboldt who accepted me as his graduate student and having his belief in my ability to complete this research opportunity. Many thanks to Dr. Mourad Gabriel for teaching me how to catch foxes, deploy cameras, fix fox traps, and so many more skills I've implemented throughout my project. I'd like to thank the U. S. Forest Service Law Enforcement and Investigations, for providing funding support to purchase five GPS collars, along with other necessary supplies. In addition, I would likely to deeply thank the U.S. Forest Service Law Enforcement and Investigations, for providing an escort into my trespass grow study sites. Thank you to the following officers who escorted me into sites to check my cameras throughout the year in all forms of weather: Special Agent Nick Roe, Special Agent Tyler Bolen, Captain Chris Magallon, Officer Matt Swanson, Officer Logan Brown, Officer Tim

Stiefken, Officer Charles Mayer, Officer Jason Rasmussen, Officer Chelisa Rodriquez, and Officer Brenden Pero. I would like to thank Cal Poly Humboldt's Wildlife Department Stockroom which provided me with the equipment necessary for the completion of my project.

I would like to recognize the following organizations that provided funds for this research effort: The Stanley and Lorene Harris Scholarship, the Lee-Mossman Scholarship, the Tuttle Climate Graduate Scholarship, the Marin Rod and Gun Club Scholarship, The Sacramento-Shasta Chapter of the Wildlife Society, and Cannabis Irrigation Supply. Thank you, Advanced Telemetry Systems, for donating GPS collars and downloading equipment that allowed me to collect the data needed to answer my research questions. Thank you to Emily Armstrong Buck, Douglas Page, and Wade Burris of the Brown Lab and all other wildlife graduate students for their endless support, guidance, and comradery.

Thank you to Sausage and Gumbo, my canine kids, for always being excited to have me home after trapping for a week in the woods and for giving world class cuddles. Finally, thank you to my supportive and loving friends and family, especially Mom, Aunt Marie, and Aunt Cynthia, for always being there, no matter the time, place, or reason.

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INTRODUCTION

Though cannabis is grown worldwide and used daily by two percent of the global population (Bennett 2018), it is categorized as a Schedule I drug in the United States (equivalent to methamphetamine or d-Lysergic Acid Diethylamide, LSD) under the Comprehensive Drug Abuse Prevention and Control Act of 1970 (Everett 2018). The restriction of cannabis as a Schedule I drug, in part, led to an increase in demand and a large profit margin in the illicit market (Everett 2018). Annually, the value of the illicit market of cannabis cultivation is estimated to be $45–50 billion (Everett 2018) and accounts for half of the 2.2 million drug seizures around the world (Bennett 2018).

In northern California, cannabis has been cultivated illegally for decades and had become the primary export of many local economies since the decline of the timber industry in the 1980s (Everett 2018). The Emerald Triangle is the most well-known region for cultivation, an area in northern California comprised of Humboldt, Mendocino, and Trinity Counties. In 2014, California's cannabis crop had an estimated value of $31 billion, equivalent to the highest ten agricultural crops combined across the state (Everett 2018). The combination of a Mediterranean climate, numerous freshwater sources, steep topography, and vast stretches of public land and remote private parcels has secured northern California as the covert cultivation mecca.

Once legalization passed in California and became initialized in early 2018 under Proposition 64, the legal industry blossomed, though illegal cultivation continues to flourish (Cannabis Ground 2019). Despite this new opportunity to shift towards legalization, law enforcement estimates that there are between 10,000–15,000 grow sites operating annually in Humboldt County alone, with only 15% of growers applying for permits to become legal producers (Franklin et al. 2018). Several reasons explain why a current illegal cultivator may not pursue the permit process to cultivate legally (Goldstein and Sumner 2022). Cannabis is regulated under a punitive tax structure, where taxes are applied to the gross profit, as opposed to the net income, which fails to consider the costs of producing that product (Maxson-Landis and Scates 2022). The State Water Resources Control Board's cannabis cultivation policy may require cultivators to upgrade failed or undersized stream crossings, move their cultivation area farther from a stream system, and limit water usage, all of which increase operational costs (California Water Boards 2022). With high standards for product contamination, legal cultivators also run the risk of their harvest being destroyed if regulatory agencies deem it too contaminated for sale (Valdes-Donoso et al. 2019). If cultivators choose to remain in the illicit market, they do not have to change anything about their operation to satisfy regulations, which increases profits as a result. The illegal grow operations absent of regulatory oversight thrive in the illicit market, causing extensive disturbance across the landscape (Owley 2018 and Gabriel et al. 2013b).

Trespass Cannabis Grow Sites

Grow Site Features

Illegal cannabis operations on public lands (hereafter referred to as trespass grow sites) are extremely hazardous to the environment through the reckless use of federally banned pesticides and extensive habitat modification (Owley 2018, Gabriel et al. 2013b). The cultivation season runs between June and October; however, preparation for cultivation can begin as early as February, and the harvest period can last until December in some regions of California. Cultivation plots have various shapes and sizes and are usually cleared of trees, brush, and other native vegetation. The cleared material is then typically piled around the boundary of the plots. The plot can be terraced with evenly spaced holes carved into the ground for cannabis planting. Growers create extensive trail systems from cultivation plots to different site features, like camp sites and process areas. Often, each feature within the grow site has several trail entrances and exits. Approximately one acre of trespass cannabis cultivation damages 10 acres of surrounding land (Mallery 2011).

A source line brings water to the cultivation plots from a water source potentially a few hundred meters to multiple kilometers away, depending on the location. The source line connects to the irrigation lines laid throughout the plot or can connect to a cistern. Cisterns can be carved into the ground and lined with tarp or constructed above ground, built up with harvested logs and lined with tarps. Growers sometimes mix fertilizers and pesticides into the cistern and then pump the water to the surrounding plots. Growers typically leave their trash and unused fertilizers and pesticides in piles within or around the cultivation plot boundaries.

Camp sites are hypothesized to have considerable impacts on wildlife behavior due to their attractive food sources. Multiple growers will live in camp sites for many months, generating large amounts of trash and food waste, while they apply rodenticides and other pesticides to deter wildlife from damaging their camp or crop. A camp site can consist of a series of tarps, tents, and sleeping bags with structures built out of logs or terraced dirt platforms. Camp sites typically have multiple propane tanks, camp stoves, containers of perishable and non-perishable food, and other general camp items. Growers often store pesticides and fertilizers within their camp, sometimes only a few feet from their food caches.

Process areas are where the harvested cannabis plants are dried and trimmed in preparation for export. Growers spend a large amount of time at these features, often eating and generating trash that may entice wildlife to visit. In some grow sites, such as Study Site 2 within this study, process areas are similar to camp sites with food, sleeping gear, and clothing items present.

Depending on the size of the trespass grow, enough food for five to six months must be periodically brought in for each grower, which generates copious quantities of refuse. Growers tend to dig holes to dispose of their trash or pile it up in an area away from their camps. Trash pits can be several feet deep and consist of trash generated over multiple harvest seasons. Growers collectively throw out their food trash, pesticides, fertilizer, and other refuse in the same trash pit. When a grow site is vacated, either because growers have harvested their crop and abandoned it for the season or law enforcement have raided the grow, wildlife search the trash pits and camp sites for food. Wildlife pull trash piles apart, which distributes refuse items in every direction for dozens of meters.

Direct Environmental Impacts of Trespass Grow Sites

Trespass cannabis production typically occurs in sensitive, biodiversity-rich watersheds that host rare state-and federally listed species (Wengert et al. 2021). With the first rain, exposed soil and applied fertilizer from cultivation plots can be washed out of the grow site, leading to further runoff of the high nutrient topsoil, discarded chemicals, trash, and human waste (Owley 2018, Rokos 2021, Kerlikowske 2011).

Growers spend multiple months living on public lands, commonly poaching wildlife for sport and sustenance (Wengert et al. 2018). Poisoned animals documented at trespass grow sites include Pacific fisher (*Pekania pennanti*), gray foxes (*Urocyon cinereoargenteus*), turkey vultures (*Cathartes aura*), and American black bears (*Ursus americanus*, Smith 2021, Gabriel et al. 2013a, Cannabis News 2021). Law enforcement and researchers have discovered wire snares and trip lines within grow sites and have found carcasses with evidence of bullets or arrows as the likely cause of death (G. Wengert, Integral Ecology research Center, personal communication).

Wildlife on Trespass Grow Sites

Pesticide Application on Trespass Grow Sites

Numerous rodenticides and insecticides are applied at grow sites to reduce damage from resident wildlife; research has found that these pesticides can incapacitate and kill wildlife when they are consumed (Gabriel et al. 2013a, Gabriel et al. 2013b). Researchers have documented cases of extensive trespass grow pesticide exposure in wildlife species of special concern. Second-generation anticoagulant rodenticides kill animals over multiple feedings and have been found in 80% of Pacific fisher and 70% of northern spotted owl (*Strix occidentalis caurina*) carcasses tested (Gabriel et al. 2018). The Southern Sierra Nevada population of Pacific fisher was listed under the Federal Endangered Species Act (ESA) in 2020 (Sierra Forest Legacy 2021) and northern spotted owls are listed as threatened under the same act (Federal Registrar 2020). Researchers and law enforcement commonly find purposefully poisoned attractants deployed to kill resident wildlife that pose a threat to cannabis production (Gabriel et al. 2018). Wengert et al. (2021) found that within the federally listed southern Sierra Nevada population of Pacific fisher, all denning females have at least some potential for having trespass grow sites in their home ranges. The presence of these pesticides may create an ecological trap where predators are attracted to compromised prey, which in turn negatively impacts the predator's physiology through biomagnification of pesticides (Robertson and Hutto 2006). Rodents targeted with the application of pesticides may not immediately die and then become prey for predators and scavengers (Gabriel et al. 2018).

Indirect Environmental Impacts of Trespass Grow Sites

Habitat is one of the most important components to consider for a species' conservation efforts, as a loss of habitat quality or a reduction in habitat availability can hamper a population's ability to sustain itself (Morrison 1998). The trail systems that connect different grow site features can act as funnels, leading various wildlife species to interact with each other that would otherwise not come into contact. On the other hand, wildlife may avoid areas surrounding trespass grows, which further impact the dynamics of that ecosystem.

Gray Foxes

I used the gray fox as the focal species of this study because I am able to examine the impacts of trespass grows on a common carnivore species with a relatively limited home range size (Gabriel et al. 2009a, Helmer 2019). Gray foxes are relevant in the examination of trespass grow habitat relationships because they have been commonly documented on trespass cannabis grow sites both dead and alive (Helmer 2019), and they do not have a special status listing and associated limitations to research efforts. They are opportunistic omnivores (Bekoff et al. 1984, Saunders 1988), making them susceptible to trespass grow disturbance because of their use of animal and plant food sources, including mice and rats that have been exposed to rodenticides or native vegetation that have been sprayed with pesticides.

There are critical spatial similarities and temporal overlaps across the habitats and seasons in which gray foxes raise young and growers cultivate. Gray foxes prefer a mix of fields and woods with interspersed trees and farmland (Scholars Portal 2015), which is exactly how a newly cleared cultivation plot within a trespass grow appears. Critical gray fox breeding periods coincide with the beginning of the cultivation season and the peak of activity on the site (Owley 2018). These characteristics distinguish the gray fox as an appropriate species to study in order to assess the disturbance experienced by mesocarnivores when a trespass grow is present.

I evaluated the impacts of trespass grow sites on gray fox third-order habitat selection and fourth-order habitat use to determine the extent of disturbance that gray foxes experience when a trespass grow site occurs within their home range. I hypothesized that gray foxes would show selection of trespass grow sites over nearby areas with little human disturbance. I evaluated this hypothesis by testing my predictions listed below at the third and fourth orders of habitat selection (Johnson 1980).

Predictions

My predictions were as follows:

1. Gray foxes preferentially select trespass grow sites over other undisturbed areas and they commonly use landscape features near the grow sites.
2. Within the grow sites, camp sites, trash pits, process areas and toxicant piles are used disproportionately more by gray foxes in comparison to cultivation plots and trails.
3. Gray foxes use grow sites for food resources and, as a result, feeding behaviors will be more commonly observed than locomotion, vigilance, scent-marking or resting.

STUDY AREA

This research was conducted on six trespass grow study sites located within the Shasta-Trinity National Forest and the Klamath National Forest in northwestern California (Figure 1). These study sites were selected because the grow sites were active within two years of this research effort and their relatively close spatial proximity allowed more site visits. The data collection period for third-order habitat selection was September 2020 through April 2021, and the data collection period for the fourth-order habitat use extended from September 2020 through June 2022.

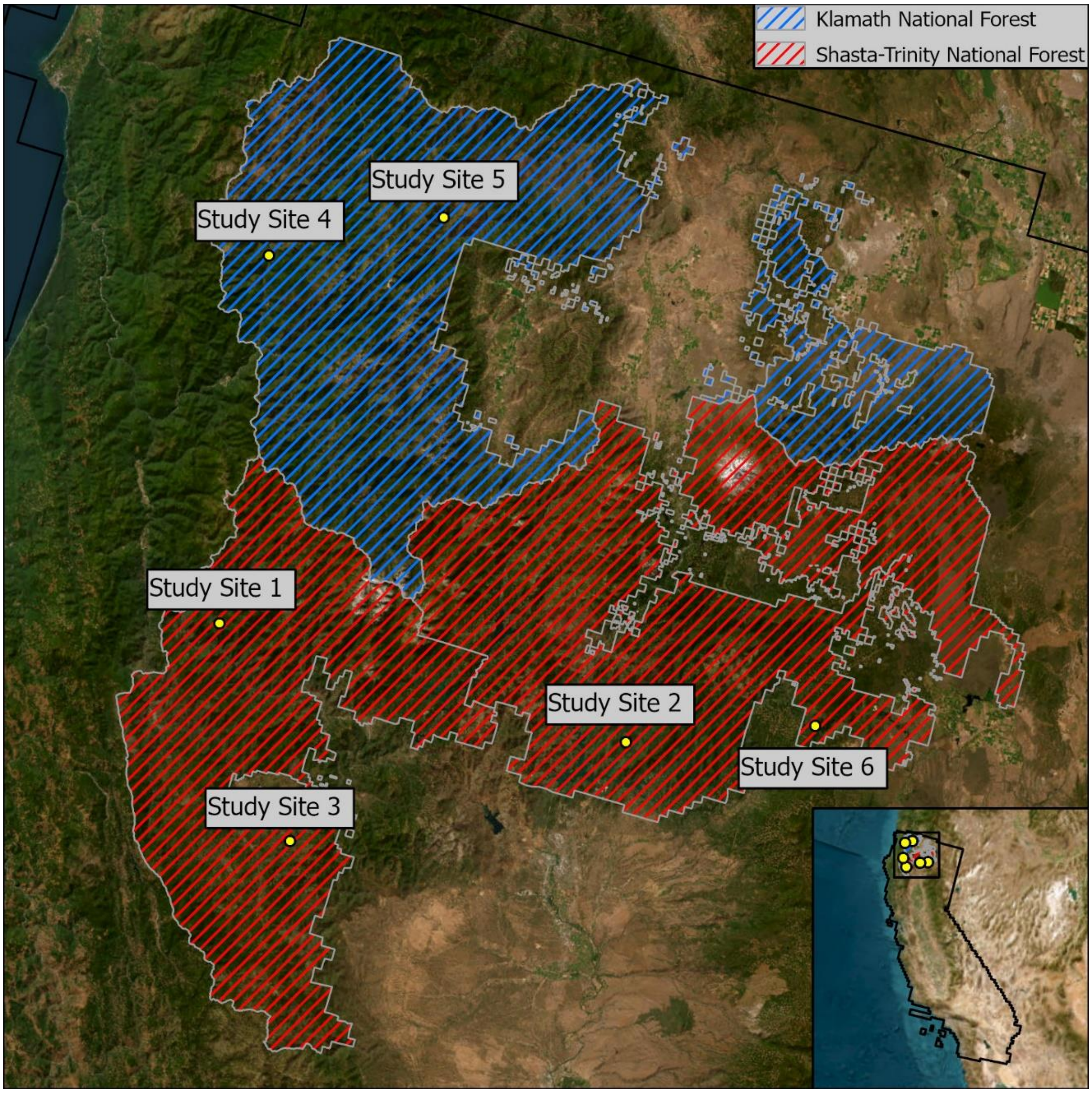


Figure 1. All six trespass grow study sites located in northern California, USA, with research occurring between Fall 2020 and Summer 2022.

The Shasta-Trinity National Forest is comprised of 2.2 million acres with more than 6,278 streams and rivers (Shasta Trinity National Forest n.d.). Elevation ranges between 300 to 4,300 m (Shasta Trinity National Forest n.d.). Temperatures ranges between -9.4 ºC and 33.3 ºC, with an average of 8.2 ºC (Willyweather 2022b). Average annual rainfall is between 76–152 cm with 90-percent of rainfall occurring in the winter season (Pacific Gas and Electric 2006). Vegetation varies, with typical tree species including Douglas fir (*Pseudotsuga menziesii*), Ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), gray pine (*Pinus sabiniana*), black oak (*Quercus kelloggii*), tan oak (*Lithocarpus densiflorus*), Pacific madrone (*Arbutus menziesii*), and understory shrubs including white leaf manzanita (*Arctostaphylos viscida*), western azalea (*Rhododendron occidentale*), and extensive chaparral (United States Department of Agriculture n.d.a., United States Department of Agriculture n.d.b).

The Klamath National Forest extends over 1.7 million acres in Siskiyou County, California and Jackson County, Oregon (Klamath National Forest n.d.). Elevation measures from 274 to 2,743 m (Klamath National Forest n.d.). Temperatures average 11.1 ºC, with the average low around 3.4 ºC and an average high of 19 ºC (Willyweather 2022a). Vegetation is similar to Shasta-Trinity, with Ponderosa pine, Douglas fir, as well as true firs (*Abies sp*.), incense cedars (*Calocedrus*), and other hardwood and mixed conifer species (Klamath Forest 2022, Willyweather 2020b).

In the Shasta-Trinity National Forest, I deployed cameras in four study sites. Study Site 1 is located approximately 8.9 km northeast of Burnt Ranch, California. This site consisted of a growsite that was raided in 2019, with a mixed evergreen forested habitat, and has an elevation that extended between 830 m and 990 m (Appendix 1). Study Site 2 is located 4.5 km northeast of O’Brien, California. This site consisted of one main growsite with a nearby satellite camp, was raided in 2021, is primarily composed of a live oak woodland, and has an elevation range between 350 m and 520 m (Appendix 2).

In addition, I utilized Study Site 1 and Study Site 2 for both camera and GPS collar deployment. Study Site 3 is located approximately 14.3 km southeast of Hayfork, California. This site hosted one grow site and was raided in 2020, is composed of an oak-shrub forest and chaparral habitats and has an elevation range around 1,000 m (Appendix 3). Study Site 6 is the final site located on the Shasta-Trinity National Forest and is located 9.47 km southeast of Big Bend, California. This site hosted one grow site, with a mixed evergreen and riparian forest habitat and had an elevation range between 800 and 1000 m (Appendix 6). This site began in 2019 and was active through 2021.

I deployed cameras in two study sites within the Klamath National Forest. Study Site 4 is located approximately 12.7 miles northwest of Somes Bar, California. This site had one grow site and was raided in 2021, consisted of temperate forest, and had an elevation range between 400 and 500 m (Appendix 4). Study Site 5 is located approximately 14.6 miles southeast of Seiad Valley. This site consisted of one grow site, with rocky forested habitat, and had an elevation of approximately 1,100 m (Appendix 5).

MATERIALS AND METHODS

Third Order Habitat Selection

Trapping

I captured gray foxes with Tomahawk (Model 108) and Duke (Model #3 1110) traps with attached wooden boxes constructed of plywood and fiberglass reinforced panels to provide insulation for caught animals (Gabriel et al. 2009b). Traps had one metal slide that could be slid into a gap in the back of the box which then served as the back wall of the trap. When an animal was caught, a second metal slide closed a gap in the front of the cubby box to secure the animal. Traps were camouflaged with clipped vegetation, rocks, old logs, and other woody debris. Bait within the trap varied between raw chicken and rabbit skins. I initially used Gusto (Caven's Quality Animal Lure, Pennock, MN) and gray fox urine as lures to draw the foxes into the area of the trap and replaced the lure every third day. Gusto was either mixed with Vaseline (Unilever, Anglewood Cliff, NJ) and smeared on the trap plate or poured on nearby vegetation and fox urine was sprayed on nearby vegetation.

I trapped gray foxes from September to February, pausing trapping in mid-March and resuming in late April to reduce the risk of trapping female foxes, as well as females of sympatric species, such as the Pacific fisher, with late-term pregnancies (National Park Service 2018). Each trap was set with a radio transmitter that signaled when the trap door closed. Trap transmitters emit two different types of radio frequencies, which indicate if the trap door is closed with an animal possibly inside, or open. I initially checked each trap transmitter frequency to determine which traps should be prioritized for a physical check in the morning. In the evening, only traps with positive trap transmitters were physically checked. Between March and April, I checked traps twice a day in person, in the morning and evening. Outside of this period, I checked the traps once every twenty-four hours, each morning in person, while evening traps were checked with trap transmitters. Most trapping efforts were located along U.S. Forest Service roads or decommissioned logging roads. These areas were sought out because the topography was flat enough to deploy a trap without the risk of it rolling down a hill.

Traps were deployed to capture foxes that did and did not have trespass grow sites within their home ranges by placing traps within or beyond a 1.3 km radius of known trespass grow sites, a maximum home range size published in past literature (Gabriel et al. 2009a). Researchers examining female gray fox home range size variation found the mean estimated home range to be approximately 1.22 km^2 for foxes in the Sacramento Valley (Fuller 1978), while foxes in southern California had home ranges of approximately 1.10 km^2 (Kodani 1996). Other studies found a variation of male home range size varying between 1 km^2 (Fryxell 1982), 0.71 km^2 (Kodani 1996) and 0.54 km^2 (Matthews 2000). Due to this variation between study results, I chose the maximum likely home range radius of 1.3 km, as this distance would incorporate both male and female home range sizes. Once I recovered collar data and generated home range estimates, I classified gray foxes without grow features within their home range as "reference" foxes, regardless of their distance to the grow site, whereas foxes with grow features within their home range were considered "impact" foxes.

Throughout the study, trapping efforts were impacted by limited site access from roadblocks by downed trees, heavy snowfall, concern for grower presence, and forest closures due to fires throughout the 2020 and 2021 field seasons. Study Site 2's grow site was active in 2020 and 2021, limiting access to beyond 600 m for trapping due to possible impacts of activity at the grow site. In other trapping efforts, foxes were caught and collared much closer to the site, so it is possible this operational buffer of 600 m could have impacted trapping success.

Processing

An IACUC (2020W67) was approved before camera deployment and trapping efforts began in September 2020. Foxes were removed from traps into a cloth handling cone, given an initial drug dose, and then weighed to confirm additional chemical immobilization was not needed. In the few instances where foxes required an increased drug dose, an additional twenty-five percent of the original dose was administered. I chemically immobilized foxes with 10 mg/kg of ketamine hydrochloride and 0.75 mg/kg midazolam injected intramuscularly into the fox's flank. I placed a cloth over the eyes and assessed respiratory rate, heart rate, and temperature every five minutes for distress.

Body measurements (ear to notch, hind foot, body length, and body length including tail) and sex were recorded, and age was estimated based on irruption and wear of teeth (Farias et al. 2012). I documented reproductive condition through inspection of female teats, which included color, swelling, matted hair, or lactation. I photographed all angles of each fox while they were chemically immobilized. I collected a fecal sample by gently swabbing the anus with a polyester swab. I collected one vibrissa sample and a hair follicle sample from each animal and stored them at room temperature. All ectoparasites, such as fleas and ticks, were collected and stored in 70% ethanol with 5% glycerol (Gabriel et al. 2009b). A passive integrative transponder was injected subcutaneously into the nape of every fox to identify future re-captures in the event a fox dropped their collar. I collected blood into sterile vacutainer tubes with ethylenediaminetetraacetic acid (EDTA), as well as serum using a serum separator tube (Gabriel et al. 2009b).

I deployed Advanced Telemetry Solutions (ATS) w500 Wildlink global positioning system (GPS) collars (w500 Wildlink model, Advanced Telemetry Systems, 470 First Ave. N.W. Isanti, MN 55040) on foxes after an initial examination of age and body condition. Once the collar data was successfully downloaded and all relevant biological samples were collected, foxes were placed back into the cubby box and monitored to visually confirm revival from the anesthesia. All trapped animals were released at the location where they were trapped and the boxes were cleaned and disinfected before being reset. All biological samples, except vibrissae and hair, were kept frozen at -20 ºC until thawed for laboratory analysis.

GPS Collars and Telemetry

Wildlink W500 GPS collars were deployed on seven gray foxes between September 2020 and April 2021 to measure habitat use and habitat selection (Drake 2015). I programmed ATS collars using the “ATS Fixes for Loggers” computer application. For the study site terrain setting, I chose to program collars at the “Forest” setting, which allowed a 120-second maximum fix time and the “Heavy Canopy” setting, which allowed a 180-second maximum fix time, as appropriate. The very high frequency (VHF) transmitter setting was on for at least 12 hours every day, with various transmitter start and stop times, based on when I would likely be able to triangulate the fox during daylight hours. Mortality pulses were set to initiate at six hours after no detection of movement. Collars were programmed to attempt a GPS fix once every two hours. I set activity data to record the entire time between fixes and enabled remote downloads. The activity sensor records a percentage of seconds in movement and seconds stationary between each two-hour fix. This information can determine what times of day the fox is active and the areas in which they primarily explore or rest. VHF collar frequencies ranged between 160–161 hertz. Collars collected data between three to seven months, dependent on the animal’s weight and the associated collar’s battery life. All collars weighed at or under the recommended five-percent body weight threshold (Wilson et al. 1996).

Once collars were deployed, I used triangulation, either with an OMNI antennae or Yagi antenna and an R-1000 Communication Specialist receiver, to locate collared gray foxes throughout the duration of the project (Koprowski and Corse 2005). I drove the nearby USFS roads to pick up the collar telemetry signals. Once I detected the specific frequency of the ATS w500 Wildlink GPS collar, I attempted a remote download with a Microsoft Surface Pro 7 Windows 10 tablet. I used the ATS “ATS Fixes for

Loggers” computer application to remotely-connect with the collar to download the stored GPS data.

This remote download feature allowed me to periodically download the collar’s dataset, which was used to understand the general outline of each foxes’ home range. With the knowledge of each foxes’ home range, I was able to target specific areas where the chances of downloading the collar would be higher. The same download process was completed until a successful collar download was achieved or terminated due to time constraints. I attempted to get a download on each fox at least once every four weeks, though site accessibility often delayed downloads to eight weeks. I routinely reviewed collar downloads in the field to ensure they worked properly. As a result of the capture process potentially impacting fox movement after deploying the collars, I omitted the first 24 hours of data from all analyses. I used the remaining data to establish home ranges and identify preferentially selected locations within the collared individual’s home range.

Statistical Analyses

High impact sites within the trespass grow consisted of camp sites, process areas, trash pits, and toxicant storage sites, while low impact sites consisted of cultivation plots and trail systems. The independent variables for this project were the trespass grow features, the age and eradication date of the trespass grow operation, amount of trash, number of camp sites, number of trash pits, number of cultivation plots, number of toxicant piles present, number of fertilizer and pesticide present and amounts, study site topography, vegetation structure, water sources, and distance from U.S. Forest Service roads. Response variables were gray fox usage of trespass grow sites and non-grow site areas within their home range and their observed behavior at high and low impact features within the trespass grow. The unit of replication for the habitat selection analysis are gray fox individuals and the unit of replication for the habitat usage analysis are gray fox observations.

Autocorrelated Kernel Density Estimate

The Resource Selection Function analysis process began with the generation of autocorrelated kernel density estimates using the continuous-time movement model (ctmm) package in R (Version 2022.02.1; Figure 2 – 4). Because of the short time lapse between each GPS coordinate (two hours), autocorrelation was likely because points close in time would also be close in space (Muff et al. 2020). Past research has found that home range estimates that ignored autocorrelation could be incorrectly small and conventional analyses that failed to consider position autocorrelation significantly underestimated home-range size (Calabrese et al. 2016, Fleming et al. 2017). Autocorrelated kernel density estimates were utilized because they account for uncertainty as showcased in the confidence intervals around the 95% contour, while traditional kernel density estimates give false impressions of precise uncertainties (Calabrese et al. 2016).

The GPS data was initially edited through the omission of points that were likely incorrectly documented by the collar or were recorded at a time when grower presence could have impacted gray fox habitat selection. Each fox’s collar recorded a minimum of 200 GPS coordinates to quantify their home range size (Seaman et al. 1999, Constible et al. 2006, Uyeda et al. 2012). I also evaluated the GPS error for the ATS collars used in this study by deploying one stationary collar at Study Site 1 for eight days, which collected 95 GPS coordinates and then deployed the same collar at Study Site 2 for just over 15 days, which collected 189 points.

I created a variogram to determine that each fox had enough recorded points and home range crossings to allow a correct home range analysis and to showcase the autocorrelation structure of the data (Fleming et al. 2017). The variograms used plotted the semi-variance in positions as a function of the time lag that separated observations, allowing me to visualize the autocorrelated relocation dataset structure through unbiased means (Calabrese et al. 2016). In each instance, the variogram displayed an asymptote with a small upward curve at short lags, which showed that each fox was a range resident with persistent movement across their home range (Calabrese et al. 2016).

I used the model fit function within the ctmm package in R Studio to determine the most appropriate model fit. The following three models were displayed in this step of autocorrelated kernel density estimate production: Ornstein-Uhlenbeck foraging anisotropic, Ornstein-Uhlenbeck foraging (OUf) anisotropic, and Ornstein-Uhlenbeck isotropic models (Table 3). Anisotropic models incorporate properties with different values measured in different directions (Calabrese et al. 2016). An integrated Ornstein-Uhlenbeck process and Ornstein-Uhlenbeck foraging process are most appropriate for data that showcases upward curvature at short lags in the variogram, as this indicates velocity autocorrelation.

I incorporated the best model's performance into a semi-variance function, which is the theoretical analog to the originally generated variogram (Calabrese et al. 2016). Examination of the semi-variance function of the best-fit model allowed an initial view of the estimated parameter fit, which matched the features of the variogram when fit correctly (Calabrese et al. 2016). Finally, I fit the selected model through maximum likelihood using the ctmm.fit package, which produced a range of fit-related quantities of point estimates, confidence intervals, and AICc (Akaike information criterion specific to small sample sizes, Calabrese et al. 2016). I selected the model with the best fit, based on the AICc, and then generated a 95% autocorrelated kernel density estimate home range shapefile.

Resource Selection Functions

I analyzed individual fox habitat selection with generalized linear models. These generalized linear models utilized logistic regression analysis with a binomial distribution as the exponential family (Bolker et al. 2009). I used this analysis because it only examines random intercepts, which is appropriate when examining the covariates of one individual (Harrison et al. 2018). I confirmed that the correlation matrix of the covariates had values less than 0.7, a threshold that has been determined as the cutoff point for eliminating positively correlated covariates (Nettleton 2014). In no instance was it appropriate to eliminate any of the environmental covariates, so I incorporated all of them into the generalized linear model analysis. I examined the habitat covariates with remotely sensed data from ArcGIS, the National Landcover Database, and Landsat. I extracted the following information from the acquired remotely sourced data: Euclidean distance estimates to the grow site polygon, slope, aspect, elevation, distance to vegetation classes (Table 1), distance to roads, distance to streams and vegetation class edges, and vector ruggedness measurements.

Table 1. Descriptions of the three vegetation classes utilized in the resource selection function and generalized linear model analyses, provided by the National Landcover Database in 2019.

Vegetation Class	Description of Vegetation Class
Grassland	Areas greater than 80% herbaceous vegetation or graminoid vegetation, which may sometimes be used for grazing.
Shrub	Areas with shrubs (true shrubs, young trees in an early successful stage and stunted trees due to environmental conditions) less than 5 meters tall with canopy cover greater than 20% of total vegetation.
Forest	Composed of deciduous forest, evergreen forest, and mixed forest. Deciduous forests are dominated by trees greater than 5 meters with at least 20% total vegetation cover and experience greater than 75% foliage loss resulting from seasonal changes. Evergreen forests are like deciduous forests; however, the canopy is never without green foliage. Mixed forest includes both deciduous and coniferous forests with neither having greater than 75% of total tree cover.

Resource selection function analysis began with an individual autocorrelated kernel density estimate shapefile for each fox, which was used to generate random points that examined the potentially “available” locations within a fox’s home range. Ten random points were generated for every used point collected with the GPS collars. Used points were buffered by ten meters in relation to the generated random points, specifically to evaluate the truly available, but unused locations. A 10-meter buffer was used, based on the 10-meter Digital Elevation Model (DEM) model used in the environmental covariate analysis. This new dataset was used to extract the raster values from Euclidean distance rasters of the grow site and environmental covariates. Raster values for slope, aspect, and elevation were also extracted (Miller et al. 2012, Benson 2013). All raster files were generated from a 10-meter DEM. The covariates were scaled, then I applied a weight (W = 1,000) to the used points to confirm convergence to the Independent Power Producer likelihood (Muff et al. 2020). The random intercepts were scaled and I fit the model of all the selected covariates, summarized it, and diagnosed it.

Resource selection function models of the grow site were created first with a minimum convex polygon applied to all trespass grow site features, including camps, process areas, cultivation plots, trash pits, and water sources. A 20 m buffer was added to the minimum convex polygon to compensate for the likely GPS error of the collar coordinates and the distribution of trash around site features. I then extracted the difference between each GPS point and the buffered growsite polygon. I chose to not delineate site features because of their close spatial proximity to each other throughout the site, which could introduce autocorrelation error.

A pair of resource selection functions was created for each impact fox, which included an analysis with and without the growsite covariate. The AICc values between the two analyses were compared to determine if the presence of a grow site was selected for by the fox.

Fourth Order Habitat Use

Camera Deployment

I used a variety of Bushnell camera models for still photos and Browning camera models for videos to document the collared and uncollared gray fox use of high and low impact site features within the six study sites (Theimer et al. 2015). The video-recording Browning camera sets triggered with a one-minute delay interval after recording one-minute of footage. The great majority of cameras recorded 20 second videos, despite being set to record 1-minute-long videos. Browning trail camera models have a factory program that records 20 second videos at night to conserve battery life, regardless of the user's chosen camera program. I set Browning cameras with the high-quality video feature, Smart IR on, and night exposure set to fast motion. I programmed Bushnell cameras to a three-image capture set with a 0.6 dynamic interval. The image size was set to HD and full screen, the LED reference on low, and the sensor level set to auto. Cameras were attached to trees with mounts or straps, and always handled with gloves and sprayed with carbon spray to reduce scent contamination. Everything brought into the trespass grow was hiked out, and no form of bait was left within the grow site, as scent contamination could confound the wildlife behavior documented on deployed cameras.

Cameras were checked at three-to-eight-week intervals, with some cameras checked once every three months due to limited access by law enforcement escort restrictions. I switched out cameras broken by wildlife with operational cameras and checked the camera’s program at each field visit. Batteries were replaced if the charge was less than 66% for Bushnell cameras or less than 85% for Browning cameras. I either downloaded SD cards in the field or collected and switched them out for empty SD cards; I then formatted cameras before re-setting them using the “Format Execute” or “Delete All” functions on the Bushnell and Browning cameras, respectively. I used the software Advanced Renamer (Kim Jenson, Hulubulu Software) for data management to rename photos and export names, dates, and times of each recorded image. I later used this information for data analysis.

Each site had a large quantity of fertilizers, pesticides, and discarded trash (Appendix 7). The amount of raw food present at the time of the assessment was estimated and the overall amount of trash generated through the consumption of food was documented. As a result, the total amount of raw food brought into the site and consumed is much higher than the estimated amount reported during the assessment. All study sites had some form of pesticide application, which was later confirmed through laboratory analysis (Appendix 8). I deployed cameras in numerous locations where tests confirmed pesticide presence.

Spatial Sampling Design

There were between 10 and 12 camera pairs deployed at each of the six study sites at one time. Seven camera pairs were deployed at Study Site 1, with three camera pairs in the three camps, one camera pair on a carbofuran-positive sprayer, and three camera pairs in three cultivation plots. Carbofuran, a carbamate insecticide that inhibits cholinesterase (Environmental Protection Agency 2016), was federally banned in the US in 2008 (American Bird Conservancy 2008). Despite this, trespass growers regularly use carbofuran to purposefully poison wildlife (Wengert 2019), with several toxicology samples of these study sites testing positive. The presence of carbofuran underlines the likely chance of acute or chronic poisoning of resident gray foxes, and, as a result, an analysis of their behavior around carbofuran and other items within toxicant piles is relevant.

Twelve camera pairs were deployed at Study Site 2, with one camera pair at the camp, one camera pair at a toxicant pile, four camera pairs within plots and along trails, three camera pairs at three trash pits, and three camera pairs at three process areas. Study Site 2 had a greater number of cameras because cameras were pulled when the growers returned for the 2021 grow season and redeployed at new site features when the grow site was raided by law enforcement at the end of the season in 2021.

Seven camera pairs were deployed at Study Site 3, with two camera pairs at the two camp sites, two camera pairs at two toxicant piles, two pairs within cultivation plots, and one pair at a trash pit. At Study Site 4, one camera pair was deployed in the camp, two pairs in toxicant piles, three pairs along trails and in cultivation plots, and one camera pair in a trash pit next to the camp. At Study Site 5, two camera pairs were deployed in camps, one pair in a cultivation plot, two pairs near trash pits, and one pair within a process area. At Study Site 6, one camera pair was deployed in a camp, one camera pair near a toxicant pile, one camera pair along a trail, one camera pair in a plot, and one camera pair near a trash pit.

Behavior Categorization

Each second of documented fox behavior was accounted for in the data management portion of this research project. All observed wildlife species were identified to their lowest taxonomic rank, and when possible, their behaviors were documented as present or absent. I categorized the different behaviors of gray foxes observed to determine usage of the grow site features. I classified behaviors as social (amicable or hostile), scent marking (rubbing on a substrate, defecating, or urinating), vigilant (head raised, surveying surroundings, ears facing forward), resting (sitting or lying down), feeding (actively foraging by ingesting or processing food or drink or holding material in the mouth), and locomoting (walking, running, and climbing, Koprowski and Corse 2005). Hostile behaviors were delineated as chasing behavior, aggressive physical contact, or attempted aggressive physical contact, while amicable behaviors were classified as instances where animals did not pursue each other but were within the same recorded video. Social behavior was recorded as a categorical covariate of presence or absence when interactions were seen on video. Vigilant behavior was noted when a fox specifically lifted their head to surveil their surroundings. When their head dropped from vigilant behavior, often down to smelling their surroundings, I considered that locomotive behavior, as they were in the process of moving through the grow site. I did not consider this sniffing behavior as feeding or scent marking as the fox did not handle anything in its mouth or directly leave scent. Locomotion was any behavior where the fox took greater than one step in any direction. A combination of behaviors was often recorded in the same video.

Independent Reviewer Assessment of Behavior Data

All fox videos were renamed and randomly selected for review by an independent observer to evaluate bias in classifying the type and extent of wildlife behavior. The reviewer watched 20% (57 videos) of the fox behavior data, watching each video multiple times and recording every second of the different behaviors they observed.

Statistical Analyses

High impact sites within the trespass grow consisted of camp sites, process areas, trash pits, and toxicant storage sites, while low impact sites consisted of cultivation plots and trail systems. I recorded the proportion of seconds that foxes spent at each site feature, in each of the fox behavior categories, excluding social behavior. I ran a Shapiro-Wilks test to determine that the data set was normally distributed. I divided the number of seconds spent in each behavior by the number of camera trap days and then compared the proportion to all other behaviors to determine the gray fox’s relative use of high and low impact grow site features (Koprowski and Corse 2005). I then ran a Wilcoxon test to determine the significance between high and low impact site features on different gray fox behaviors.

The success rate of detection between videos and photos was compared by classifying each photo or video that was within two minutes of each other as the same event. I chose to delineate the time to two minutes because the video cameras were set to record one minute of data with a one-minute delay. I then divided the number of photos by the number of videos to get a proportion of events and averaged the proportion so I could apply this estimated detection value across all sites.

RESULTS

A total of 12 foxes were captured over the duration of this project, with eight GPS collars deployed on seven individuals (Table 2, Appendix 9). I deployed collars on three foxes within 0.4 and 0.5 km of Study Site 1, and two collars on foxes between 4.3 and 4.6 km from Study Site 1. I collared one impact fox, Fox 5, within 0.3 km of Study Site 2. I collared another impact fox, Fox 6, approximately 1.3 km from Study Site 2 on the other side of a ridge. Fox 6 was originally meant to serve as a reference animal; however, after I discovered a small satellite camp within her home range, I determined that she would serve as one of the impact foxes for this study.

Table 2. The number of trap days and successful captures at Study Site 1 and Study Site 2 between Fall 2020 and Spring 2021 in northern California.

Site	Number of Trap Days	Number of Captures
Study Site 1	771	9 (3 recapture)
Study Site 2	184	3 (1 recapture)

Third Order Habitat Selection

Between September 2020 and April 2021, I collared seven foxes, resulting in a minimum of 252 and a maximum of 2,501 GPS fixes per fox (Table 3). One of the seven collars was not downloaded after the initial release because she could not be relocated. As a result, her data could not be incorporated into autocorrelated kernel density estimates. The remaining six collared foxes had sufficient data for this analysis. The averaged success rate of the ATS GPS collars varied between 75-percent and 100-percent over the 24-hour period with Fox 1 and Fox 3 having the lowest GPS coordinate accuracy (Appendix 10).

The model for Fox 6 revealed the Ornstein-Uhlenbeck anisotropic process as the best fit model, while Fox 5 revealed the Ornstein-Uhlenbeck Foraging process as the best fitting model. The four foxes at Study Site 1 experienced a combination of the Ornstein-Uhlenbeck process, the Ornstein-Uhlenbeck Foraging process, and the Ornstein-Uhlenbeck Foraging (OUf) process anisotropic home range models (Table 3). As a result, these models were applied to each fox's home range to calculate their respective autocorrelated kernel density estimates.

In evaluation of the GPS collar error estimates, Study Site 1 had an error rate of 105 (+/1 10.57) m. At Study Site 2, the GPS error rate was 26.931 (+/1 1.9) m. The median error rate between the two study sites was 64.93 (+/- 1.93) m. This demonstrated the variation in GPS accuracy that likely occurred throughout this research project. I applied a 20 m buffer to the grow site features used in the habitat selection analyses, and as this is relatively close to the error rate in Study Site 2, this analysis of gray fox habitat selection was determined to be more accurate than if a buffer was not applied.

Table 3. The treatment, fox, sex, number of GPS coordinates, and autocorrelated kernel density estimates of all collared foxes, alongside the highest performing model (OU = Ornstein-Uhlenbeck, OUF = Ornstein-Uhlenbeck foraging, OUf = undistinguished timescales within Ornstein-Uhlenbeck foraging) at Study Site 1 and Study Site 2 in northern California between Fall 2020–Summer 2021.

Site	Treatment	Fox	Sex	# of GPS Coordinates	AKDE (km^2)	Model
Study Site 1	N/A	Fox 0	F	0	Unknown	N/A
Study Site 1	Impact	Fox 1	F	1,936	2.69	OU anisotropic
Study Site 1	Reference	Fox 2	F	913	2.50	OUF anisotropic
Study Site 1	Reference	Fox 3	F	2,467	5.45	OUF anisotropic
Study Site 1	Reference	Fox 4	M	557	3.13	OUf anisotropic
Study Site 2	Impact	Fox 5	M	1,502	0.82	OUF anisotropic
Study Site 2	Impact	Fox 6	F	252	0.67	OU anisotropic

Autocorrelated Kernel Density Estimates

Impact Fox 1 and reference Fox 2 had a partial home range overlap at Study Site 1; meaning that they likely used portions of the same habitat (Figure 5). Meanwhile, reference Fox 3 and reference Fox 4 had nearly a complete home range overlap and likely used similar resources across their home ranges (Figure 6). Impact Fox 5 and Fox 6 at Study Site 2 had a partial home range overlap when I initially included all of Fox 5’s recorded coordinates. However, when the dataset was narrowed, the home ranges no longer overlapped (Figure 7). This is relevant to note as the final resource selection analyses evaluated different areas with Fox 5’s and Fox 6’s respective home ranges.

The two collared reference foxes were approximately 4.3 km and 4.6 km from Study Site 1, respectively. The elevation range for the two reference foxes were between 740 m and 1324 m. The difference in elevation showcases the wide extent of topography and potential microhabitats that these two foxes used in the reference areas. I ground-truthed areas surrounding the two reference foxes at Study Site 1 for the presence of trespass grow sites and did find an area with a small, burned grow site estimated to have operated between 2016 and 2018 with no infrastructure. The potential disturbance from this site was so small, due to the age and the minimal amount of refuse present, it was determined that these foxes could function as reference individuals.

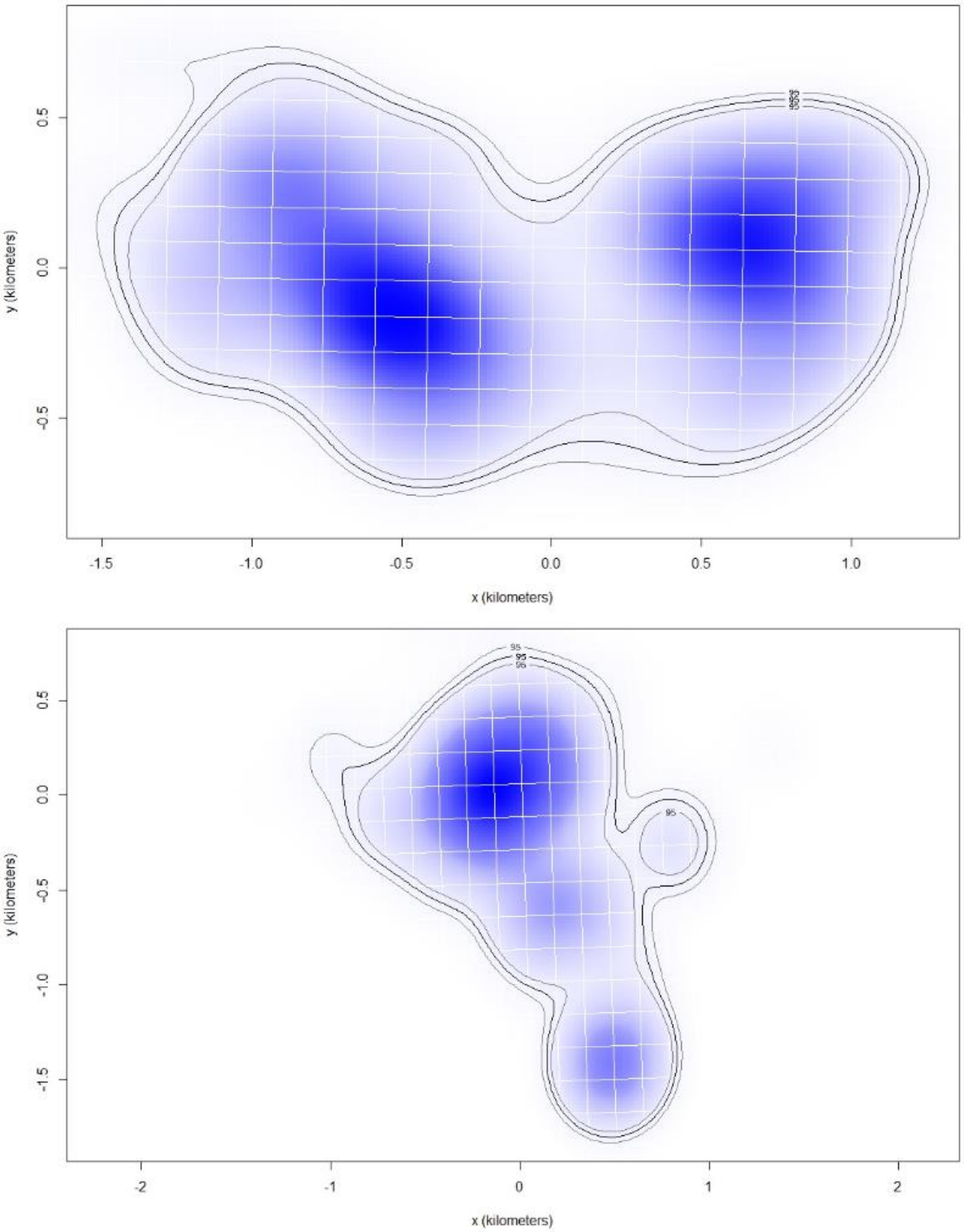


Figure 2. An autocorrelated kernel density estimate of impact Fox 1(top) and reference Fox 2 (bottom), collected in Fall 2020 and Spring 2021 near Study Site 1 in northern California. A grid is plotted within the graph to showcase the standard deviations of each kernel within the home range, while the middle contour shows the maximum likelihood area where these foxes spent 95% of their time. The darkest areas within the home range represent areas with the highest density of GPS coordinates.

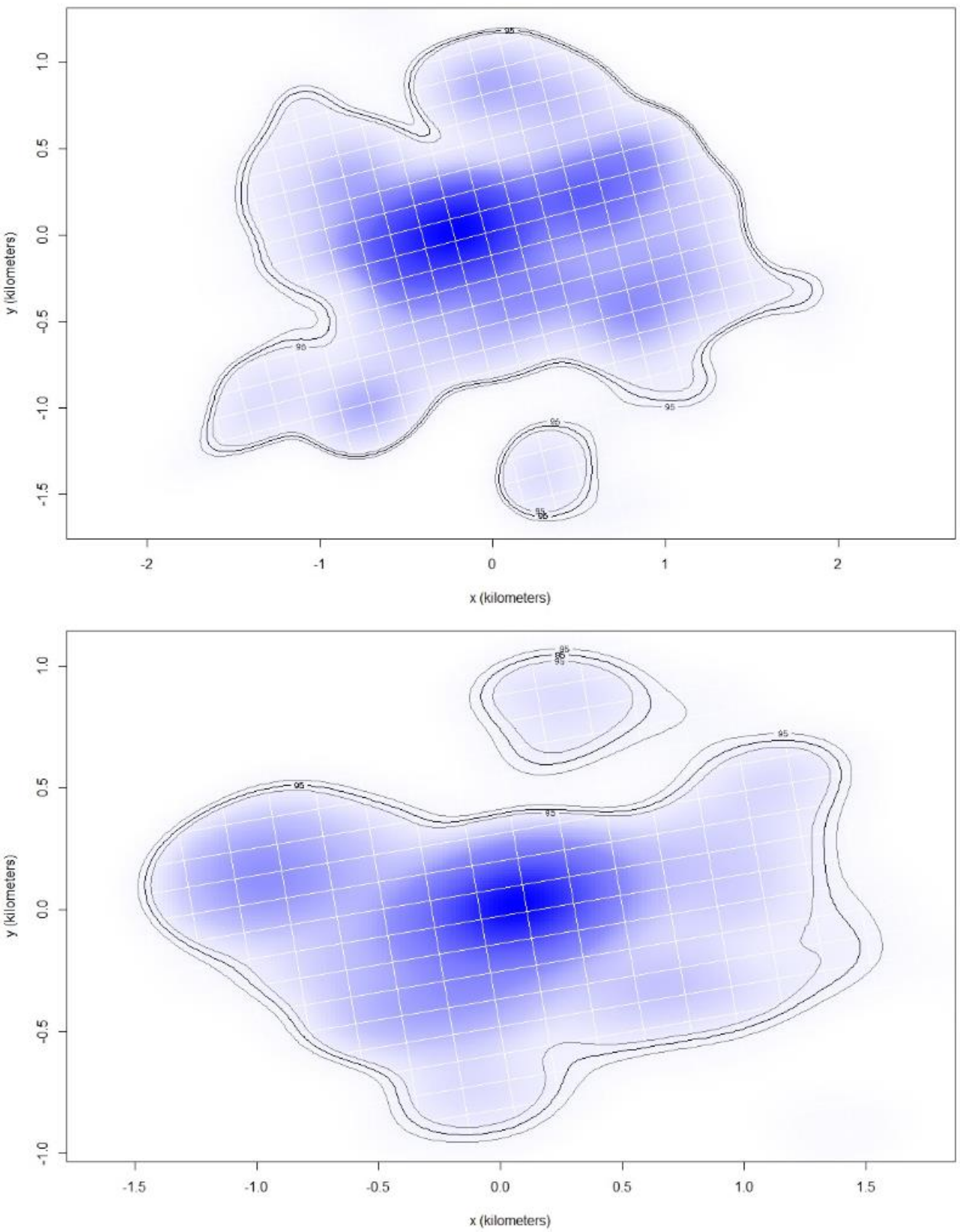
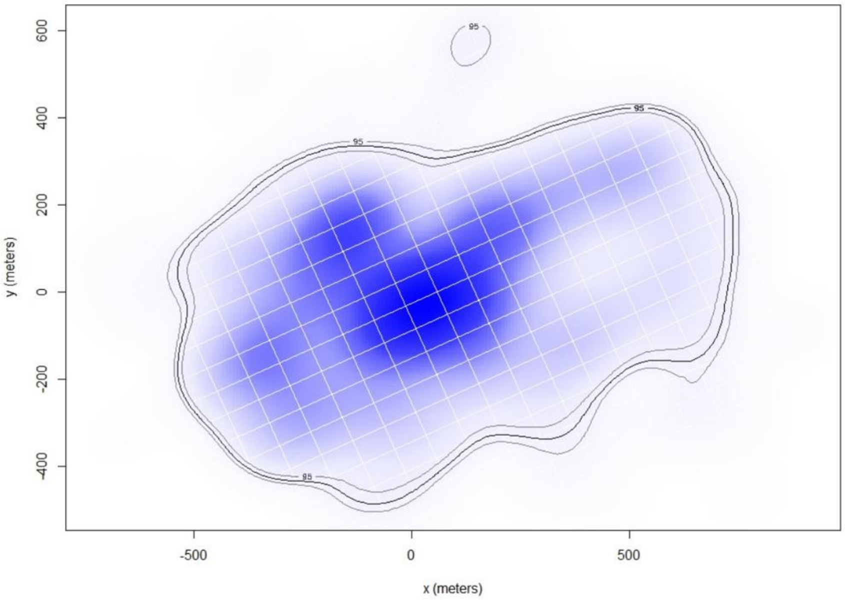


Figure 3. An autocorrelated kernel density estimate of reference Fox 3 (top) and reference Fox 4 (bottom), collected in Fall 2020 and Spring 2021 near reference areas associated with Study Site 1 in northern California. A grid is plotted within the graph to showcase the standard deviations of each kernel within the home range, while the middle contour shows the maximum likelihood area where these foxes spent 95% of their time. The darkest areas within the home range represent areas with the highest density of GPS coordinates.



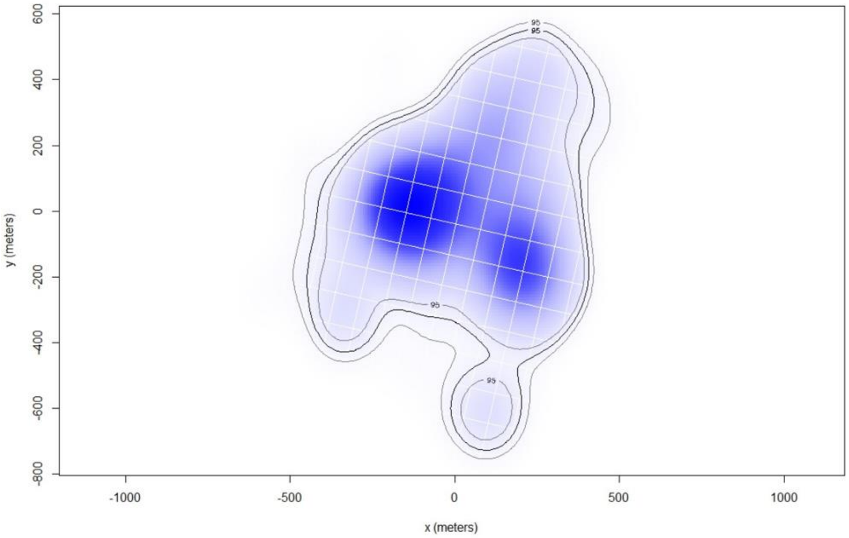


Figure 4. An autocorrelated kernel density estimate of impact Fox 5 (top) and impact Fox 6 (bottom), collected in Fall 2020 and Spring 2021 near Study Site 2 in northern California. A grid is plotted within the graph to showcase the standard deviations of each kernel within the home range, while the middle contour shows the maximum likelihood area where these foxes spent 95% of their time. The darkest areas within the home range represent areas with the highest density of GPS coordinates.

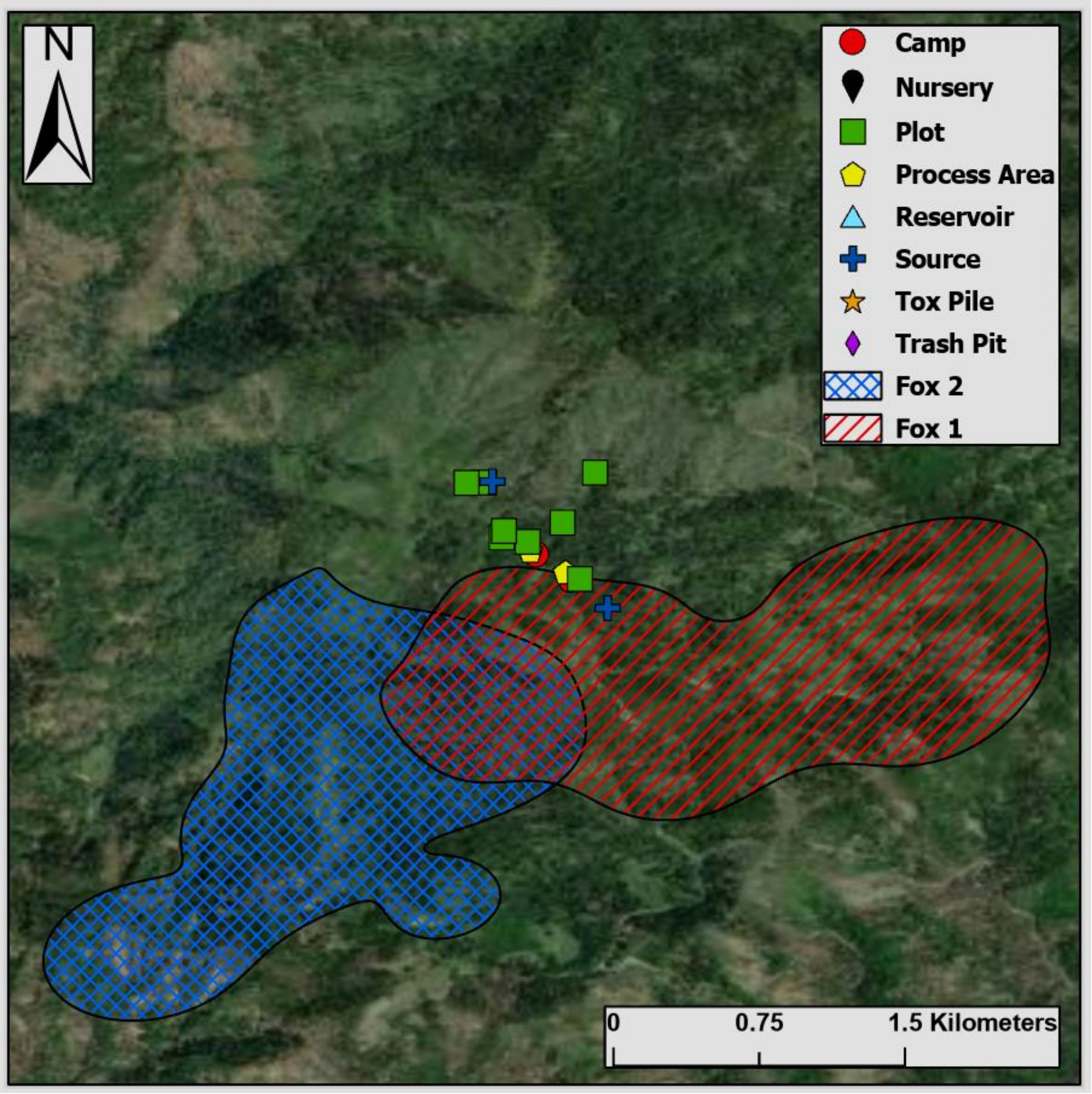


Figure 5. The 95% autocorrelated kernel density estimate of impact Fox 1 (red) and reference Fox 2 (blue) in relation to Study Site 1 in northwestern California.

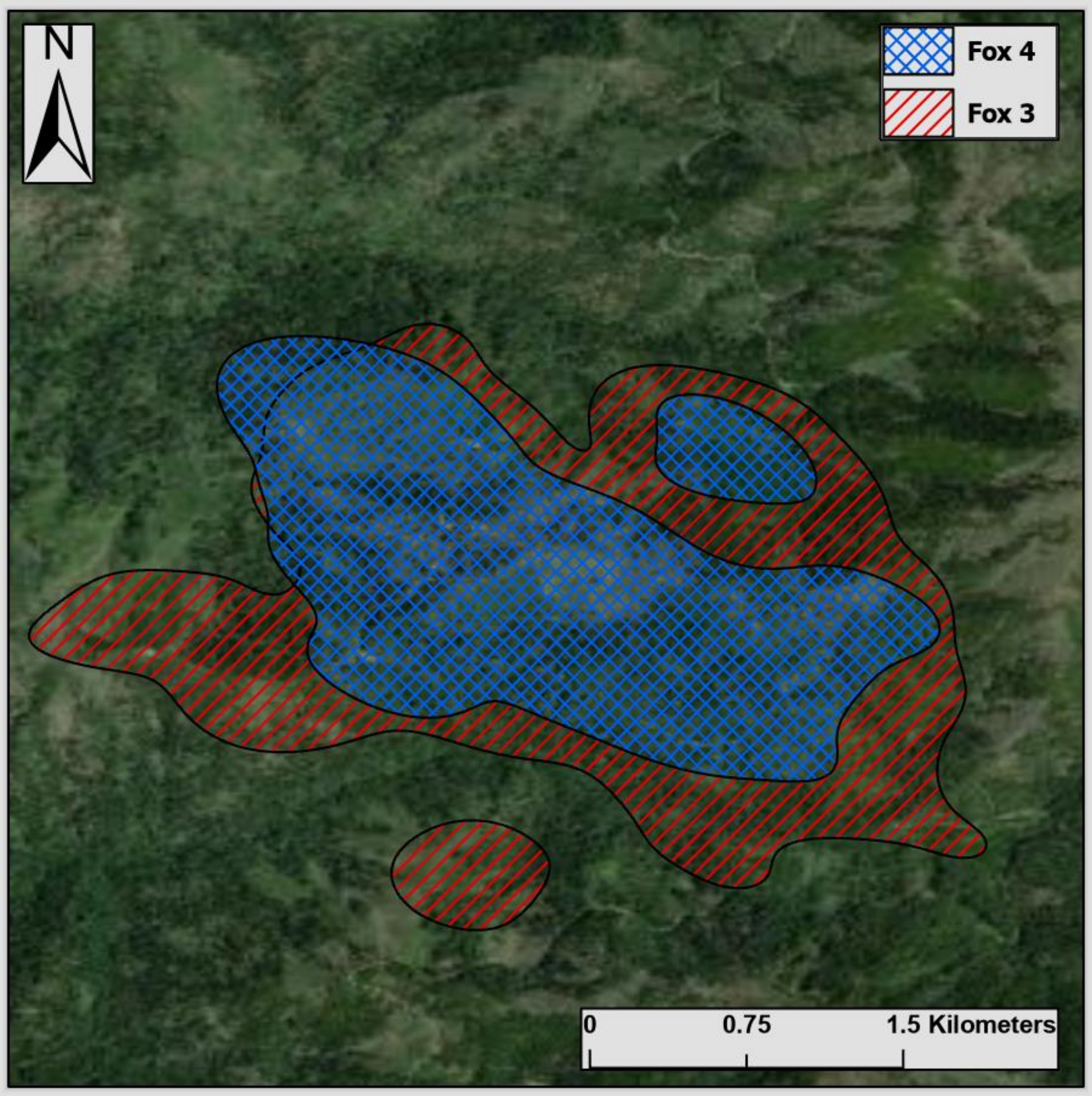


Figure 6. The 95% autocorrelated kernel density estimate of reference Fox 3 (red) and Fox 4 (blue) associated with Study Site 1 in northwestern California.

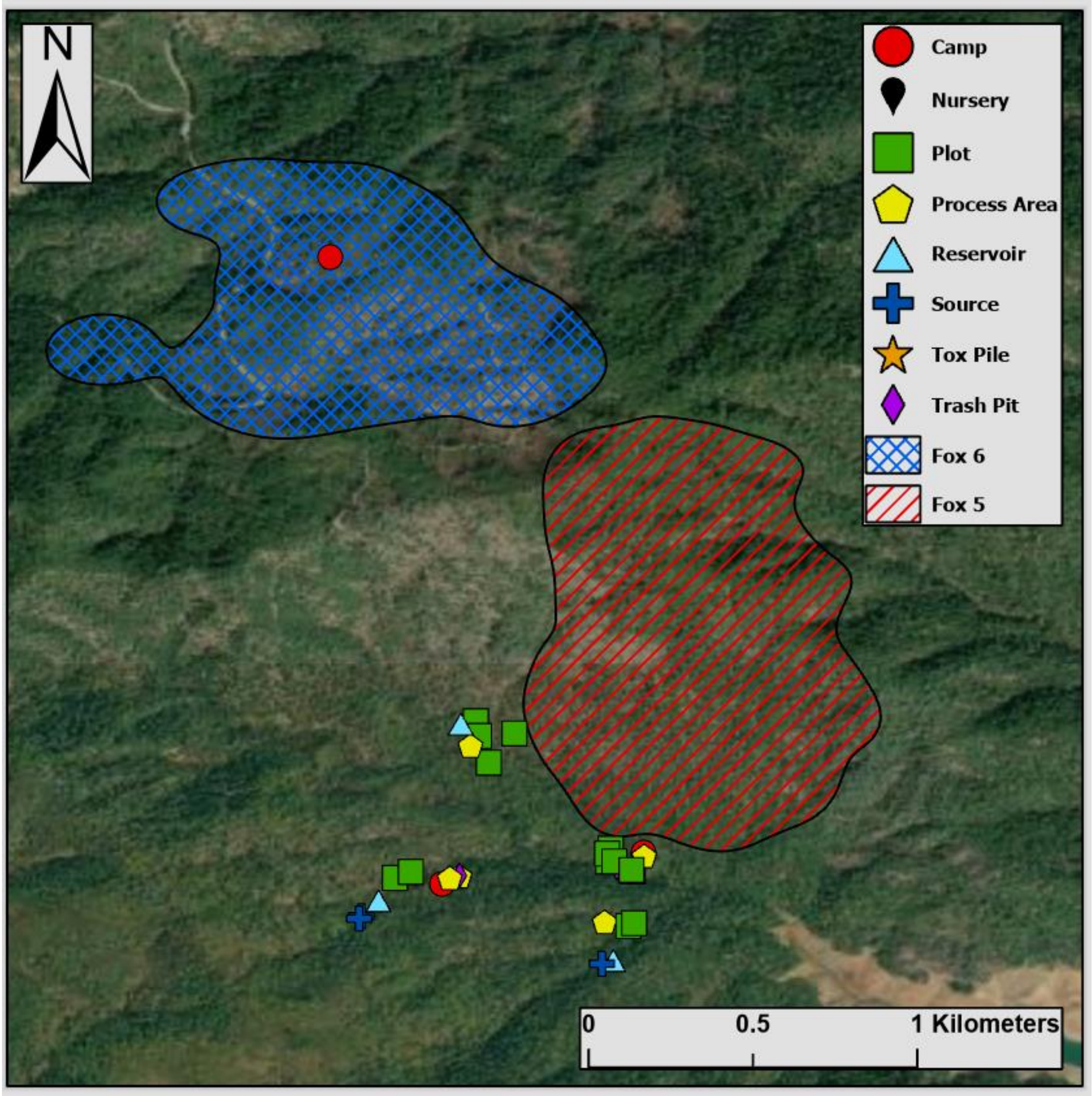


Figure 7. *The 95% autocorrelated kernel density estimate of impact Fox 5 (red) and impact Fox 6 (blue) of Study Site 2 in northwestern California.*

Resource Selection Functions

The covariates in the resource selection function analysis reflected use relative to availability. The generalized linear model analyses revealed multiple environmental covariates to be significant for gray fox habitat selection (Figure 8 – Figure 13). Of the environmental covariates examined in the resource selection function analysis, all foxes were found to prefer areas with greater aspect, specifically south, southwest, and west directions (Figure 14). All remaining environmental covariates showed a variation of selection between collared foxes at Study Site 1 and Study Site 2. Fox 1 did not appear to select for the trespass grows (p-value = 0.1549), as the best model included only the environmental covariates (Table 4). Fox 5 selected for trespass cannabis grows ($p < 0.01$), as did Fox 6 ($p < 0.01$), which was confirmed by the high significance of the grow site covariate analyzed alongside the environmental covariates (Table 5 and Table 6).

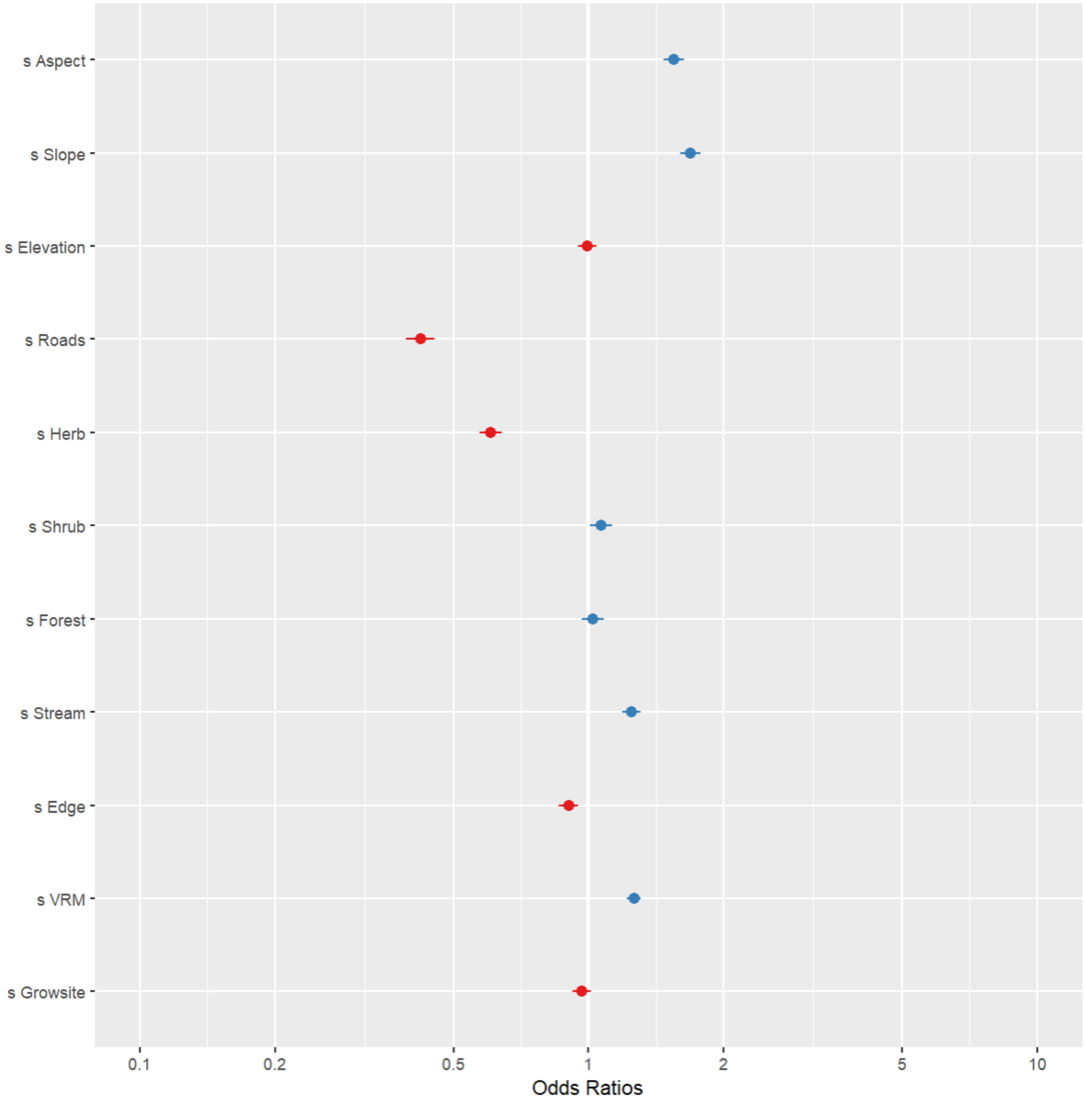


Figure 8. The habitat selection results of Fox 1's modeled preference and avoidance of 10 scaled environmental covariates and the growsite covariate. The coefficients are model estimates from a generalized linear model (logistic regression) with putative absence (pseudoabsences) represented by random locations within Fox 1's home range. All odds ratio values, except the aspect, slope, elevation, and VRM covariates, reflect the distances to each given feature, with lower distances (shown in red and placed to the left of the central axis) highlighting greater selection for that covariate. Blue odds ratios, which appear on the right of the central axis suggest avoidance of those covariates. For aspect, slope, elevation, and VRM covariates, points appearing on the left of the central axis show selection for lesser values, which covariates appearing on the right show selection for greater values.

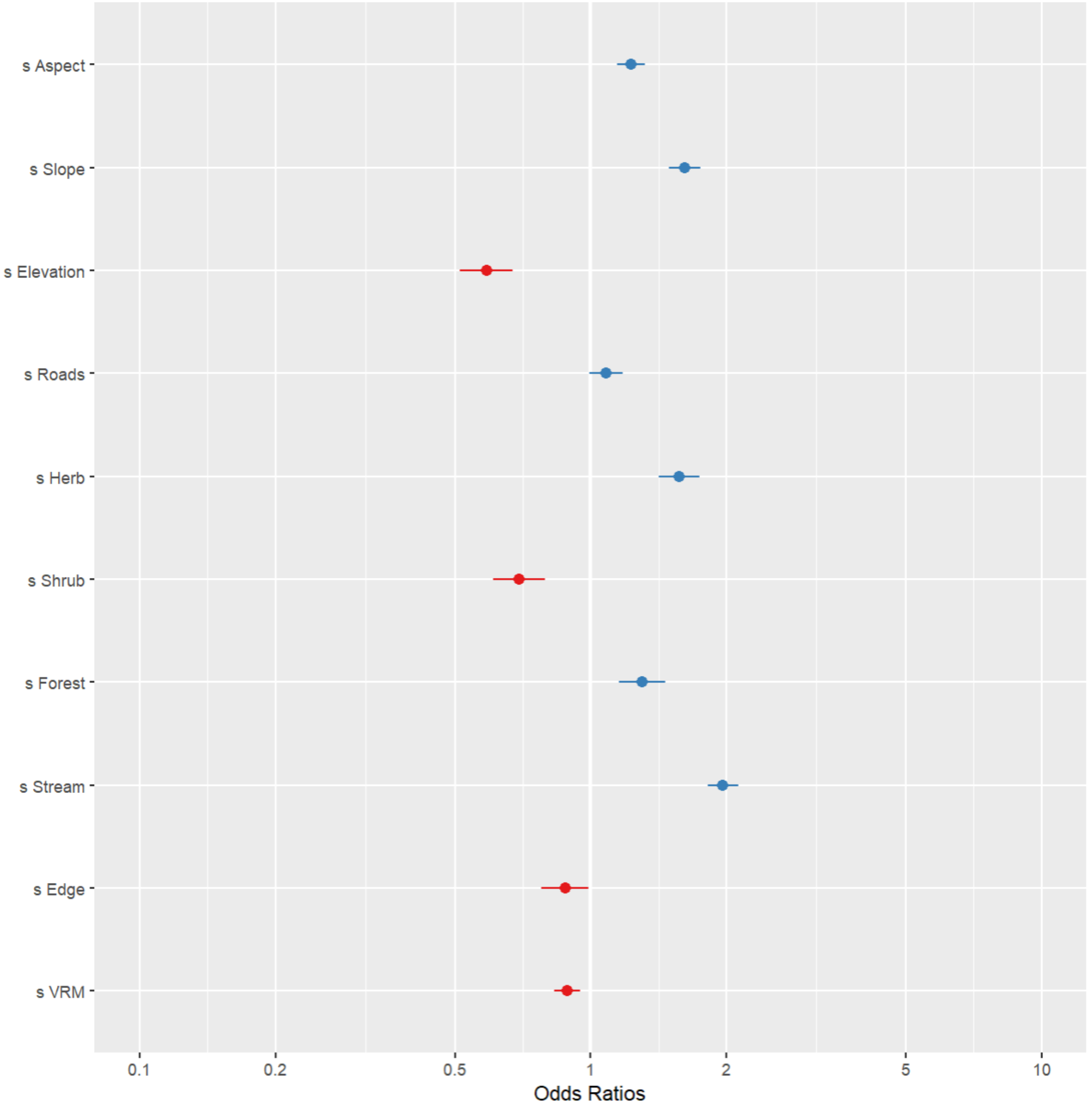


Figure 9. T*he habitat selection results of Fox 2's modeled preference and avoidance of 10 scaled environmental covariates. The coefficients are model estimates from a generalized linear model (logistic regression) with putative absence (pseudoabsences) represented by random locations within Fox 2's home range. All odds ratio values, except the aspect, slope, elevation, and VRM covariates, reflect the distances to each given feature, with lower distances (shown in red and placed to the left of the central axis) highlighting greater selection for that covariate. Blue odds ratios, which appear on the right of the central axis suggest avoidance of those covariates. For aspect, slope, elevation, and VRM covariates, points appearing on the left of the central axis show selection for lesser values, which covariates appearing on the right show selection for greater values.*

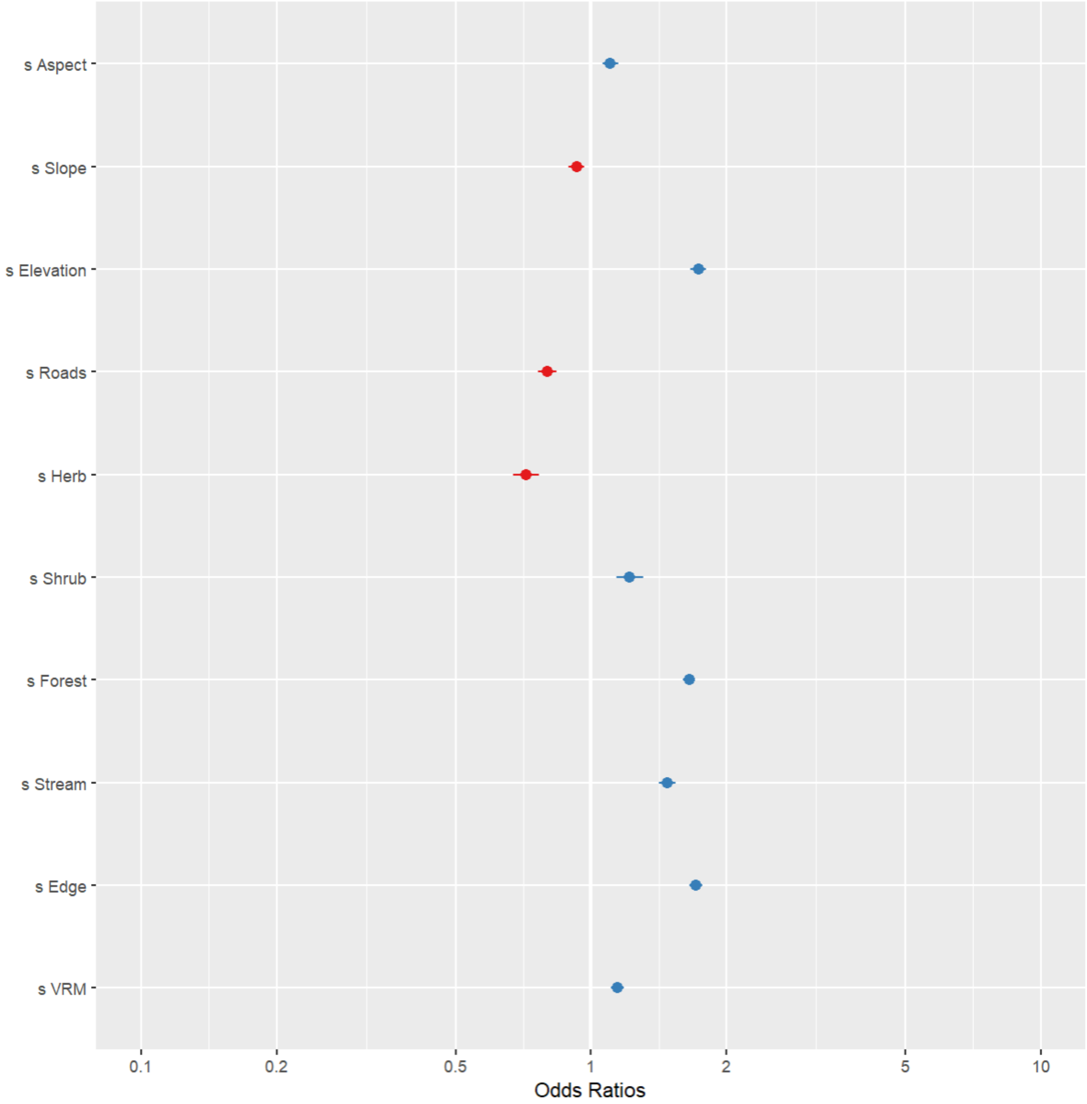


Figure 10. The habitat selection results of Fox 3's modeled preference and avoidance of 10 scaled environmental covariates. The coefficients are model estimates from a generalized linear model (logistic regression) with putative absence (pseudoabsences) represented by random locations within Fox 3's home range. All odds ratio values, except the aspect, slope, elevation, and VRM covariates, reflect the distances to each given feature, with lower distances (shown in red and placed to the left of the central axis) highlighting greater selection for that covariate. Blue odds ratios, which appear on the right of the central axis suggest avoidance of those covariates. For aspect, slope, elevation, and VRM covariates, points appearing on the left of the central axis show selection for lesser values, which covariates appearing on the right show selection for greater values.

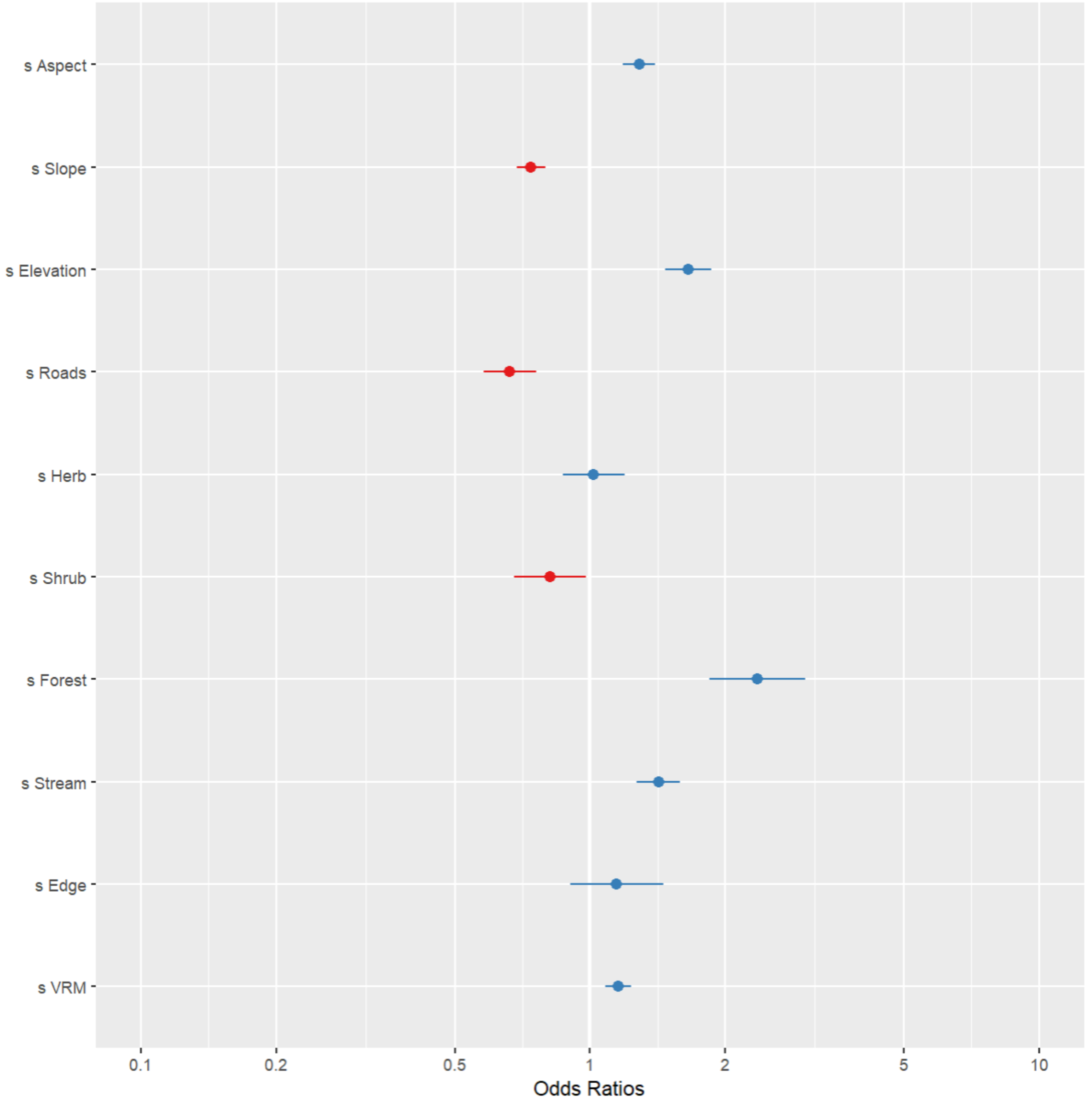


Figure 11. The habitat selection results of Fox 4's modeled preference and avoidance of 10 scaled environmental covariates. The coefficients are model estimates from a generalized linear model (logistic regression) with putative absence (pseudoabsences) represented by random locations within Fox 4's home range. All odds ratio values, except the aspect, slope, elevation, and VRM covariates, reflect the distances to each given feature, with lower distances (shown in red and placed to the left of the central axis) highlighting greater selection for that covariate. Blue odds ratios, which appear on the right of the central axis suggest avoidance of those covariates. For aspect, slope, elevation, and VRM covariates, points appearing on the left of the central axis show selection for lesser values, which covariates appearing on the right show selection for greater values.

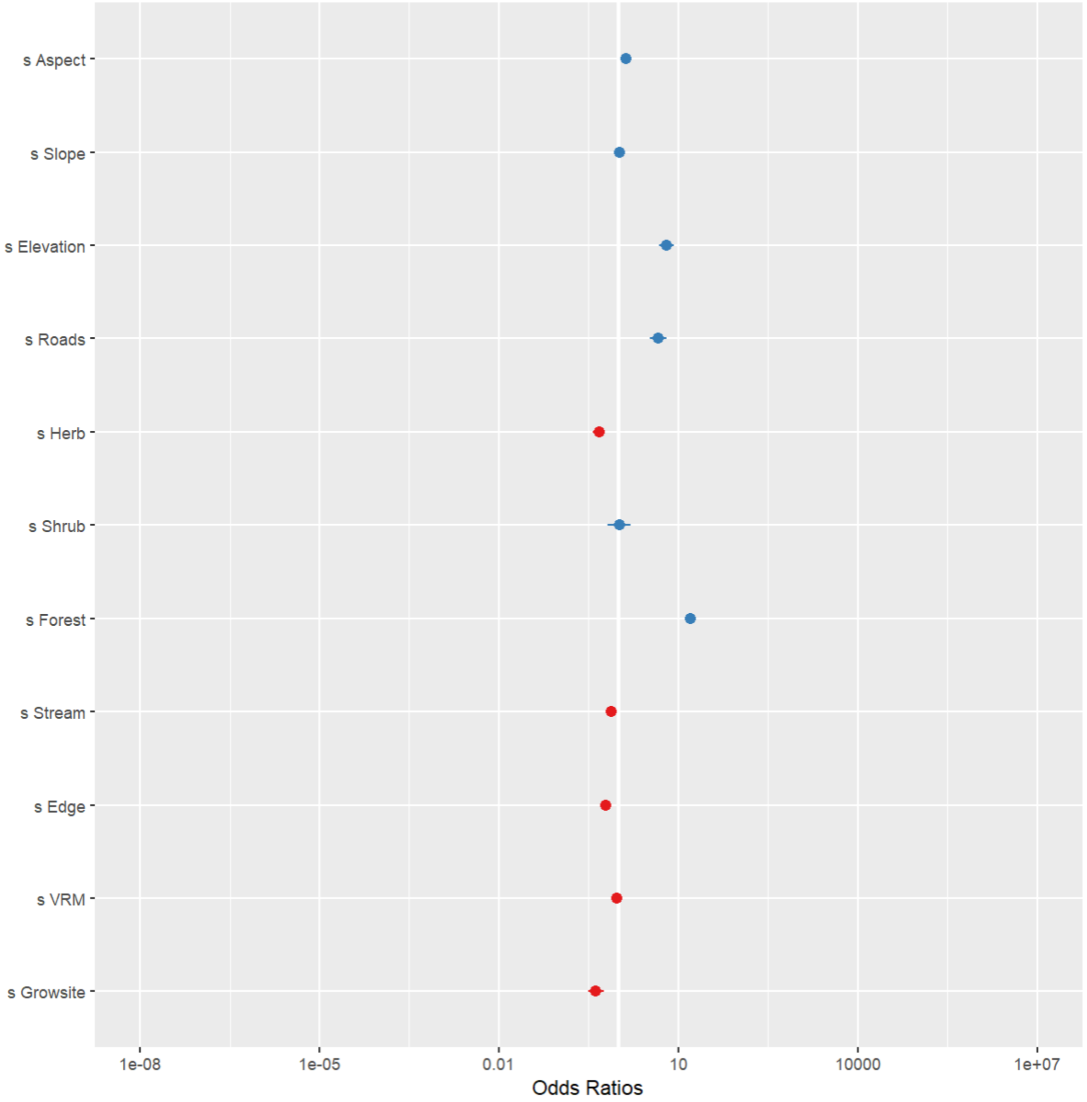


Figure 12. The habitat selection results of Fox 5's modeled preference and avoidance of 10 scaled environmental covariates and the growsite covariate. The coefficients are model estimates from a generalized linear model (logistic regression) with putative absence (pseudoabsences) represented by random locations within Fox 5's home range. All odds ratio values, except the aspect, slope, elevation, and VRM covariates, reflect the distances to each given feature, with lower distances (shown in red and placed to the left of the central axis) highlighting greater selection for that covariate. Blue odds ratios, which appear on the right of the central axis suggest avoidance of those covariates. For aspect, slope, elevation, and VRM covariates, points appearing on the left of the central axis show selection for lesser values, which covariates appearing on the right show selection for greater values.

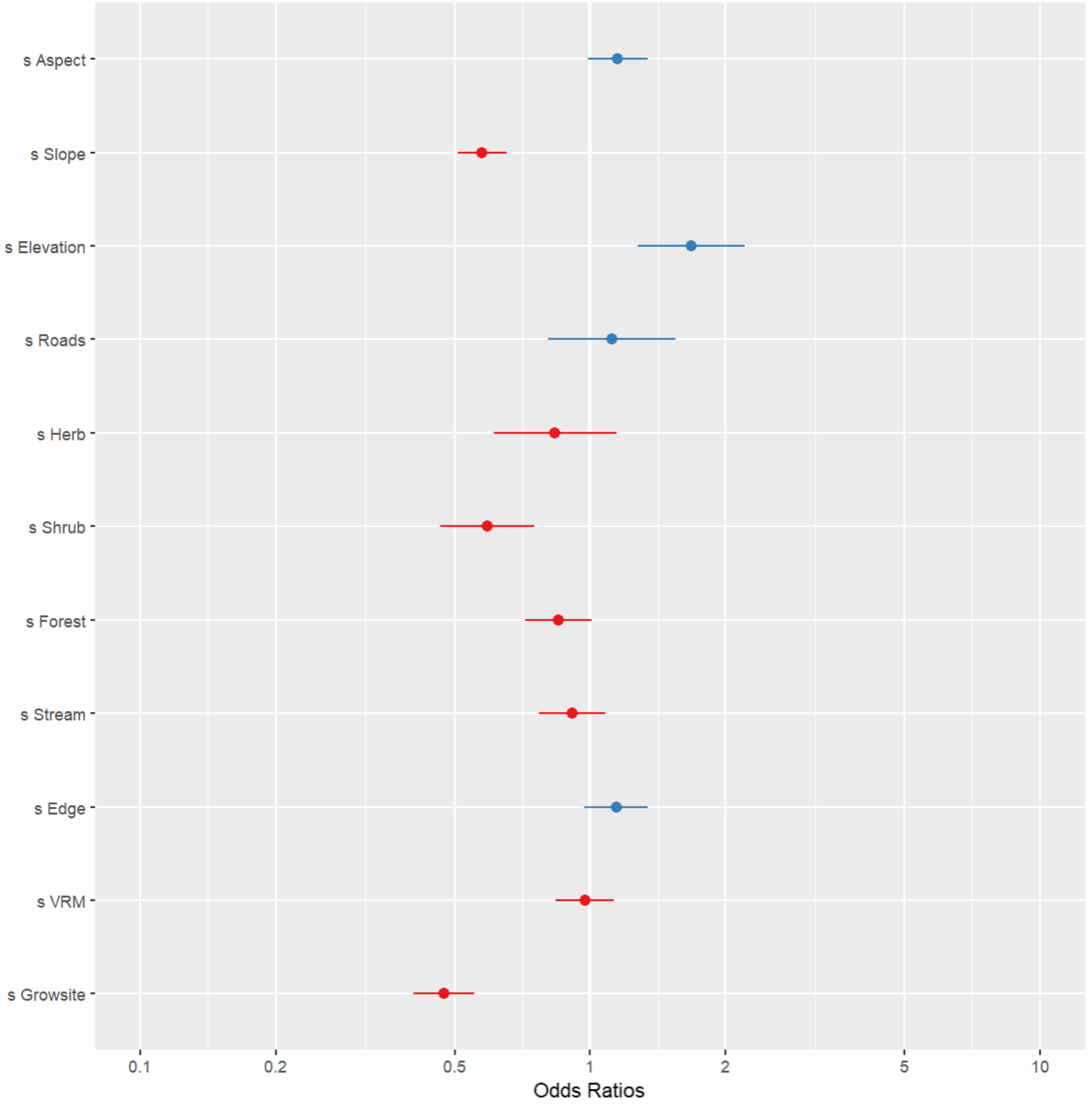


Figure 13. The habitat selection results of Fox 6's modeled preference and avoidance of 10 scaled environmental covariates and the growsite covariate. The coefficients are model estimates from a generalized linear model (logistic regression) with putative absence (pseudoabsences) represented by random locations within Fox 6's home range. All odds ratio values, except the aspect, slope, elevation, and VRM covariates, reflect the distances to each given feature, with lower distances (shown in red and placed to the left of the central axis) highlighting greater selection for that covariate. Blue odds ratios, which appear on the right of the central axis suggest avoidance of those covariates. For aspect, slope, elevation, and VRM covariates, points appearing on the left of the central axis show selection for lesser values, which covariates appearing on the right show selection for greater values.

Table 4. Resource selection function models of the extracted covariate values of used and random GPS locations of Fox 1, located at Study Area 1 in the Shasta-Trinity National Forest, ranked by AICc.

Model	K[a]	AICc	Δ AICc[b]
Fox ~ Aspect + Slope + Elevation + Roads + Grassland + Shrub + Forest + Stream + Edge + Rugged	10	37235.00	0.0
Fox ~ Aspect + Slope + Elevation + Roads + Grassland + Shrub + Forest + Stream + Edge + Rugged + Growsite	11	37234.67	0.33

[a] Number of parameters

[b] Difference between AICc and top model AICc

Table 5. Resource selection function models of the extracted covariate values of used and random GPS locations of Fox 5, located at Study Area 2 in the Shasta-Trinity National Forest, ranked by AICc.

Model	K[a]	AICc	Δ AICc[b]
Fox ~ Aspect + Slope + Elevation + Roads + Grassland + Shrub + Forest + Stream + Edge + Rugged + Growsite	11	28,922	0.0
Fox ~ Aspect + Slope + Elevation + Roads + Grassland + Shrub + Forest + Stream + Edge + Rugged	10	28955	33

[a] Number of parameters

[b] Difference between AICc and top model AICc

Table 6. Resource selection function models of the extracted covariate values of used and random GPS locations of Fox 6, located at Study Area 2 in the Shasta-Trinity National Forest, ranked by AICc.

Model	K[a]	AICc	Δ AICc[b]
Fox ~ Aspect + Slope + Elevation + Roads + Grassland + Shrub + Forest + Stream + Edge + Rugged + Growsite	11	4873.7	0.0
Fox ~ Aspect + Slope + Elevation + Roads + Grassland + Shrub + Forest + Stream + Edge + Rugged	10	4968.6	94.9

[a] Number of parameters

[b] Difference between AICc and top model AICc

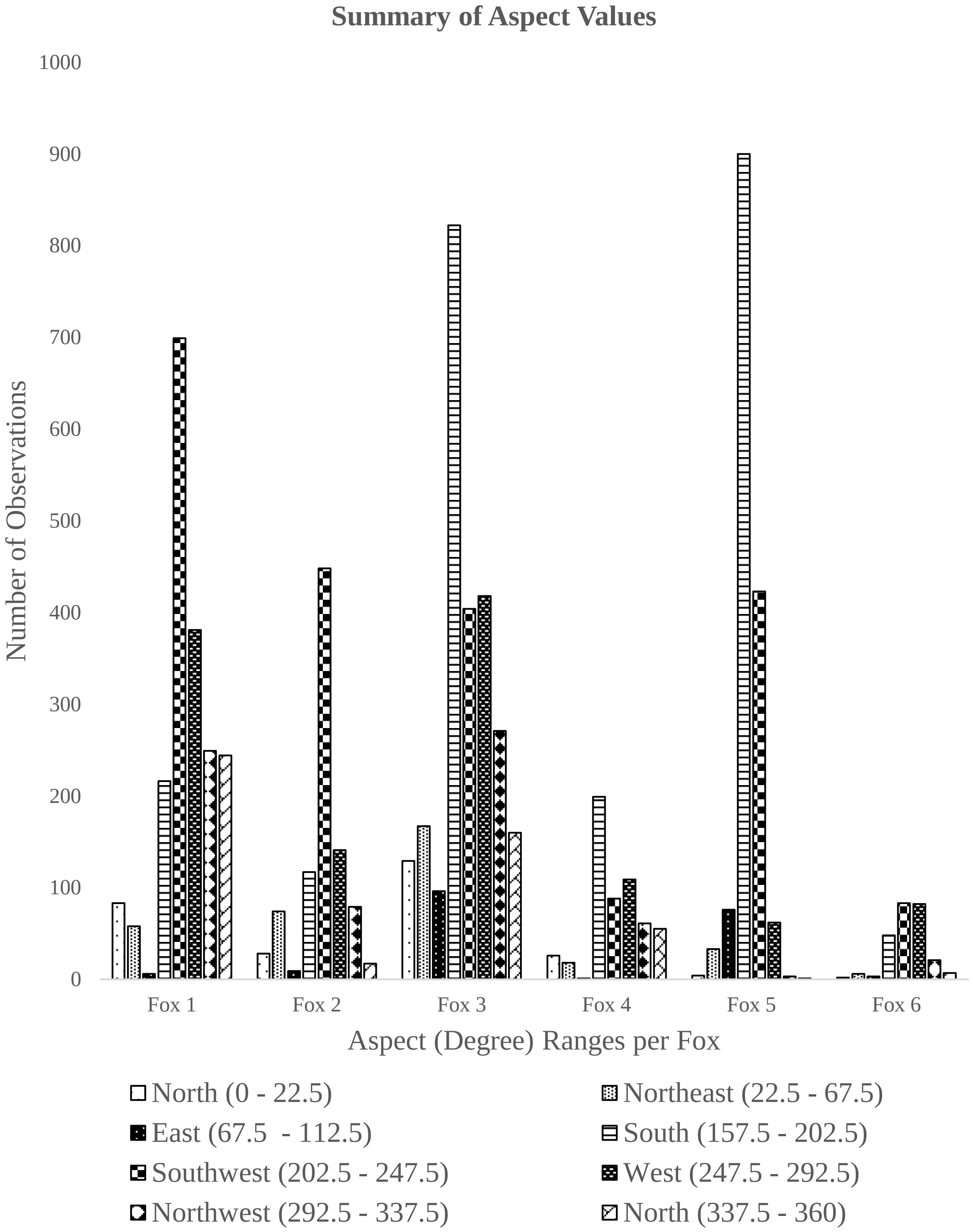


Figure 14. Summary of extracted aspect values and the ArcGIS degree ranges associated with each recorded GPS location for all six collared foxes.

Fourth Order Habitat Use

Camera Deployment

I deployed 88 cameras across six trespass grow sites, which were operational for 22 months, between September 2020 and June 2022 (Table 7). There was a total of 5,393 high impact camera deployment days and 1,787 low impact camera deployment days across all six study sites (Appendix 11). A deployment day is measured as each 24-hour period that a camera was deployed in the field.

Of the 287 videos recorded, ninety percent of cameras recorded 20 second videos, with the next highest recorded video lasting 60 seconds (3.5%), followed by various video lengths ranging between one second and 30 seconds (remaining 5.5% of videos). Browning camera manufacture settings switch cameras to record 20-second videos at night, regardless of their user's chosen program. The sixty-second videos were recorded on Bushnell cameras.

Table 7. The number of high and low impact camera-video pairs at six study sites in northern California, between Fall 2020–Summer 2022.

Study Site	N of Low Impact Cameras Pairs	N of High Impact Cameras Pairs
Study Site 1	3	4
Study Site 2	4	8
Study Site 3	2	5
Study Site 4	3	4
Study Site 5	1	5
Study Site 6	2	3

Behavior

Over the course of the data collection period, I documented several instances of gray foxes present within the trespass grow study sites, both on video and in photos. Videos of gray fox behavior (n = 287) totaled 2,908 seconds and 1,046 photos of foxes were recorded across all six study sites (Table 8 and Table 9). Of the 287 videos, 245 videos captured foxes exiting the frame before the video concluded (85.4%), while 42 videos ended with the gray fox still in frame (14.6 %). A total of 245 delineated events of foxes were documented greater than two minutes apart and 43 videos recorded foxes documented less than two minutes apart (Table 10). Events were delineated by a time difference greater than two minutes from the last observation, regardless of the number of photos of videos documented in that two-minute timeframe. The count of fox observations (n = 287) was utilized for the behavior analysis. I recorded approximately 2.3 photo events for every single video event, so it is possible there were twice as many fox visitation events that were not recorded on video. Oftentimes, photo and video cameras did not record the exact same view and the video cameras were set to more stringent parameters than photo cameras, which confounds the comparison of video and photo detection success.

The most common behavior across high and low impact site features was locomotion, followed by vigilance, scent marking, and feeding (Table 11, Figure 15). I observed no resting behavior at any of the six study sites. Feeding occurred at all site features, though it was the least documented behavior, which is in direct contradiction to the prediction of this behavior being the most common because of the available food brought in by growers.

When I pooled sites together by the counts of fox videos (n = 287), then averaged proportions of behavior, locomotion was documented approximately the same number of times across camp sites, trash pits, toxicant piles, process areas, cultivation plots, and trails (Figure 16). Vigilant behavior was more common at campsites, toxicant piles, trails, cultivation plots, and trash pits, than in process areas. Marking behavior was more common at process areas, trash pits, and toxicant piles. Feeding activities were most common at toxicant piles, process areas, trails, and cultivation plots, while camp sites and trash pits had minimal detections. Five instances of social behavior, three of which were amicable, were recorded and two videos recorded hostile behavior. The amicable behaviors consisted of two videos of foxes walking together along trails in Study Site 4 and a ringtail and gray fox investigating the camp site at Study Site 4. The hostile videos consisted of a gray fox seemingly being chased by a spotted skunk (*Spirogale gracilis*) through a cultivation plot in Study Area 2 and a spotted skunk stomping at a gray fox at Study Site 4.

Locomotion and vigilance behaviors were recorded approximately the same number of times across all site features in Study Site 1 (Figure 17). I observed no instances of marking, feeding, or socializing behavior. At Study Site 1, I observed slightly higher observations of locomotion at high impact sites, while vigilance was slightly higher at low impact sites. At Study Site 2, locomotion and vigilance was slightly more common at cultivation plots and trails, though marking behaviors were significantly more common at process areas, camp sites, trash pits, and toxicant piles (Figure 18). At Study Site 3, locomotion was numerically (not statistically) more common in cultivation plots and trails than camp sites, toxicant piles, trash pits or process areas (Figure 19). At Study Site 4, the frequency of locomotion was similar among site features, while vigilance occurred more commonly in camp sites, toxicant piles, trash pits, and process areas (Figure 20). This site had the highest number of social interactions detected. Only one fox was recorded at Study Site 5, and it exhibited vigilant and locomotive behaviors in one of the cultivation plots (Figure 21). At Study Site 6, I observed more instances of locomotive behavior in cultivation plots and trails, while marking behaviors were more common across process areas, camp sites, trash pits, and toxicant piles (Figure 22).

Table 8. The total number of videos and photos of gray foxes at each site feature of interest across all six study sites.

	Camp	Toxicant Pile	Trash Pit	Process Area	Plot / Trail
Number of Videos	69	28	43	48	99
Number of Photos	245	246	132	105	318

Table 9. The total number of videos and photos of gray foxes at each study site, pooled across all six trespass grow study sites.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Number of Videos	13	116	10	137	1	10
Number of Photos	25	281	18	685	4	33

Table 10. A summary of all fox photo (n = 343) and video (n = 245) events recorded at each site feature type across all six study sites between Fall 2020 and Summer 2022. An event is an observation of a fox documented at least two minutes after the last previous observation of a fox. The two-minute delay is related to the camera's one-minute trigger delay and the one-minute of data that Browning cameras were originally set to record.

Site Feature	Photo Event	Video Event
Camp 1	55	43
Camp 2	10	5
Camp 3	1	2
Plot / Trail 1	29	16
Plot / Trail 2	47	58
Plot / Trail 3	25	17
Process Area 1	2	5
Process Area 2	9	15
Process Area 3	28	22
Tox Pile 1	20	18
Tox Pile 2	63	5
Trash Pit 1	46	30
Trash Pit 2	2	2
Trash Pit 3	6	7

Table 11. The total number of seconds of recorded gray fox behavior across all six trespass grow study sites, documented between Fall 2020 and Summer 2022.

Behavior	Marking	Vigilance	Feeding	Locomotion
Seconds	157	345	95	2,311

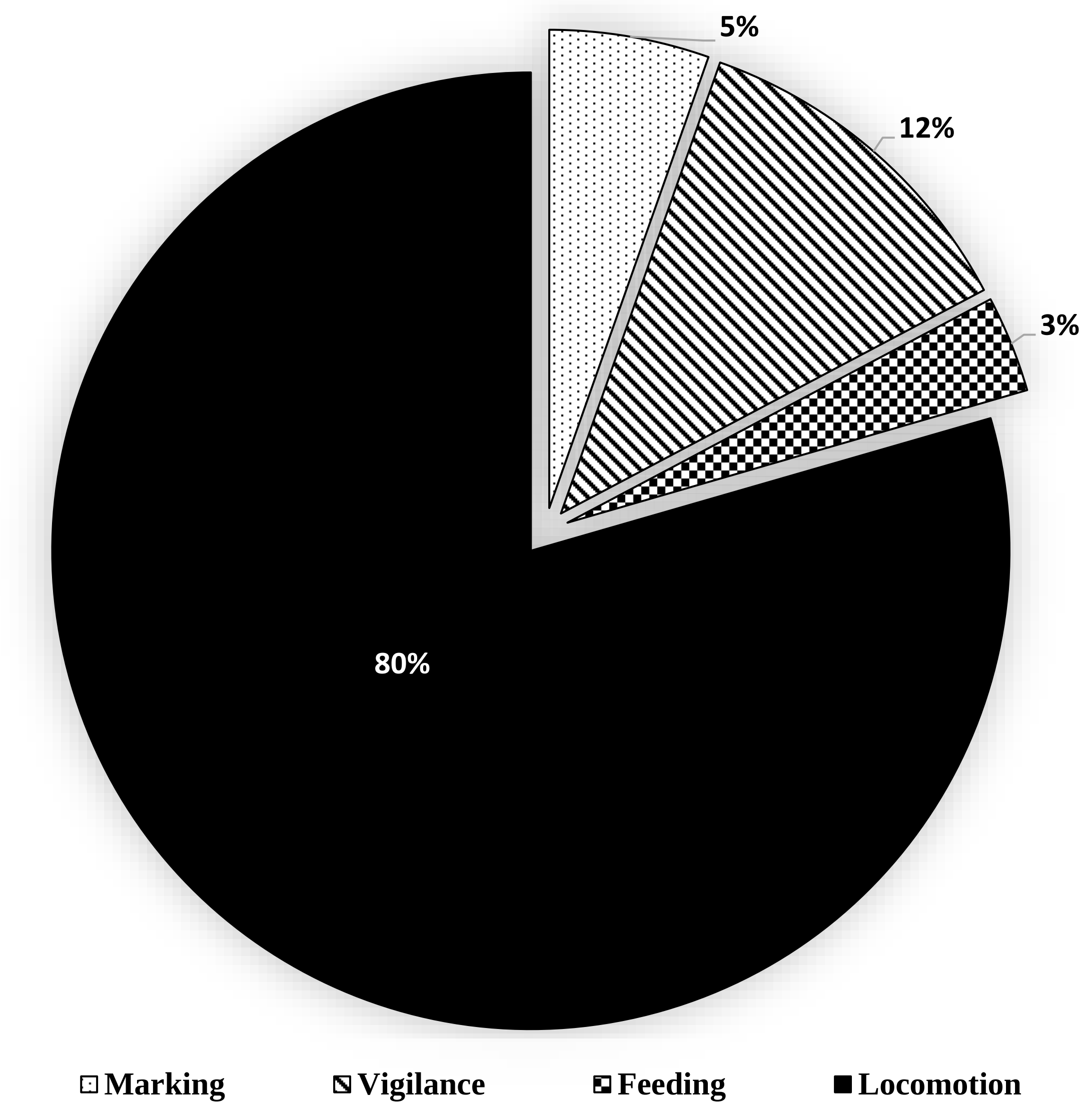


Figure 15. The percentage of each gray fox behavior across both high and low impact site features within six trespass grow sites, recorded between fall 2020 and Summer 2022.

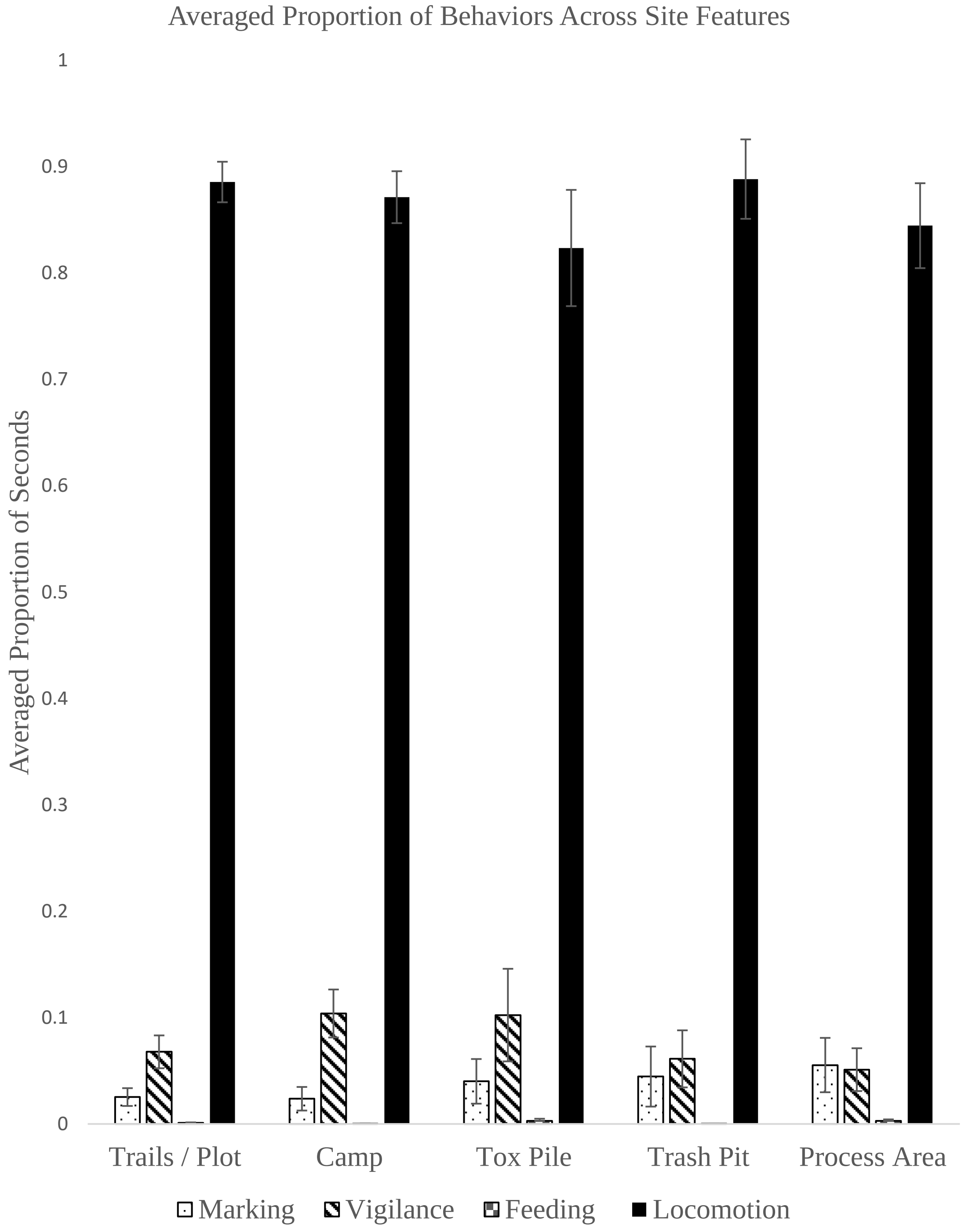


Figure 16. The proportion of time spent in each behavior across impact site feature types between September 2020 and June 2022 at all six trespass grow sites.

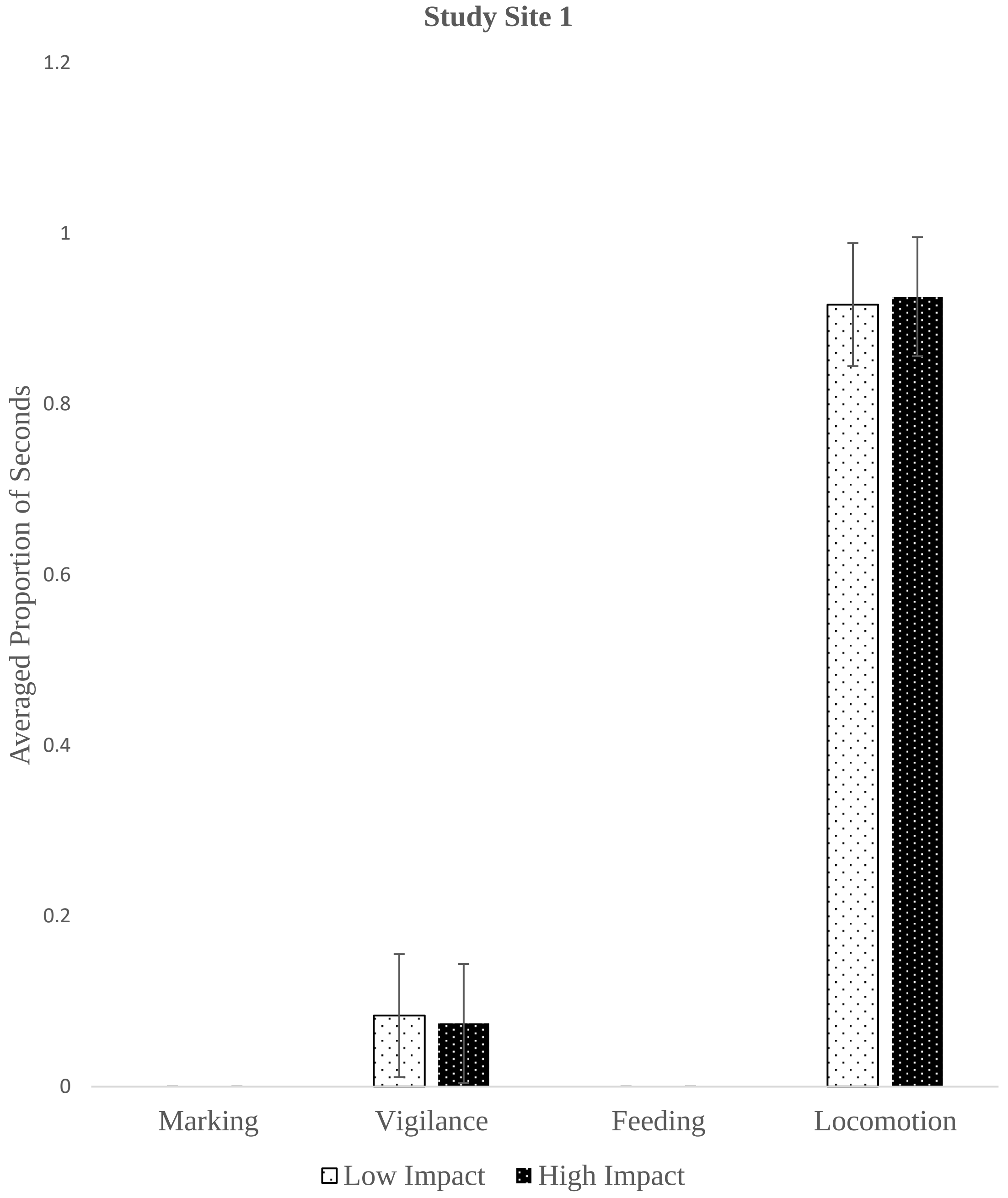


Figure 17. The proportion of time spent in each behavior in relation to high impact areas (trash pits, camp sites, toxicant pits, process areas) and low impact areas (cultivation plots and trails) at Study Site 1 between September 2020 and April 2021.

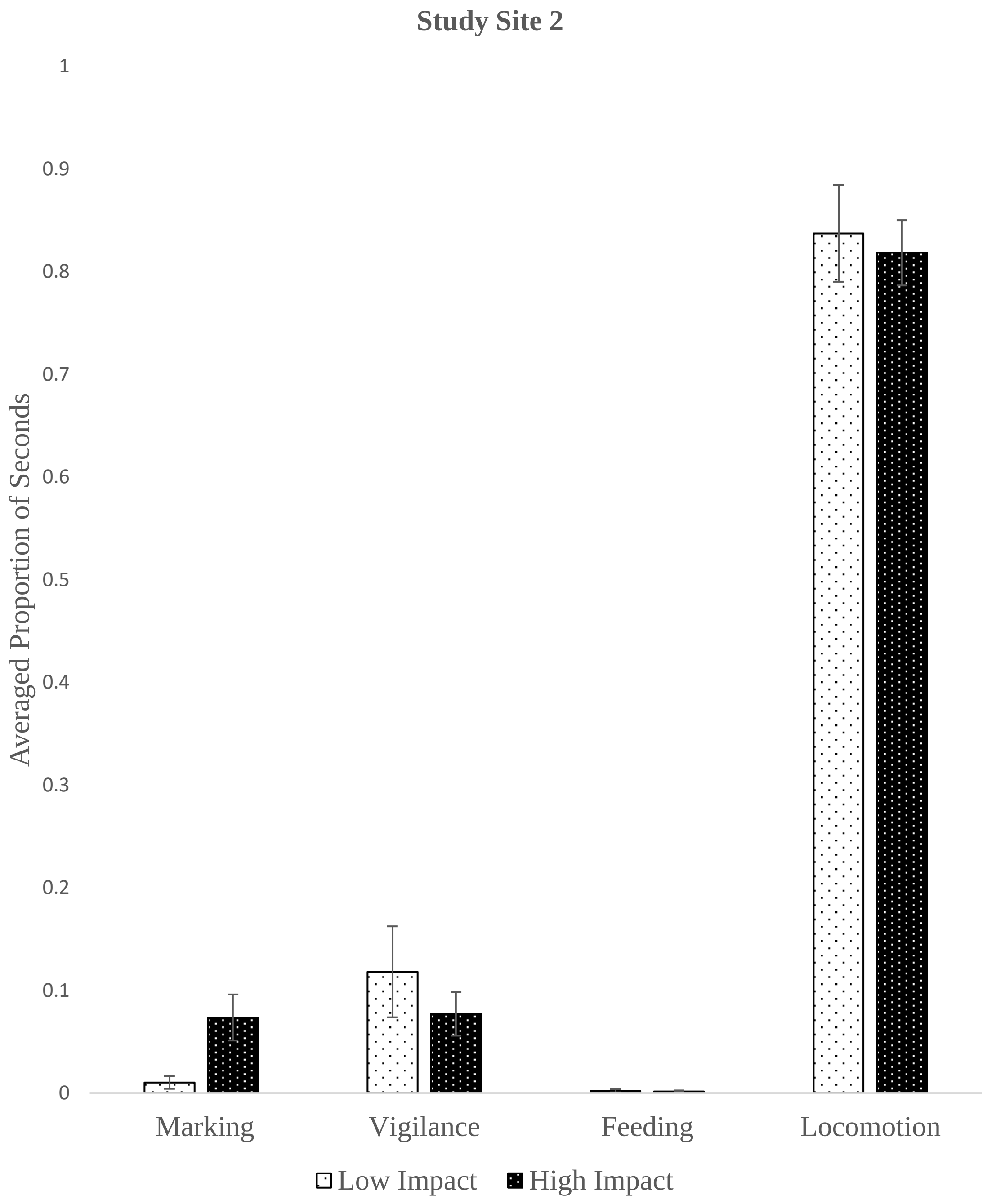


Figure 18. The proportion of time spent in each behavior in relation to high impact areas (trash pits, camp sites, toxicant pits, process areas) and low impact areas (cultivation plots and trails) at Study Site 2 between October 2020 and May 2022.

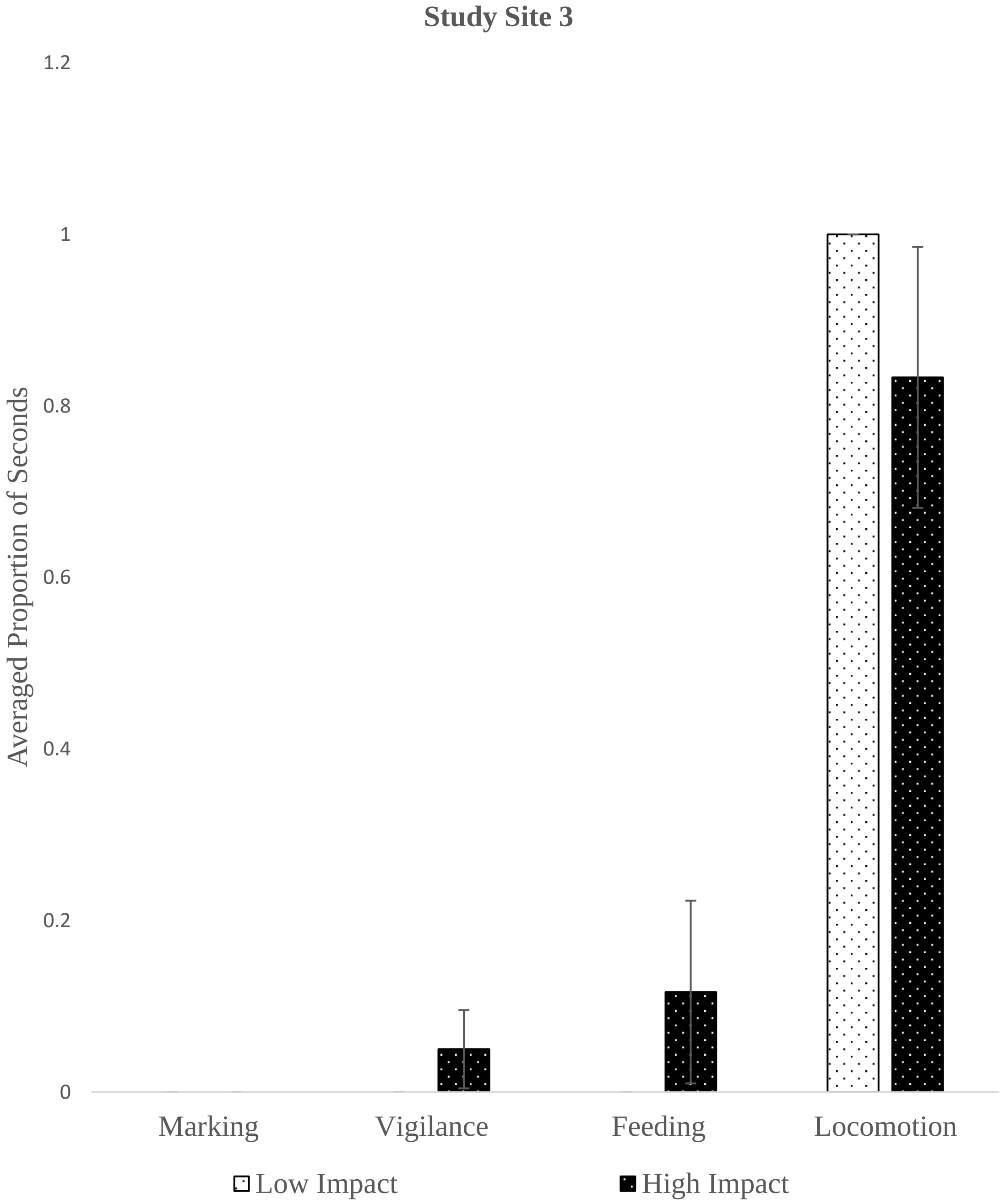


Figure 19. The proportion of time spent in each behavior in relation to high impact areas (trash pits, camp sites, toxicant pits, process areas) and low impact areas (cultivation plots and trails) at Study Site 3 between February 2021 and June 2021 at Study Site 3.

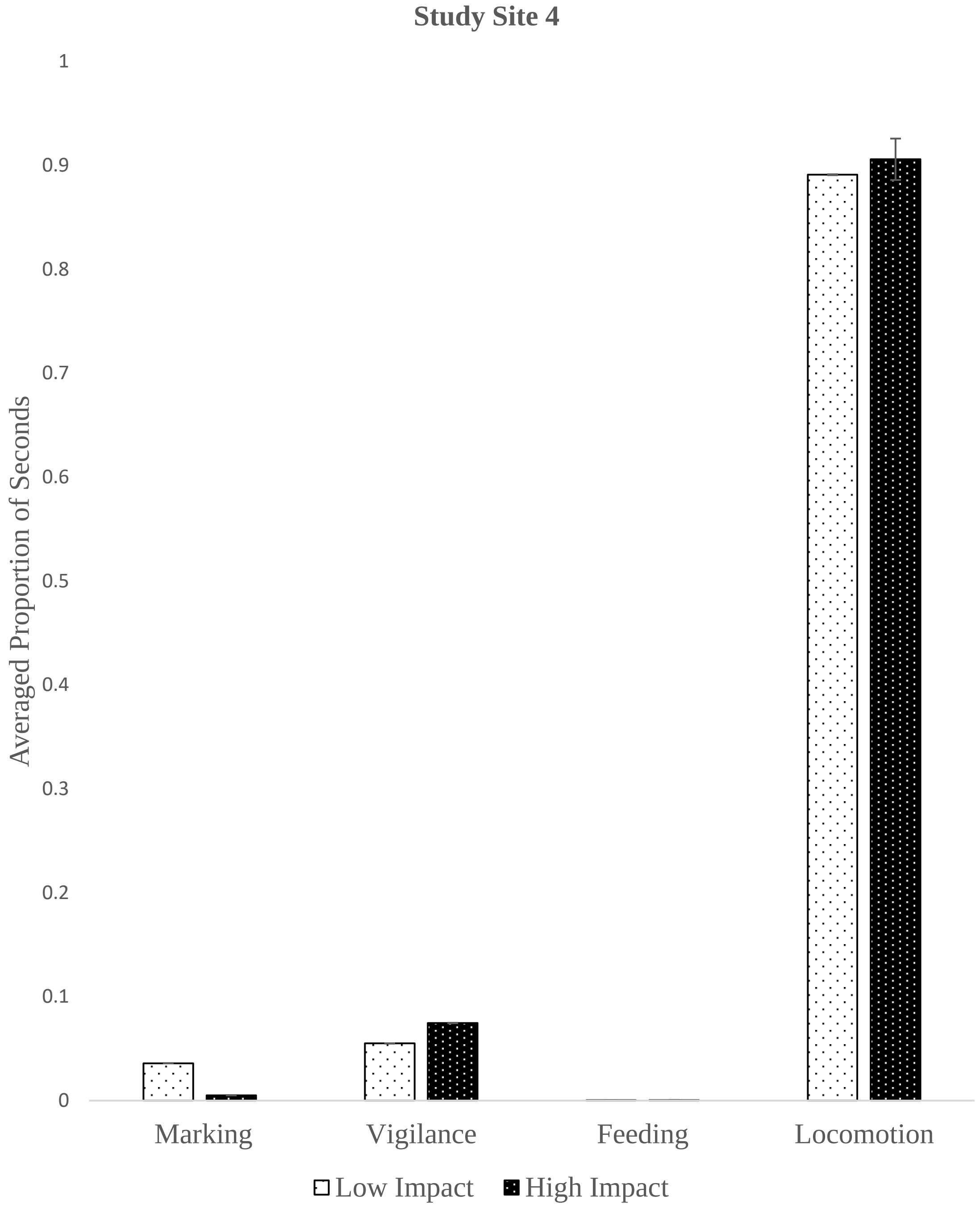


Figure 20. The proportion of time spent in each behavior in relation to high impact areas (trash pits, camp sites, toxicant pits, process areas) and low impact areas (cultivation plots and trails) at Study Site 4 between October 2021 and May 2022 at Study Site 4.

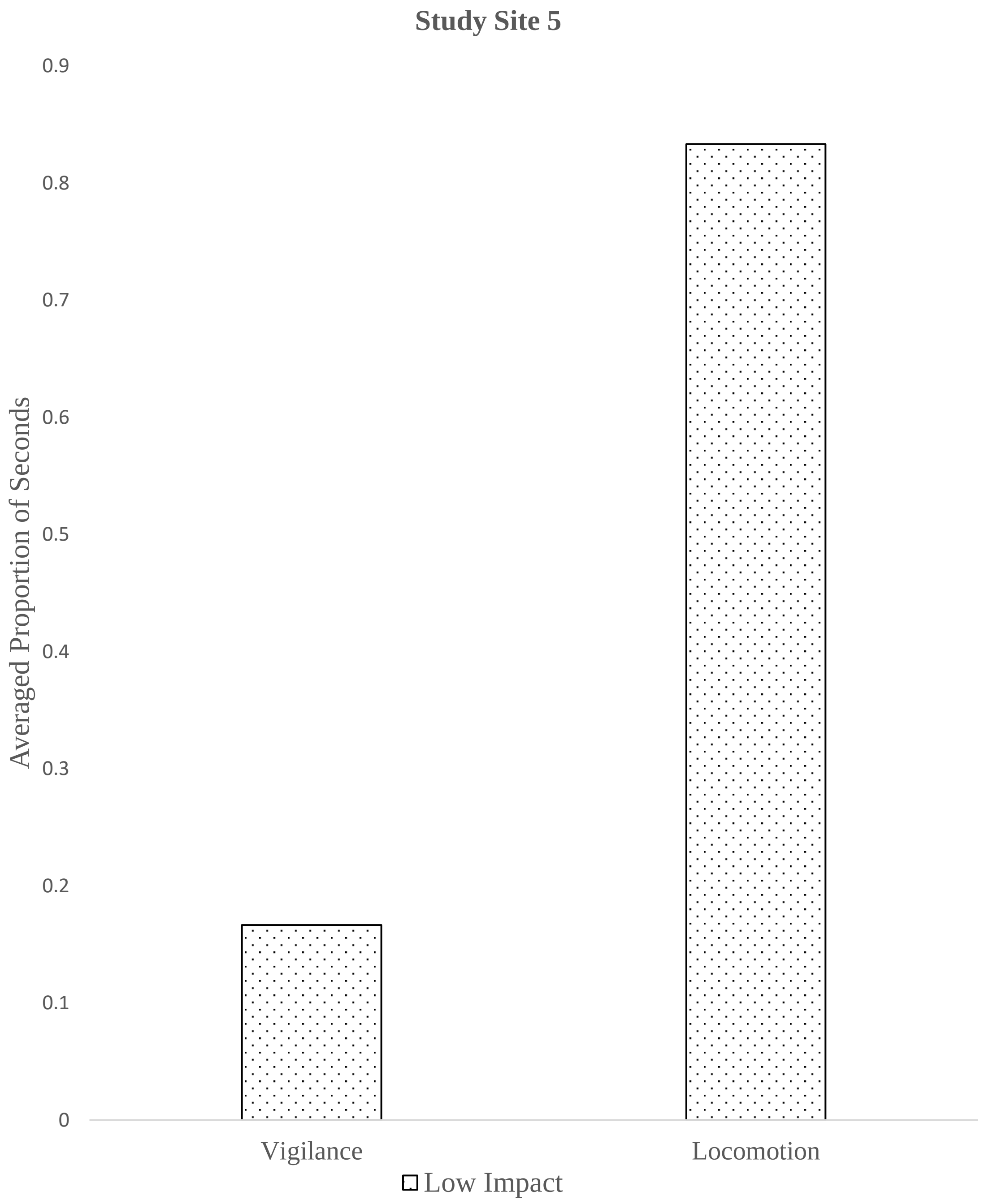


Figure 21. The proportion of time spent in each behavior in relation to high impact areas (trash pits, camp sites, toxicant pits, process areas) and low impact areas (cultivation plots and trails) at Study Site 5 between November 2021 and March 2022.

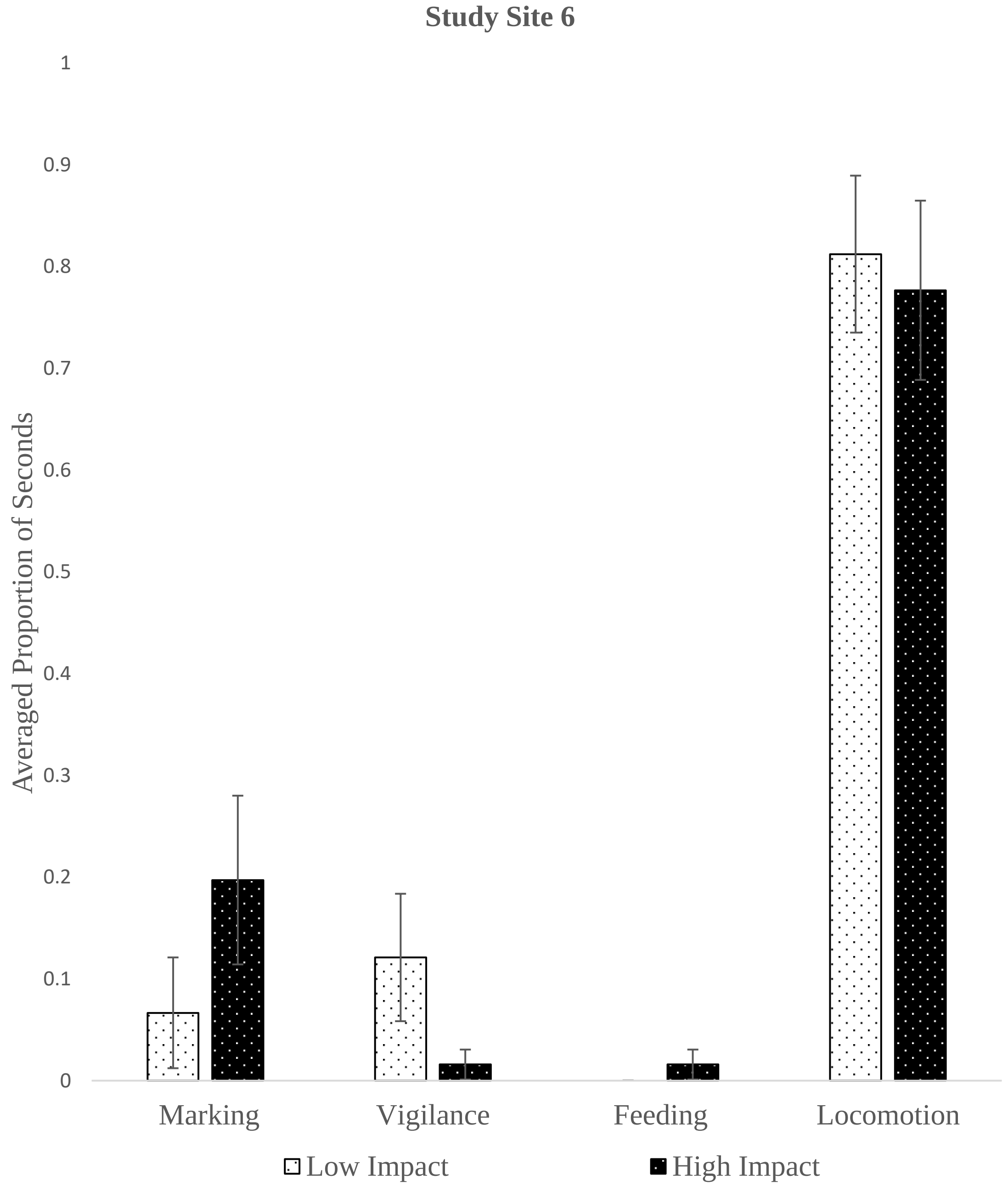


Figure 22. The proportion of time spent in each behavior in relation to high impact areas (trash pits, camp sites, toxicant pits, process areas) and low impact areas (cultivation plots and trails) at Study Site 6 between December 2021 and February 2022.

Independent Reviewer Assessment of Behavior Data

Of the 57 videos reviewed by an independent observer, 26 matched my evaluations exactly (46%). There was one instance where the estimated time spent in scent-marking did not line up (1.7%), three cases where vigilant behavior did not match perfectly (5.2%), three instances where feeding behaviors did not match perfectly (5.2%), and 29 videos where locomotive behavior did match (50.8%). Of those 29 videos of locomotion, I estimated the behavior as occurring for one second longer than did the independent observer (24.1%). There were seven videos in which I estimated the behavior as one second less than the independent observer (12.3%). All videos but one was recorded for a total of 20 seconds, therefore, this difference of one second represents a 5% difference in estimated behavior. Of the fifteen videos documenting locomotion with a difference greater than one second, six videos had a difference of two seconds (10.5%). Eight locomotion videos had greater than a two-second difference (14%). In those eight videos, multiple behaviors were documented, and it was the differences in seconds between these behaviors that led to discrepancies. Despite the discrepancy of a few seconds, this had a minimal impact on my results and were supportive of my findings. I used the data I recorded for my analysis.

DISCUSSION

Third-Order Habitat Selection

Trespass grow sites can serve as an attractant to resident wildlife, creating ecological traps that increases wildlife morbidity and mortality. The habitat modifications that growers create when cultivating cannabis creates ecological traps, by clearing out thick, native brush for cannabis plants, establishing trails between site features, and deploying pesticide-tainted bait traps. To evaluate the potential likely impacts of grow sites on habitat selection, I deployed GPS collars on three impact gray foxes to determine their habitat selection of trespass cannabis grows and documented their locations every two-hours for several months. This is the first study to examine gray fox selection of trespass grows, as well as the first to examine gray fox selection of the specific 10 environmental covariates incorporated in the resource selection function analyses. In addition, I evaluated 287 videos of gray foxes exhibiting a variety of behaviors at trespass grow site features, which confirmed their use of trespass cannabis grows.

Resource Selection Functions

Through habitat selection analyses on the gray foxes' home ranges, I found two of the three impact foxes selected for trespass grow sites, which suggests that these sites pose as a significant conservation threat due to the anticoagulant rodenticides, pesticides, and fertilizers often used there (Wengert 2019). Foxes may select trespass grow sites because of the trail systems connecting features in habitats that would otherwise be more inaccessible. There is also a possibility that foxes use grow sites for hunting, though this was rarely documented on the deployed cameras in this study.

Fox 6 showed the greatest selection for trespass grows sites. However, the abandoned camp located in her home range had the least amount of food refuse, which was hypothesized to be a critical attractant of foxes to trespass grows. She may have instead used the area because of its prime location in a relatively flat open area surrounded by thick oak brush. Fox 5 showed selection for the trespass grow site, though less so than did Fox 6. It is possible that because Study Site 2 was located deep in a drainage, Fox 5 used the upper locations of the site, but did not spend large amounts of time at the core of the grow site; and therefore, was documented as using the grow site less often. Process areas and camp locations were located on the outer sections of the trespass grow polygon, meaning that Fox 5 could utilize these areas sufficiently without the need to travel further inside the growsite footprint.

The analysis of Fox 1 revealed that the model without the growsite covariate had the lowest AICc value and was therefore the best model. This lack of modeled selection for the growsite could be related to the lack of food resources due to the site’s age, the location of the camp sites deep in the drainage, or the presence of large predators accessing the grow site. Though there was variability between selection of trespass grows between the three impact foxes, research has demonstrated that trespass grows pose a threat to the individuals that select such sites (Smith 2021, Gabriel et al. 2013a, Cannabis News 2021). As a result, resource managers and biologists must consider how the presence of a trespass grow sites within their species' area of interest may impact that animal's behavior.

Foxes selected areas with greater aspect, specifically those facing south, southwest, and west. All foxes, except Fox 5, selected areas farther from streams. However, this does not mean foxes do not utilize streams. Rather, they may need limited access to this resource and therefore use it less often. There was a variable selection for vegetation between foxes.

Female Fox 1 showed significant selection for all covariates except elevation and forest vegetation. Fox 1 selected areas with greater slopes, rugged terrain, areas facing southwest and west, areas closer to roads, grassland, and vegetation edge and areas farther from shrubs and streams. Female Fox 2 appeared to select for all covariates other than roads. Fox 2 selected areas with greater slopes, less rugged terrain, lower elevation, areas facing southwest and west, areas farther from grassland, forest patches, and streams, and areas closer to shrubs and vegetation edge.

A few kilometers from Study Site 1, the home ranges of reference Foxes 3 and 4 overlapped extensively (Figure 6). Of the six foxes examined for habitat selection, female Fox 3 showed significant selection for all covariates. Fox 3 selected areas facing south and west, lesser slope, greater elevation, areas closer to roads and grassland, and areas farther from shrubs, forest patches, streams, and vegetation edge, and greater terrain ruggedness. Male Fox 4 selected for all covariates except grassland and vegetation edge. Fox 4 selected areas facing south and west, lesser slope, greater elevation, areas closer to roads and shrubs, and areas farther from forests and streams and greater terrain ruggedness.

The four foxes related to Study Site 1 may have selected areas with greater slope due to habitat constraints as the area had relatively rugged topography across the landscape. In addition, the selection of these foxes for greater aspect may have been biased by trapping along roads, which may have been purposefully built in areas of greater aspect, and this could have constrained my selection pool to foxes within those areas. In addition, Fox 1, Fox 3, and Fox 4 selected areas closer to roads and greater terrain ruggedness, possibly because the road provides greater accessibility or hunting opportunities, while more rugged topography provides cover from predators. Three female foxes, Foxes 1, 2 and 3, selected for areas with greater slope. Fox 3 and Fox 4 selected for areas farther from forests, but female Fox 3 selected for areas closer to grassland. The male, Fox 4, selected for areas with shrub vegetation. This may be a form of sex-based habitat partitioning, or random chance, as research has yet to evaluate this aspect of gray fox ecology. Studies on interspecific habitat partitioning found Chilean gray foxes (*Dusicyon griseus*) and culpeo foxes (*Dusicyon culpaeus*) selected different habitat niches to avoid competition (Johnson and Franklin 1994), while research examining temporal habitat partitioning between coyotes (*Canis latrans*) and red foxes (*Vulpes vulpes*) found partitioning present at three levels of home range analysis: home range, location, and resting (Gosselink et al. 2003).

At Study Site 2, Fox 5 selected areas facing south and southwest, greater elevation, areas farther from roads, and areas closer to streams, vegetation edge and grasslands. Fox 6 selected areas with lower slopes, areas facing southwest and west, areas farther from grassland and roads, and areas closer to shrubs and forests. The selection and avoidance of grassland and shrub vegetation differed between the sexes in Study Site 2; the male fox selected areas with grassland and the female fox selecting for shrub vegetation. Both foxes showed a significant selection for the grow site present within their home range.

The difference in elevation between Study Site 1 and Study Site 2 may have contributed to differences in the vegetation (Ohdo and Takahashi 2020); this is congruent with past research on elevational impacts to plant communities. This in turn could impact gray fox habitat selection due to the variation in different vegetation types (Deuel at al. 2017). The similarities in selection of aspects could have been confounded by my trapping along forest roads that were near trespass grows, which may have been purposefully built on the south, southwest, and west facing slopes. My findings of gray fox selection for forest patches and trespass grows, which function similar to agricultural fields, were congruent with published research (Deuel at al. 2017). Gray foxes have been shown to prefer roads in past research on diurnal refugia (Deuel at al. 2017); three out of six gray foxes avoided roads. This result is likely due to the rough topography that the fox would have to overcome to access areas closer to the U.S. Forest Service road system.

My study supports previous reports that forest cover and distance to water strongly impact gray fox occupancy (Egan et al. 2021, Cooper et al. 2012). Other studies examined distance to roads and areas with greater human use in relation to gray fox habitat selection and found similar results of preference for these covariates (Deuel 2017). Spatial and temporal research on gray foxes reported that distance to streams had little effect on gray fox habitat selection (Lesmeister et al. 2015). Foxes in my study avoided streams in the majority of my models; perhaps due to the complex topography present in northern California in comparison to the interior plains of Illinois where the previously mentioned study was conducted. Gray foxes in my study selected areas closer to vegetation edge, similar to coyotes, which were found to select vegetation edge for hunting opportunities (Lesmeister et al. 2015). It is possible that my foxes also selected these areas for increased cursorial hunting opportunities. Future research efforts should include a larger sample size across more than two study sites to examine the selection of these covariates by gray foxes.

In the spring of 2021, the growers returned to Study Site 2. Around this time, a significant shift occurred in Fox 5’s home range, and he began using habitats beyond a ridge in an area originally targeted for reference foxes. Research has found that gray fox home ranges increase for both sexes in late autumn and winter, but decrease in spring, during the whelping period (Crooks and Van Vuren 1995). With consideration to published seasonal range movement, Fox 5’s shift was likely more so impacted by grower presence than seasonal changes. This is particularly interesting because it complicates the finding that gray foxes preferentially select trespass grows. It is possible that the presence of growers deters wildlife, but, after they leave, the trespass grow site footprint attracts wildlife.

Wildfire Impact on Dataset.

During the Monument fire in 2021, and several weeks after its containment, the U.S. Forest Service restricted access to Study Site 1. During this period, the batteries of the GPS collars on Fox 1, Fox 2, and Fox 3 were drained, and no further GPS downloads were possible. An analogous situation occurred for Fox 5 located in Study Site 2. This lack of access reduced my ability to collect further data, which impacted the datasets available for these analyses.

Collection of GPS Data.

I did not use the temperature variable on the ATS GPS collars in this study, as the collar recorded a combination of ambient temperature and body heat which does not accurately represent the foxes' body temperatures. The "ATS Fixes for Loggers" program requirement that downloads be completed once every 11 minutes impacted download success, as cases occurred when the collared fox traveled far enough away to preclude a download in the time it took for the program to initiate again.

Fourth Order Habitat Use

Behavior

I documented gray fox behavior over twenty-two months across six trespass grow sites and observed foxes at camp sites, trash pits, toxicant piles, and process areas. This likely occurred because of the amount of food and food refuse, camping materials, and other attractions common to areas where multiple growers live over an extended period.

The proportion of seconds of each fox’s behavior demonstrated that foxes at three of the six study sites used camp sites, trash pits, process areas and toxicant piles most often than cultivation plots and trails. Of the three sites that gray foxes visited cultivation plots and trails more often, one of those sites had a singular observation of a gray fox in a cultivation plot. Excluding that incident, three of the five study sites found foxes to more commonly visit high impact areas than low impact areas. Such features within trespass grow sites present visual, auditory, and olfactory stimuli foreign to naïve wildlife and seems to warrant further investigation.

Foxes in this study used trespass grow sites in a variety of ways and exhibited all but one of the predicted behaviors. The most documented behavior across all site features was locomotion. Vigilant behavior was the next most common, followed by scent marking, feeding, and then social behavior. There were no instances of foxes resting at trespass grows. In nearly every video reviewed, foxes were recorded moving through sites, pausing to observe their surroundings, sometimes scent marking, but nearly always exiting the video frame before the video ended. Though these behaviors indicate clear use of the grow site, gray foxes may primarily travel through and remain vigilant due to heightened anxiety while within the grow site footprint.

My results do not support the hypothesis that food resources at trespass grows contribute to heightened feeding behavior observations. It is reasonable that hunger might lead a fox to investigate a trespass grow as a result of the food attractants, prey species and associated smells from growers. It is possible that once the fox investigates the site and fails to find food, they move on without feeding. The variation in food resource availability likely influenced the proportions of behavior documented at the six trespass grow sites. Study Site 1 had been abandoned a year prior to this study, and the majority of the food refuse had already been scavenged by wildlife. At Study Site 2, grower activity between camera trap efforts in 2020 and 2021 resulted in the restocking of fresh food. The remaining four study sites had large quantities of food and food refuse, though the number of feeding behaviors detected differed greatly among sites. Study Site 6 had a large quantity of food resources, and the least number of deployment days but a relatively high number of fox observations, whereas Study Site 3 had large amounts of food resources, with many more deployment days, but was rarely used. Past research has found that the presence of black bears can indirectly shield gray foxes from predation by bobcats by altering bobcat's space use (Moll et al. 2021). It is possible that the presence of other wildlife species, like black bears, impacted gray fox use of trespass grows at Study Site 1 and Study Site 3, as these predators were documented far more often at these sites than at the other sites.

Locomotion and marking behaviors in process areas, camps, toxicant piles, and trash pits may covary. Scent can share important information between individuals, and it seems reasonable that areas with higher rates of locomotive behavior would also have higher rates of scent marking. As the number of gray foxes moving through an area increases, the propensity to leave scent and seek out other foxes' scent would also likely increase, and this might impact the proportions of behaviors recorded at different site features.

There were five documented cases of gray foxes exhibiting social behavior, three of which were categorized as amicable, and two deemed hostile. One video of a ringtail and gray fox showed amicable behavior. It is possible that these mesocarnivores did not perceive the other to be a threat. In the other two amicable videos, the two foxes documented together may have been a mating pair or related which might help explain the lack of antagonistic behaviors. One video showed a hostile spotted skunk pursuing a gray fox across a cultivation plot with the spotted skunk moving quickly along the same path as the gray fox. The other hostile video recorded a spotted skunk stomping at a gray fox at a camp site. Predation did not appear likely with the behaviors observed, so the gray fox pursuit could possibly be a matter of establishing territorial boundaries, while the stomping behavior could be a simple warning for the fox to keep its distance.

Between June 2020 and October 2020, the Monument fire limited access to Study Site 3. During that period, six cameras deployed at the camp, toxicant pile, and trash pit were stolen and never recovered resulting in the loss of four months of data.

I expected Browning cameras to record one-minute of data during daylight, however, this rarely occurred. In addition, the company’s manufacturing standard of limiting videos recorded at night to twenty-seconds did not significantly impact the behaviors documented, as most videos showed foxes exiting the frame before the video finished its recording.

Independent Reviewer Assessment of Behavior Data

Despite the overall differences in behavior classification estimates, most of the inconsistencies between myself and the independent reviewer was a difference of one to two seconds. This in turn represents a difference of 5% – 10% in data results for those specific behaviors.

CONCLUSIONS

This research demonstrates that gray foxes may select features of trespass grow sites within their home ranges. Further research needs to evaluate gray fox habitat selection of trespass grow sites with larger sample sizes of study sites and collared individuals to further evaluate selection of different site features. Gray foxes extensively used trails for travel into the grow sites and between site features. Marking behavior was commonly observed in camp sites, toxicant piles, trash pits, and process areas, signifying that gray foxes find these features useful to communicate territorial boundaries and fitness. Though feeding was the least common documented behavior, it was still documented, demonstrating that foxes consume items within the trespass grow footprints. As a result, potential pesticide poisoning is a significant threat that must be considered. In addition to gray foxes, over forty other species were detected, almost all of which exhibited some form of feeding behavior across all six study sites examined. Further research from this dataset will incorporate gray fox behavior and all other documented species' behavior to evaluate wildlife use of trespass grow sites and the interspecific and intraspecific interactions of wildlife species at these sites.

Four of the six study sites had multiple samples that tested positive for carbofuran and methamidophos, two extremely toxic and federally banned pesticides. Cultivation plots, toxicant piles, and trash pits are the most likely features to have high concentrations of pesticides, either from application on cultivation plots, being stashed in toxicant piles, or discarded in trash pits with toxic residue still present. The gray foxes documented within these sites were likely exposed to these dangerous pesticides by interacting with these site features, which would be expected to directly impact their fitness.

Currently, no other research project has reported such fine scale data on gray fox selection and use of trespass grow sites. I encourage resource managers to use the results of this research in combination with other trespass grow studies to further support reclamation efforts to clean up these grow sites to mitigate further impacts on residential wildlife.

REFERENCES

American Bird Conservancy. 2008. EPA issues landmark decision to prohibit deadly pesticide carbofuran residues on food. <https://abcbirds.org/news/epa-issues-landmark-decision-prohibit-deadly-pesticide-carbofuran-residues-food/>. Accessed 3 Nov 2022.

Bekoff, M., T. J. Daniels, and J. L. Gittleman. 1984. Life history patterns and comparative social ecology of carnivores. Annual Review of Ecology and Systematics 15(1):191–232.

Bennett, E. A. 2018. Prohibition, legalization, and political consumerism: insights from the US and Canadian cannabis markets. Oxford University Press, Oxford, England.

Benson, J. F. 2013. Improving rigor and efficiency of use-availability habitat selection analyses with systematic estimation of availability. Methods in Ecology and Evolution 4(1):244–251.

Bolker, B. M., M. E. Brooks, C. J. Clark, S. W. George, J. R. Poulsen, M. H. H. Stevens, and J.S. S. White. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends in Ecology and Evolution 24(3):127–135.

Calabrese, J. M., C. H. Fleming, and E. Gurarie. 2016. ctmm: an R package for analyzing animal relocation data as a continuous-time stochastic process. Methods in Ecology and Evolution 7(1):1124–1132.

California Water Boards. 2022. Cannabis cultivation policy – principals and guidelines (requirements) for cannabis cultivation. <https://www.waterboards.ca.gov/water_issues/programs/cannabis/cannabis_policy.html>. Accessed 10 April 2022.

Cannabis Ground. 2019. The illegal cannabis market increases in California after legalization. <https://www.cannabisground.com/illegal-cannabis-market/>. Accessed 2 May 2022.

Cannabis News. 2021. 'We're one cigarette away': illegal marijuana farms pose wildfire risk in California's parched national forests. <https://420intel.com/articles/2021/12/01/were-one-cigarette-away-illegal-marijuana-farms-pose-wildfire-risk-californias#>. Accessed 27 April 2022.

Constible, J. M., M. J. Chamberlain, and B. D. Leopold. 2006. Relationship between landscape pattern and space use of three mammalian carnivores in central Mississippi. The American Midland Naturalist 155(2):352–362.

Cooper, S. E, C. K. Nielsen, and P. T. McDonald. 2012. Landscape factors affecting relative abundance of gray foxes Urocyon cinereoargenteus at large scales in Illinois, USA. Wildlife Biology 18(4):366-373.

Crooks, K. R., and D. Van Vuren. 1995. Spatial organization of the island fox (*Urocyon littoralis*) on Santa Cruz Island, California. Journal of Mammalogy 77 (3):801-806.

Deuel, N. R., L. M. Conner, K. V. Miller, M. J. Chamberlain, M. J. Cherry, and L. V. Tannenbawn. 2017. Gray fox home range, spatial overlap, mated pair interactions and extra-territorial forays in southwestern Georgia, USA. BioOne 1(1):1–10.

Drake, E. M., B. L. Cypher, K. Ralls, J. D. Perrine, R. White, and T. J. Coonan. 2015. Home-range size and habitat selection by male island foxes (*Urocyon littoralis*) in a low-density population. The Southwestern Naturalist 60(2/3):247–255.

Egan, M. E., C. C. Day, T. E. Katzner, and P. A. Zollner. 2021. Relative abundance of coyotes (*Canis latrans*) influences gray fox (*Urocyon cinereoargenteus*) occupancy across the eastern United States. Canadian Journal of Zoology 99(2):63–72.

Environmental Protection Agency. 2016. Carbofuran I.R.E.D. facts. <https://archive.epa.gov/pesticides/reregistration/web/html/carbofuran_ired_fs.html>. Accessed 2 Nov 2022.

Everett, Y. 2018. A challenge to socio-ecological resilience: community-based resource management organizations' perceptions and responses to cannabis cultivation in Northern California. Humboldt Journal of Social Relations 27(1):89–115.

Farias, V., T. K. Fuller, and R. M. Sauvajot. 2012. Activity and distribution of gray foxes (*Urocyon cinereoargenteus*) in southern California. The Southwestern Naturalist 57(2):176–181.

Federal Registrar. 2020. Endangered and threatened wildlife and plants; 12-month finding for the northern spotted owl. <https://www.federalregister.gov/documents/2020/12/15/2020-27198/endangered-and-threatened-wildlife-and-plants-12-month-finding-for-the-northern-spotted-owl>. Accessed 11 October 2022.

Fleming, C. H., D. Shelden, E. Gurarie, W. F. Fagan, S. LaPoint, and J. M. Calabrese. 2017. Kálmán filters for continuous-time movement models. Ecological Informatics 40(1):8–21.

Franklin, A. B., P. C. Carlson, A. Rex, J. T. Rockweit, D. Garza, E. Culhane, S. F. Volker, R. J. Dusek, V. I. Shearn-Bochsler, M. W. Gabriel, and K. E. Horak. 2018. Grass is not always greener: rodenticide exposure of a threatened species near marijuana growing operations. BMC Research Notes 11(1):1-7.

Fryxell, E. 1982. *Urocyon cinereoargenteus*. Mammalian Species. 189 (1): 1-8.

Fuller, T. K. 1978. Variable home-range sizes of female gray foxes. Journal of Mammalogy 59(1): 446–449.

Gabriel, M. W., R. N. Brown, J. E. Foley, J. M. Higley, and R. G. Bozler. 2009a. Ecology of *Anaplasma phagocytophilum* infection in gray foxes (*Urocyon cinereoargenteus*) in northwestern California. Journal of Wildlife Diseases 45(2):344–354.

Gabriel, M. W., L. V. Diller, J. P. Dumbacher, G. M. Wengert, J. M. Higley, R. H. Poppenga, and S. Mendia. 2018. Exposure to rodenticides in northern spotted and barred owls on remote forest lands in northwestern California: evidence of food web contamination. Avian Conservation and Ecology 13(1):1–9.

Gabriel, M. W., J. Henn, J. E. Foley, R. N. Brown, R. W. Kasten, P. Foley, and B. B. Chomel. 2009b. Zoonotic B*artonella* species in fleas collected on gray foxes (*Urocyon cinereoargenteus*). Vector-Borne and Zoonotic Diseases 9(6):597–603.

Gabriel, M. W., J. M. Higley, G. M. Wengert, L. Woods, and R. Poppenge. 2013a. Intentional poisoning of a fisher (*Martes pennanti*) with a carbamate insecticide laced bait at an illegal marijuana trespass cultivation site, unpublished data.

Gabriel, M. W., G. M. Wengert, J. M. Higley, S. Krogan, W. Sargent, and D. L. Clifford. 2013b. Silent forests? Rodenticides on illegal marijuana crops harm wildlife. The Wildlife Professional 7(1):46-50.

Goldstein, R. and Sumner, D., 2022. Can legal weed win? The blunt realities of cannabis economics. Univ of California Press.

Gosselink, T. E., T. R. Van Deelen, R. E. Warner, and M. G. Joselyn. 2003. Temporal habitat portioning and spatial use of coyotes and red foxes in east-central Illinois. The Journal of Wildlife Management 67(1):90-103.

Harrison, X. A., L. Donaldson, M. E. Correa-Cano, J. Evans, D. N. Fisher, C. E. D. Goodwin, B. S. Robinson, D. J. Hodgson, and R. Inger. 2018. A brief introduction to mixed effects modelling and multi-model inference in ecology. PeerJ 1(1):32.

Helmer, J. 2019. The environmental downside of cannabis cultivation. <https://daily.jstor.org/the-environmental-downside-of-cannabis-cultivation/>. Accessed 13 May 2020.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61(1):65–71.

Johnson, W. E., and W. L. Franklin. 1994. Spatial resource partitioning by sympatric grey fox (*Dusicyon griseus*) and culpeo fox (*Dusicyon culpaeus*) in southern Chile. Canadian Journal of Zoology 72(10):1788-1793.

Kerlikowske, R. G. 2011. Exploring the problem of domestic marijuana cultivation. Senate Caucus on International Narcotics Control. United States Senate, Washington, District of Columbia, USA.

Klamath Forest. 2022. Klamath Forest. <https://www.klamathforest.com/>. Accessed 27 Sept 2022.

Klamath National Forest. n.d. About the forest. <https://www.fs.usda.gov/main/klamath/about-forest>. Accessed 18 Feb 2022.

Kodani, C. H. 1996. Home range and diet of California gray fox (*Urocyon cinereoargenteus californicus*) in the Cleveland National Forest, Orange County, California. M.A. Thesis, California.

Koprowski, J. L., and M. C. Corse. 2005. Time budgets, activity periods, and behavior of Mexican fox squirrels. Journal of Mammalogy 86(5):947–952.

Lesmeister, D. B., C. K. Nielsen, E. M. Schauber, and E. Hellgren. 2015. Spatial and temporal structure of a mesocarnivore guild in Midwestern North America. Wildlife Monographs, 191:1-61.

Mallery, M. 2011. Marijuana nation forest: encroachment on California public lands for cannabis cultivation. Berkeley Undergraduate Journal 23(2):1–51.

Matthews, R. E. 2000. Activity and home range of the gray fox in the chaparral of southern California. M.S. Thesis, California State University, Fullerton, California, 46 pp.

Maxson-Landis, K., and K. Scates. 2022. Marijuana and tax: the dark reality of cannabis taxation. < https://news.bloombergtax.com/tax-insights-and-commentary/marijuana-and-tax-the-dark-reality-of-cannabis-taxation>. Accessed 12 Jan 2023.

Miller, G. J., L. L. Smith, S. A. Johnson, and R. Franz. 2012. Home range size and habitat selection in the Florida pine snake (*Pituophis melanoleucus mugitus*). Copeia 2012(4):706–713.

Moll, R. J., P. J. Jackson, B. F. Wakeling, C. W. Lackey, J. P. Beckmann, J. J. Millspaugh, and R. A. Montgomery. 2021. An Apex carnivore’s life history mediates a predator cascade. Oecolgia 196(1):223-234.

Morrison, M. L., B. G. Marcot, and R. W. Mannan. 1998. Wildlife-habitat relationships: concepts and applications. University of Wisconsin Press, Madison, Wisconsin, USA.

Muff, S., J. Signer, and J. Fieberg. 2020. Accounting for individual-specific variation in habitat-selection studies: efficient estimation of mixed-effects models using bayesian or frequentist computation. Journal of Animal Ecology 89(1): 80–92.

National Park Service. 2018. Pacific fisher description and biology. <https://www.nps.gov/yose/learn/nature/fisher-biology.htm>. Accessed Oct 25 2022.

Nettleton, D. 2014. Commercial data mining: processing, analysis, and modeling for predictive analytics project. Elsevier, Waltham, USA.

Ohdo, T., and K. Takahashi. 2020. Plant species richness and community assembly along gradients of elevation and soil nitrogen availability. AoBP Plants 12(3):1-10.

Owley, J. 2018. Unforeseen land uses: the effect of marijuana legalization on land conservation programs. University of California, Davis 51(1):1673 – 1716.

Pacific Gas and Electric. 2006. The Pacific Energy Center's guide to California climate zones. <https://www.pge.com/includes/docs/pdfs/about/edusafety/training/pec/toolbox/arch/climate/california_climate_zones_01-16.pdf>. Accessed 16 Jan 2020.

Robertson, B. A., and R. L. Hutto. 2006. A framework for understanding ecological traps and an evaluation of existing evidence. Ecology 87(5):1075–1085.

Rokos, B. 2021. Illegal marijuana farms in Orange County show how toxic danger is spread through national forests. <https://www.ocregister.com/2021/10/09/illegal-marijuana-farms-in-orange-county-show-how-toxic-danger-is-spread-through-national-forests/>. Accessed 11 Feb 2022.

Saunders, D. A. 1988. Gray fox (*Urocyon cinereoargenteus*). <https://www.esf.edu/aec/adks/mammals/gray_fox.htm>. Accessed 13 May 2020.

Scholars Portal. 2015. COSEWIC assessment and status report on the gray fox, *Urocyon cinereoargenteus*, in Canada. <http://www.deslibris.ca/ID/10064014>. Accessed 18 Feb 2022.

Seaman, D. E., J. J. Millspaugh, B. J. Kernohan, G. C. Brundigre, K. J. Raedeke, and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimates. The Journal of Wildlife Management 63(2):739–747.

Shasta-Trinity National Forest. n.d. About the area. <https://www.fs.usda.gov/main/stnf/about-forest/about-area>. Accessed 15 Nov 2019.

Sierra Forest Legacy. 2021. Pacific fisher (*Pekania pennanti*). <https://www.sierraforestlegacy.org/FC_SierraNevadaWildlifeRisk/PacificFisher.php>. Accessed 24 September 2022.

Smith, J. 2021. Backcountry drug war. <https://www.biographic.com/backcountry-drug-war/>. Accessed 27 April 2022.

Theimer, T. C, A. C. Clayton, A. Martinez, D. L. Peterson, and D. L. Bergman. 2015. Visitation rate and behavior of urban mesocarnivores differs in the presence of two common anthropogenic food sources. Urban Ecosystem 18(1):895–906.

United States Department of Agriculture. n.d.a. Trees of the Shasta-Trinity. <https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsm9_008614.pdf>. Accessed 11 July 2022.

United States Department of Agriculture. n.d.b. Wildflowers of the Shasta-Trinity. <https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsm9_008263.pdf>. Accessed 11 July 2022.

Uyeda, L., R. C. Kyes, E. Iskandar, A. J. Wirsing. 2012. Proposed research on home ranges and resource use of the water monitor lizard, *Varanus salvator*. Forestry Chronicle 88(5):542–546

Valdes-Donoso, P., D. A. Sumner, and R. Goldstein. 2019. Costs of cannabis testing compliance: assessing mandatory testing in the California cannabis market. PLOS ONE 15(1):1–20.

Wengert, G. M., executive director. 2019. Presentation on wildlife disease and ecotoxicology. The Wildlife Society – Sacramento-Shasta Chapter workshop, Sacramento, CA, USA.

Wengert, G.M., M. W. Gabriel, J. M. Higley, and C. Thompson. 2018. Ecological impacts across the landscape: trespass marijuana cultivation on western public lands. Pages 29-39 *in* C. Miller, editor. Where there's smoke: The environmental science, public policy, and politics of marijuana. Lawrence, Kansas, University Press of Kansas.

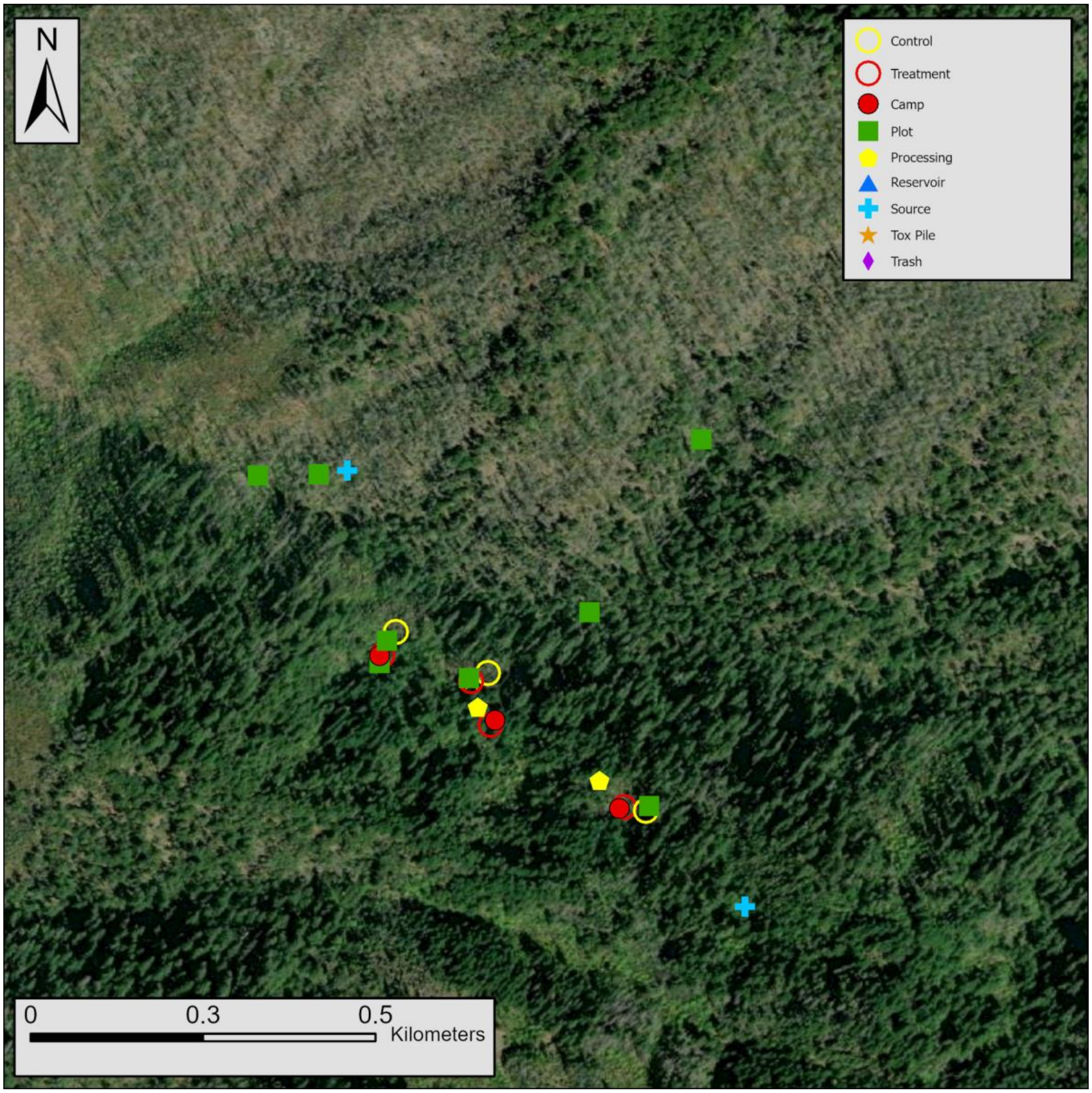
Wengert, G. M., J. M. Higley, M. W. Gabriel, H. Rustigian-Romosos, W. D. Spencer, D. L. Clifford, and C. Thompson. 2021. Distribution of trespass cannabis cultivation and its risk to sensitive forest predators in California and Southern Oregon. PLOS ONE 16(9):1–18.

Willyweather. 2022a. Klamath National Forest weather forecast. <https://www.willyweather.com/ca/siskiyou-county/klamath-national-forest.html>. Accessed 20 Apr 2020.

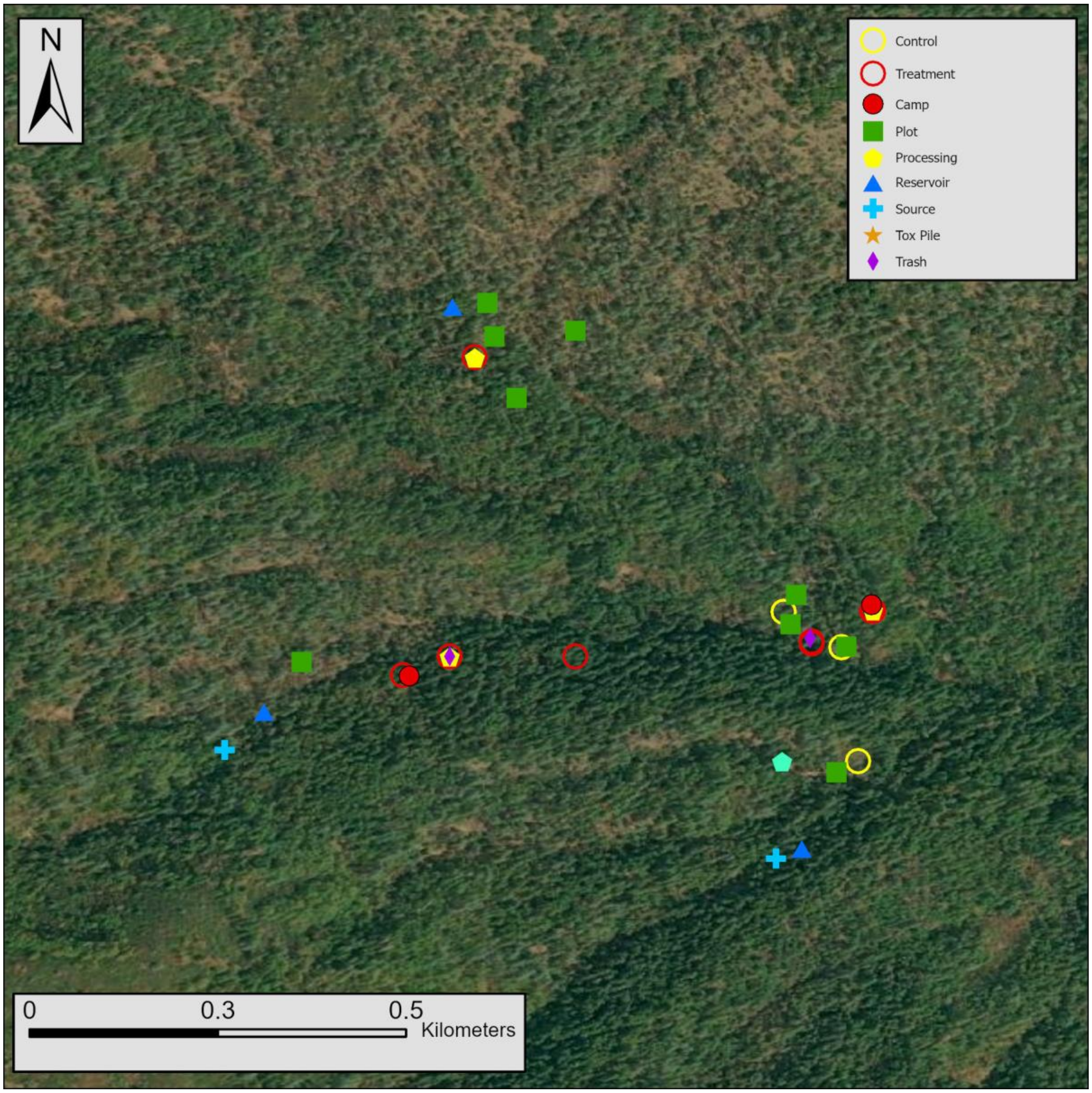
Willyweather. 2022b. Shasta Trinity National Forest weather forecast. <https://www.willyweather.com/ca/shasta-county/shasta-national-forest.html>. Accessed 20 April 2022.

Wilson, D. E., F. R. Cole, J. D. Nichols, R. Rudran, and M. S. Foster. 1996. Measuring and monitoring biological diversity: standard methods for mammals. Smithsonian Institution Press, Washington, D.C.

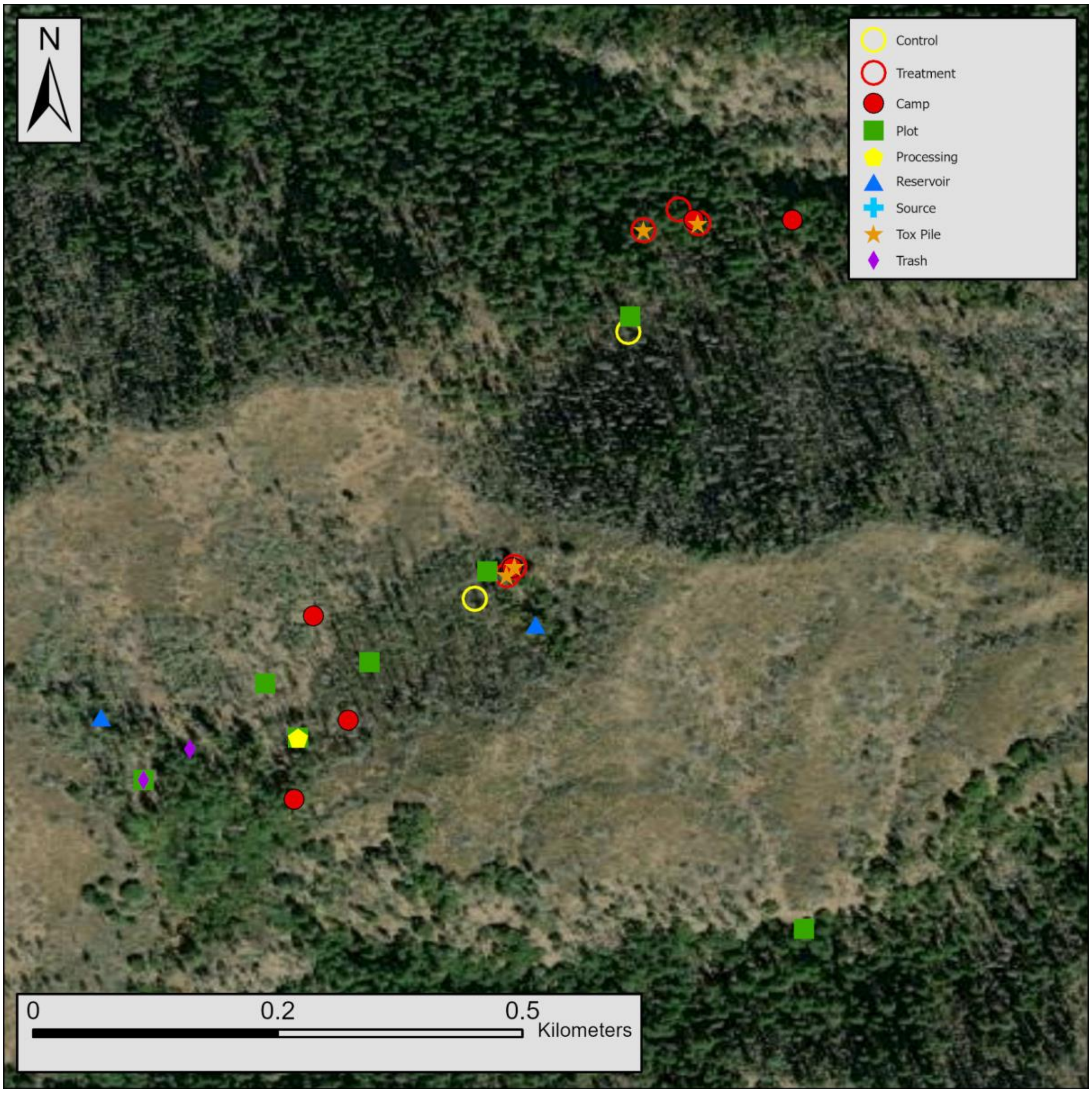
APPENDICES



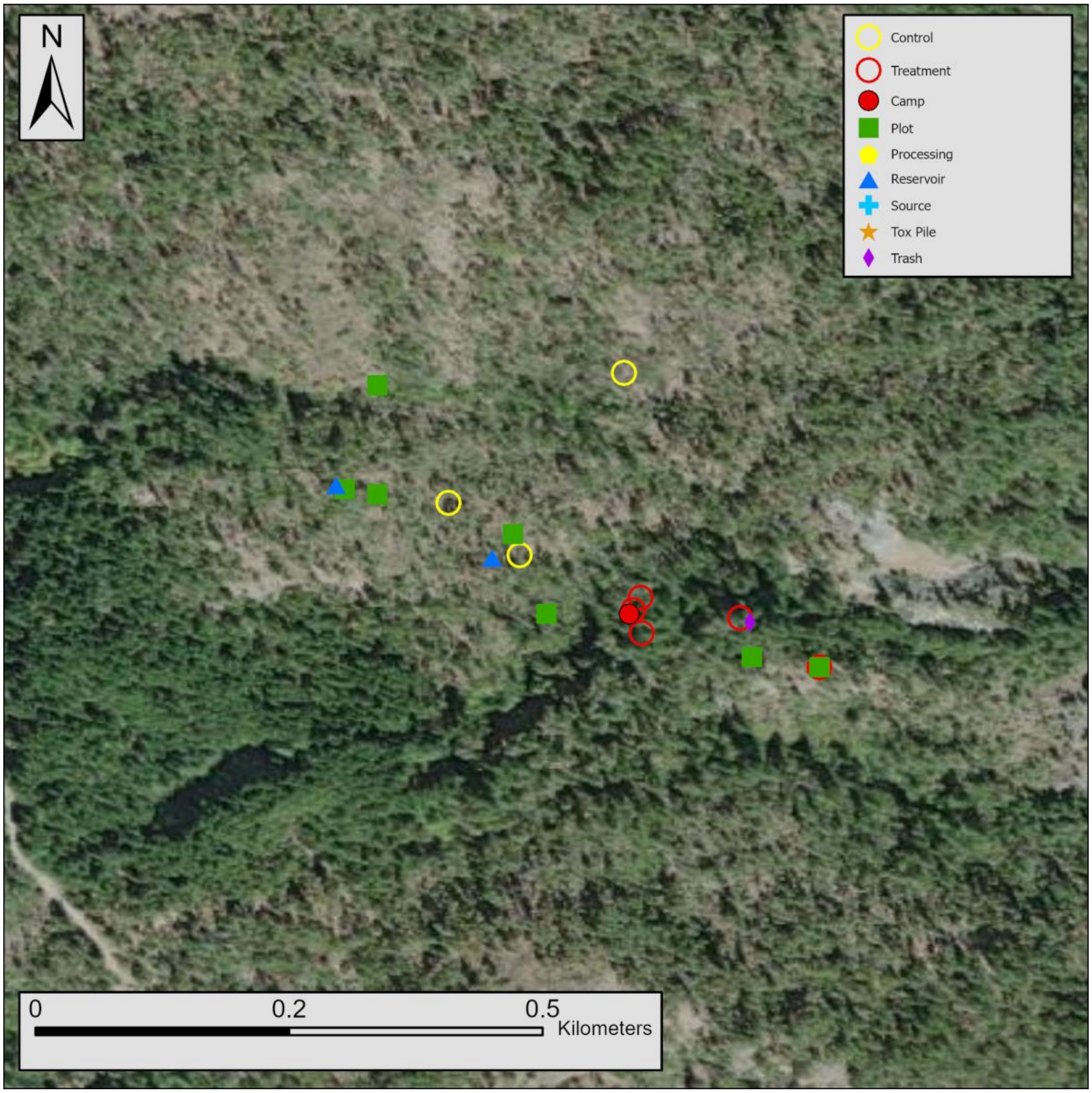
Appendix 1. The grow site features and high and low impact camera locations in Study Site 1 within the Shasta-Trinity National Forest located in northwestern California.



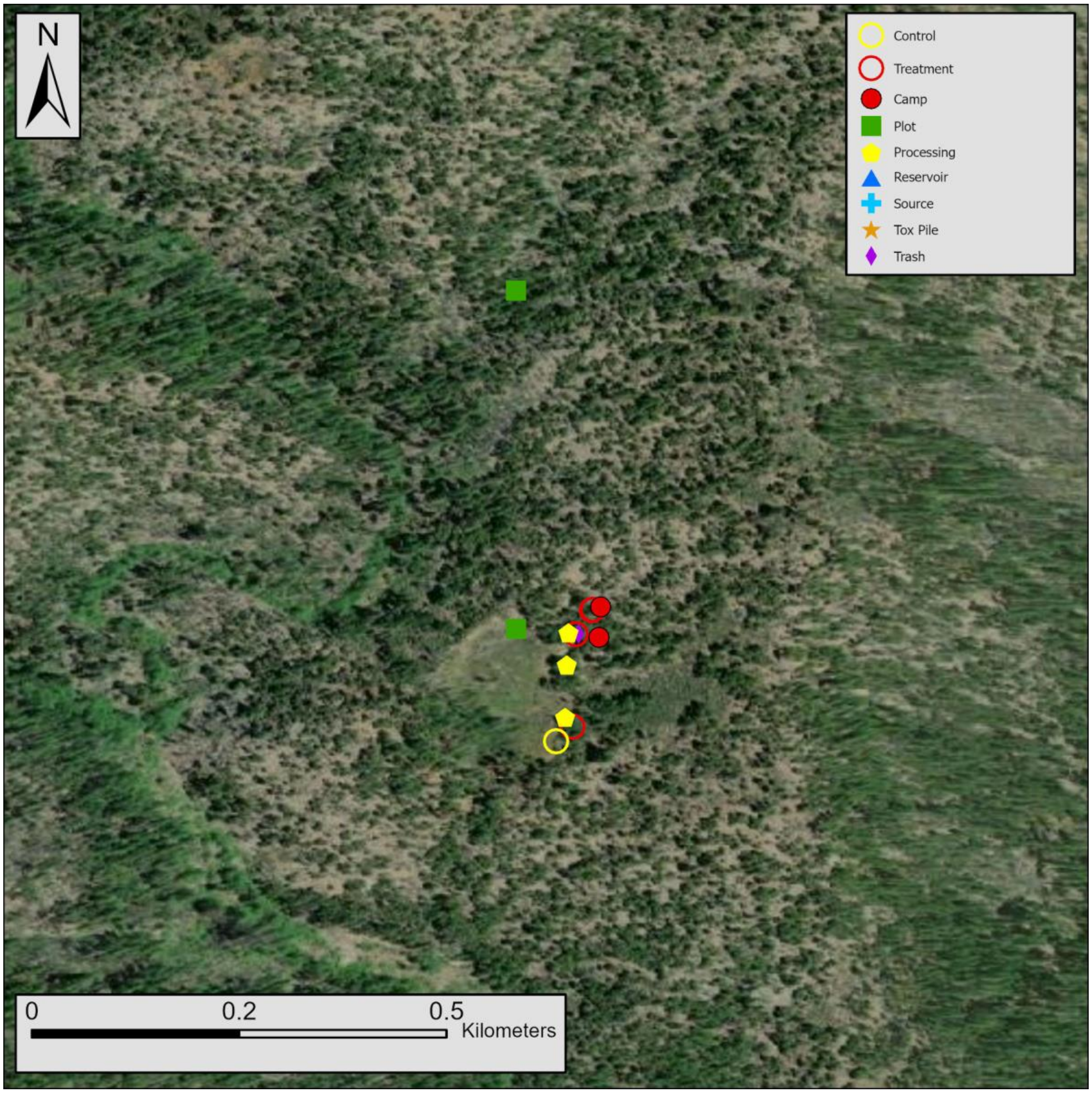
Appendix 2. The grow site features and high and low camera locations in Study Site 2 within the Shasta-Trinity National Forest located in northwestern California.



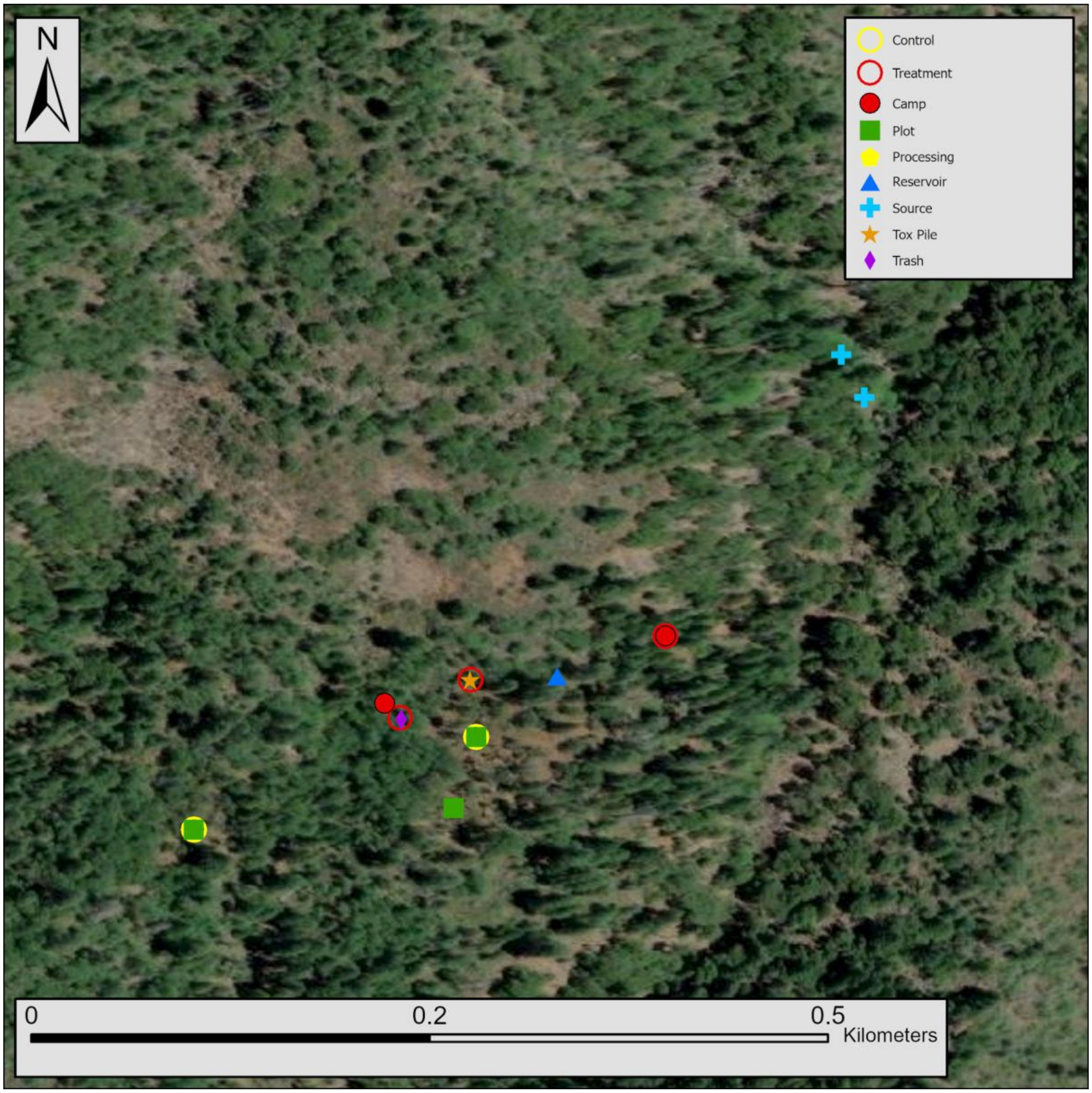
Appendix 3. The grow site features and high and low impact camera locations in Study Site 3 within the Shasta-Trinity National Forest located in northwestern California.



Appendix 4. The grow site features and high and low impact camera locations in Study Site 4 within the Klamath National Forest located in northwestern California.



Appendix 5. The grow site features and high and low camera locations in Study Site 5 within the Klamath National Forest located in northwestern California.



Appendix 6. The grow site features and high and low impact camera locations in Study Site 6 within the Shasta-Trinity National Forest located in northwestern California.

Appendix 7. The environmental assessment results of all six study sites located in northern California, occurring in 2019 through 2022.

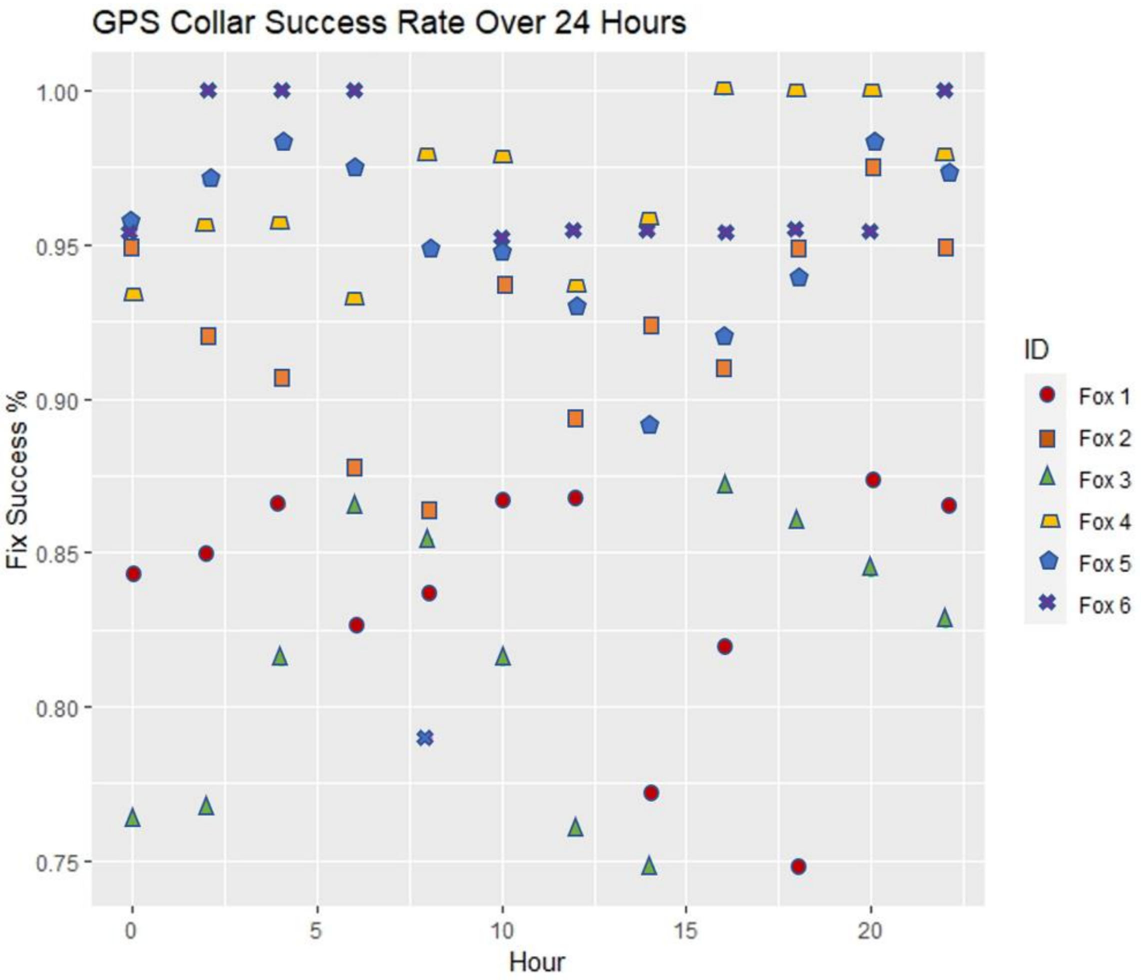
Site	Eradication Date	# of Plants	# of Pesticides	Quantities of Pesticides	# of Site Features	Estimated Amount of Refuse
1	5 Sept. 2019	8,656	5	2.95 lbs., 7.65 liters	6 plots, 3 camps, 2 process areas	~ 45 55-gallon trash bags
2	26 July 2021	7,905 – 2020, 1,193 – 2021	1	144 fl oz of pyrethroid – 2020, 208 fl oz of pyrethroids – 2021	9 plots, 3 process areas, 1 drying area, 2 trash pits, 1 source, 1 reservoir	45 55-gal trash bags
3	5 Aug. 2020	10,052	8	9 lbs. – AR, 64 fl oz malathion, 4 lbs. Alkaloid pesticide, 2 lb. and 24 fl oz of unknown chemical	2 plots, 2 camps, 1 reservoir	45 55-gallon trash bags
4	27 Sept. 2021	2,945	11	128 *Bacillus subtili*s, 576 fl oz malathion, 16 oz diphacinone, 64 oz Strychnine, 64 oz diphacinone	2 camps, 1 resting area, 1 plot, 1 cistern	25 55-gallon trash bags
5	30 Sept. 2021	1,708	5	32 fl oz Zeta-cypermethrin, 32 fl oz Gamma-cyfluthrin, 32 fl oz malathion, 32 fl oz natural repellent, 32 oz permethrin	1 plot, 1 camp, 1 kitchen, 1 trash pit, 1 nursery, 1 drying area, 1 prep area	50 55-gallon trash bags
6	Not Active/ Not Eradicated	9,983 – 2019, 496 – 2021	6	16 oz carbaryl, 132 oz bromethalin, 152 fl oz malathion	2 camps, 1 cistern, three plots	25 55-gallon trash bags

Appendix 8. The positive toxicant samples taken from each of six study sites in northern California, 2019 –2022.

Study Site	Samples	Detected Toxicants
1		
		Lambda-cyhalothrin, 3-hydroxycarbofuran
	Container 2	Carbofuran
	Soil 4, Soil 5	Carbofuran
	Sprayer 1	Carbofuran
2		
	Sprayer 1	Carbaryl, Cyfluthrin
		DEET, Imidacloprid, Thiamethoxam, Clothianidin,
3		
	Container	Azinophos-methyl, Malathion, Chlorophacinone, Diphacinone
	Sprayer 1	Malathion, Carbaryl, Carbofuran
	Sprayer 4	Carbofuran
	Sprayer 3	Malathion, Carbofuran
	Plant 1	Carbofuran
	Soil 1	3-Hydroxycarbofuran, Carbofuran
	Sprayer 2	Carbofuran
4		
	Other 1	Prochloraz, Trichlorophenol, 2-Phenylphenol, DEET, Permethrin, Imidacloprid, Permethrin, Bifenthrin Methamidophos
	Sprayer 1	Methamidophos
5		
		Malathion, DEET, Permethrin, Lambda-cyhalothrin, Cyfluthrin, Fenvalerate, Zeta-cypermethrin
6		
		Prochloraz, Trichlorophenol, DEET, 2-Phenylphenol, Tebufenozide, Methoxyfenozide, Prochloraz, Deiphenylamine, Fenvalerate, Chlorpyrifos, Bifenazate, Abamectin

Appendix 9. Biological information collected from gray foxes collared (n = 7) at impact and references sites, in northern California, Fall 2020–Spring 2021.

Biological Covariate	URCI 1	URCI 2	URCI 3	URCI 4	URCI 5	URCI 6	URCI 7
Sex:	F	F	F	M	F	F	M
Age Class:	Subadult	Adult	Adult	Adult	Juv.	Adult	Adult
Previously Reproductive:	No	No	Yes	Unknown	No	Unknown	Unknown
Weight (kg):	2.2	3.1	3.2	2.7	2.5	3.0	2.5
Ectoparasite Load:	Heavy	Rare	None	Heavy	Light	Heavy	Rare
Neck Cir (cm):	16.5	18	19	18.8	16	17	19.1
Total Length (cm):	No Data	80	92.5	83	85	90.5	102.5
Pinnae (mm):	No Data	6.9	5.8	87	73	67	79
Coat Condition:	Prime	Summer	Prime	Prime	Prime	Prime	Prime
Overall Condition:	Excellent	Good	Good	Excellent	Fair	Fair	Excellent
Collared:	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Collar Deployment Date:	9/26/20	10/7/20	10/7/20	11/19/20	11/21/20	3/1/21	4/21/21
Fox ID Used in Analysis:	N/A	Fox 1	Fox 3	Fox 5	Fox 6	Fox 2	Fox 4



Appendix 10. The averaged fix rate success over the 24-hour period for the lifetime of deployed GPS collars.

Appendix 10. The number of camera deployment days across six trespass grow study sites in northern California, operational between Fall 2020 and Summer 2022.

Study Site	Impact	Reference
Study Site 1	984	345
Study Site 2	908	571
Study Site 3	707	384
Study Site 4	872	654
Study Site 5	665	133
Study Site 6	488	122
Total	5624	2209