

ENVIRONMENTAL AND ANTHROPOGENIC INFLUENCES ON FISHER
(*PEKANIA PENNANTI*) DEN ATTENDANCE PATTERNS IN CALIFORNIA

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ABSTRACT

ENVIRONMENTAL AND ANTHROPOGENIC INFLUENCES ON FISHER (*PEKANIA PENNANTI*) DEN ATTENDANCE PATTERNS IN CALIFORNIA

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The fisher (*Pekania* [formerly *Martes*] *pennanti*) is a house-cat-sized forest carnivore in the family Mustelidae, and populations on the west coast of North America are of conservation concern. Adult female survival and reproduction has been suggested as a key element for maintaining and recovering these populations. Although many research efforts have focused on den ecology of fishers, few have focused on the behavior of denning fishers. Understanding patterns in fisher den attendance and how anthropogenic activities may influence those patterns could inform forest management practices and research methodologies for conservation benefit. I documented fisher den attendance patterns, as well as the biological, environmental, and research-related disturbance factors that influenced fisher den attendance by monitoring radio-collared female fishers in 3 isolated populations in California, United States. I found that fisher den attendance patterns were similar across the 3 populations in California, with minor differences in the environmental factors that influenced den attendance. Fishers were present at their dens greater than 50% of the time during the first 4 weeks following parturition. Proportions of time fishers were present at the den, as a function of kit age, did not vary regionally. Fishers were also generally present at the den throughout

crepuscular morning hours regardless of kit age, though den attendance during daytime and nighttime hours varied regionally. I also found that the presence of a researcher at the den while the mother was present caused fishers to spend 35-125 minutes longer at the den than they otherwise would. Following from my results, I recommend that researchers minimize events in which they approach radio-collared fishers at dens. I also recommend that future studies examine the effects of anthropogenic disturbances on denning fisher behavior, and that they link behavioral changes, reproductive success, and kit survival rates to quantify how disturbances may impact fisher populations.

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INTRODUCTION

Reproduction is among the most energetically costly activities that female mammals undertake (Wade and Schneider 1992). Lack (1954) suggested that the environment, or a parent's ability to acquire resources from the environment, limits reproduction. Williams (1966) later formalized the idea that reproduction occurs at a cost in the form of a fitness trade-off between current and future reproductive events, where fitness is defined as the contribution of an individual's genes to the next generation based on an individual's survival and reproductive success. Reproduction contributes positively to an individual's direct fitness, but at a cost that results in the reduction of another fitness component due to the allocation of resources to reproduction (Reznick et al. 2000). Reproductive costs that arise due to resource allocation trade-offs are physiological costs, because resource allocation is a physiological process (Ricklefs and Wikelski 2002). Physiological costs of reproduction are particularly high in placental mammals while lactating (Kaczmarek 1966).

Speakman (2008) divided the physiological costs of reproduction into two categories: 1) direct costs that involve the increased demand for energy and nutrients, and 2) indirect costs, which are compensatory costs that allow mammals to divert greater energy to reproduction. Primary direct costs of reproduction include increased energy and nutrient requirements, particularly the increased demand for calcium and protein for lactation in mammals, and the energetic costs of morphological changes, including organ remodeling to meet reproduction demands (Speakman 2008). Furthermore, the costs of

reproduction may be mediated by ecological factors. For example, a reproductive female with high energetic demands may increase the amount of time she spends foraging to meet those demands, and as a result may have an increased risk of predation (Zera and Harshman 2001).

Animals are theorized to exhibit movement patterns and behaviors such that they balance their energy budget in a way that ultimately maximizes their fitness (Houston and McNamara 1989, Higginson et al. 2012, Shepard et al. 2013). Deviation from these optimal activity patterns and behaviors may negatively impact an animal's survival and productivity by raising energetic requirements (Geist 1970, Burton and Hudson 1978). Studies have shown that anthropogenic activities can disturb wildlife through disruption of behavior and activity patterns (Bromley 1985, Marzano and Dandy 2012).

Anthropogenic disturbances including recreation, noise, vehicle traffic, and natural resource development/extraction can result in displacement, increased predation risk, intensified alertness and flight response, increased energy consumption, and decreased reproductive success (Bromley 1985, Littlemore and Barlow 2005, Blanc et al. 2006, George and Crooks 2006, Barton and Holmes 2007, Naylor et al. 2009).

Animals that are raising young may be especially vulnerable to human-caused disturbances, as disruption of behavior could compromise their energy budget, which is already under stress due to the increased energetic demands required to reproduce and to raise young. Carnivores that give birth and raise young in dens are at increased risk from anthropogenic disturbances, which may result in displacement and movement of

offspring to a new den site or even abandonment of offspring (Chapman 1977, Ballard et al. 1987, Thomson 1992, Linnell et al. 2000).

Female mustelids may be particularly sensitive to disturbances during reproductive periods. The long and narrow body shape of mustelids creates a high surface-to-volume ratio, resulting in increased energetic costs for thermoregulation (Brown and Lasiewski 1972) and poor ability to store fat (Harlow 1994). Additionally, many mustelids exhibit delayed implantation of embryos in which the post-implantation gestation period is short but the lactation period is prolonged (Harlow 1994). This requires higher overall reproductive effort from implantation to weaning when compared with other placental mammals (Lillegraven 1975, Harlow 1994). Furthermore, mustelids use dens to raise their young and during this time period transition from a wide-ranging foraging strategy to a central point strategy centered on the den (Higley and Matthews 2006), making them especially vulnerable to human-caused disturbances that change activity patterns or result in displacement and negatively impact energy balances. One such species that may be particularly sensitive to anthropogenic disturbances while raising young is the fisher (*Pekania pennanti*).

The fisher is a forest carnivore in the family Mustelidae. Adult fishers range from 2.0 to 5.5 kg (Powell et al. 2003) and exhibit sexual dimorphism, in which adult males are roughly twice the mass of adult females. Fishers are generalist predators with diets consisting primarily of small mammals, birds, insects, reptiles, carrion, and fruits (Martin 1994, Zielinski et al. 1999, Weir et al. 2005, Golightly et al. 2012). In California, the fisher occurs in the northwestern coastal ranges as far south as Mendocino County, in a

reintroduced population in the northern Sierra Nevada mountain range, and also in an isolated population in the southern Sierra Nevada (Zielinski et al. 2005).

Throughout the 20th century, fisher populations in the Pacific states declined and experienced range contractions, attributed to the combined effects of trapping and timber harvest (Zielinski et al. 1995, 2005). Contemporary threats to west coast fisher populations include habitat loss and fragmentation, poisoning by rodenticides, and climate change (Gabriel et al. 2012, Naney et al. 2012). The fisher is listed at the state level as endangered in Washington, a sensitive species in Oregon, and threatened in the southern Sierra Nevada range of California (Lewis and Stinson 1998, Oregon Dept. Fish and Wildlife 2008, California Department of Fish and Game 2015).

The fisher is a habitat specialist associated with old-growth stand characteristics such as dense canopy cover and complex woody structure (Harris et al. 1982, Carroll et al. 1999, Zielinski et al. 2004). Of particular importance to fishers is the availability of suitable resting and denning structures. These structures are typically large diameter trees and snags that provide suitable protection from the weather and predators and are often located in dense canopy cover forests (Powell 1993, Zielinski et al. 2004, Aubry et al. 2013).

Availability of suitable den structures for female fishers is especially important, as reproductive rates of fishers are relatively low. Fishers exhibit delayed implantation, so although females may breed when they are 1 year old, they do not give birth until they are at least 2 years old (Powell 1993). Average litter size in coastal northern California is 1.9 and ranges from 1 to 3 (Matthews et al. 2013). Between 51-89% of adult female

fishers in the Pacific Northwest region exhibit signs of denning during a given year (Truex et al. 1998, Aubry and Raley 2006, Reno et al. 2008, Matthews 2012). Not all females that den will successfully wean a kit. Matthews (2012) found that 23% of all monitored females that denned between 2005 and 2011 failed in their reproductive efforts prior to weaning kits, and only 65% of adequately monitored females that denned were successful in weaning at least one kit. Adult female survival, successful reproduction, and recruitment of kits are critical to maintaining stable populations and recovering small, isolated populations of west coast fishers (Lewis et al. 2012).

Across their range, female fishers give birth and rear kits in spring and early summer in cavities of live or dead trees (Lofroth et al. 2010). For approximately 10 weeks after birth, the kits are dependent on their mother's milk and are not mobile enough to move with the mother (Powell 1993). The use of tree cavities for dens and the increased energetic demands associated with producing and raising young (Leonard 1980, Arthur and Krohn 1991) also typically coincide with the onset of timber harvest activities in the Pacific states. Timber harvest that reduces large structures and overstory cover is believed to negatively affect fisher reproduction, survival, recruitment, prey availability, and other aspects of fisher biology and ecology (Naney et al. 2012).

Throughout the Pacific Northwest region, timber harvest generates a significant influx of money to local economies. In Oregon, sales values from forest products totaled \$7.2 billion in 2013, and the timber industry employed 43,200 workers (Simmons et al. 2015). Similarly, in California, sales values from forest products totaled \$1.4 billion in 2012 and employed 52,200 workers (McIver et al. 2015).

The timber industry is particularly important to the Hoopa Valley Tribe in northwestern California. Revenues from timber production provide direct means of economic self-sufficiency for the Hoopa Valley Tribe. At polls during the Tribe's annual Sovereign Day celebrations from 2007-2009, 92% of respondents felt it was very important to "protect and enhance Tribal sovereignty within and through forest management" and 88% felt it was very important to "develop the Hoopa forest by the Hupa people for the purpose of promoting a self-sustaining community" (Hoopa Valley Tribe, Interdisciplinary Team 2011). The Hoopa Tribal Forestry department has managed forested tribal lands on the Hoopa Valley Indian Reservation (HVIR) since 1989. The Tribe's current Forest Management Plan (1994-present) strives to sustainably manage forest resources while protecting culturally important species, such as the fisher (Hoopa Valley Tribe, Interdisciplinary Team 2011, Higley 2012).

Another region where fishers may be heavily impacted by timber harvest practices is in the northern Sierra Nevada mountain range. Between 2009 and 2011, 40 fishers taken from the northern California population were released on property privately owned and managed for timber production by Sierra Pacific Industries (SPI) east of Chico, CA (Powell et al. 2013). Prior to the translocation, fishers had been extirpated from the release area, the Stirling tract, once part of the historic range. The reintroduced fishers were successful in establishing home ranges and 63-90% of females in the population exhibit denning behavior annually (Powell et al. 2013). It is important to understand how timber harvest operations may influence denning behavior and success rates in this reintroduced population.

Additionally, fishers in the isolated southern Sierra Nevada population face adverse conditions and disturbances related to fire management as human development encroaches on fisher habitat. As the human population in the region grows, there are increasing concerns about controlling the region's fire regimes and preventing high-intensity fires that result from historic suppression of fires. Preventing frequent high-intensity fires requires heavy management of the landscape by using fuels reduction techniques and prescribed fires. While natural fire processes typically occur in the summer and fall, historic fire suppression has made low-intensity burns impractical during the traditional fire season (Knapp et al. 2009). Instead, prescribed burns in the springtime closely mimic the historic, fire-adapted landscapes by consuming fuels in a patchy distribution (Knapp et al. 2005). Many fuels reduction techniques require the use of heavy equipment for mastication of brush. Both fuels reduction and prescribed burns often occur during spring and the fisher denning season and have the potential to disrupt the behavior of denning female fishers. Prescribed burns occurring in the spring also pose a direct risk to immobile fisher kits by accumulating hazardous levels of carbon monoxide inside of den cavities (Thompson and Purcell 2016).

Despite the fisher denning season coinciding with timber production and fuels reduction activities, and the importance of mature trees and snags with cavities for reproductive female fishers, little is known about the den attendance patterns of fishers or the environmental and anthropogenic factors that might influence those patterns. Previous research suggests that developmental stage, number of young, and peak daily temperatures impact den attendance patterns of fishers (Paragi et al. 1994, Weir and

Corbould 2008). Sample sizes of these, however, have been small and may not represent population-wide trends.

Anthropogenic disturbances that alter behavioral patterns of denning fishers may increase energetic demands and negatively impact a female's ability to rear kits. Weir and Corbould (2008) and Leonard (1980) noted that monitored female fishers typically left their dens during the afternoon and warmest part of the day, presumably to forage and take advantage of higher ambient temperatures and solar radiation to provide a thermal advantage for kits inside the den cavity in the absence of the female. Temporal avoidance of crepuscular and diurnal anthropogenic disturbances by reproductive females may expose kits to greater risk of hypothermia, which may directly influence kit survival or may increase kit energetic demands for thermoregulation, thereby influencing the mother's energetic budget. Temporal avoidance of anthropogenic activities also may expose females to a higher risk of predation by bobcats (*Lynx rufus*), a primary source of mortality on the HVIR and in the southern Sierra Nevada range (Wengert 2013). While bobcats are mostly inactive in old-growth Douglas-fir (*Pseudotsuga menziesii*) stands during the daytime, they increase their activity at night, particularly in early seral habitat (Witmer and deCalesta 2011).

In addition to altering fisher den-attendance patterns temporally, disturbance generated by timber-harvest-related and fuels-management activities may alter space use patterns of denning females. If disturbed by nearby anthropogenic activities, females may avoid using areas in the vicinity of logging units and alternatively may choose to forage in less optimal habitats for capturing prey. This could result in the female having

fewer successful prey encounters and/or expending more energy to capture prey, reducing her ability to meet the energetic demands of raising young. The fisher's long and narrow body shape and poor ability to store fat make it particularly important for this species to maintain a proper balance of energy expenditure and prey consumption on a daily basis, otherwise survival may be negatively impacted (Brown and Lasiewski 1972, Harlow 1994). Altering this energy balance could affect a female fisher's ability to feed and to successfully rear her kits.

Timber harvest activities on the HVIR and SPI lands increase in intensity through the fisher denning period. While these anthropogenic disturbance factors are increasing, the energetic costs associated with female fishers raising young are also increasing. Powell and Leonard (1983) showed reproductive female daily energy expenditures nearly double from the time the kits are born to the time they are 60 days old. Thus, although the kits may be most vulnerable to exposure when they are younger and unable to thermoregulate, female fishers rearing young would be most vulnerable to disturbances that disrupt their energy balances when the kits are older and able to thermoregulate but have greater energy demands, which are met by the mother. It is critical to understand potential disturbances to denning fishers for the entire duration of the kit-rearing period.

In addition to anthropogenic disturbances brought on by timber-harvest and fuels-management activities, disturbance may also occur when researchers study denning fishers. Locating and monitoring fisher dens requires female fishers to be fitted with radio-collars, and researchers must use ground-based telemetry walk-in techniques to locate the fisher den sites. Furthermore, researchers must repeatedly approach the radio-

collared female to confirm a tree as a den tree, and they must continue to follow the fisher through the season to identify new dens and to determine whether or not the female is successful in her reproductive effort. Past den research protocols on the HVIR required walking in on radio-collared females for 3 consecutive days to confirm a structure as a den tree, followed by weekly visits thereafter to confirm continued use of the same tree, as fishers will utilize multiple den trees in a single season. Other California fisher studies follow similar protocol and also place and maintain remote cameras around the base of the den tree to estimate litter sizes. Often signals emitted from the radio-collars reflect increased activity of the females within the den while researchers are present, suggesting some level of disturbance.

Female fishers on the HVIR use an average of 3.1 dens while raising kits to weaning, though numbers range from 1 to 6 trees (Matthews 2012). Successive den moves average 328 m and range from 18-1728 m (Matthews 2012). It is suspected that females move kits to new den sites to reduce external parasite loads, after a kit dies, to avoid predators that may have keyed in on their den, to exploit food resources, or in response to change in weather conditions (Powell et al. 1997, R. Powell pers. comm., A. Facka, pers. comm., Higley pers. comm.). Disturbance by either research efforts or by timber-harvest and fuels-management activities could cause a female fisher to relocate her kits to a new den, causing her to move dens more frequently than she otherwise would. The relocation of kits to a new den tree is an activity requiring a high amount of energy and is hypothesized to put the female and her kits at higher risk of predation because movement is hampered by the act of carrying a kit. Den moves caused by

anthropogenic disturbances could also force a female to select less suitable den sites, which may increase the energetic demands placed on the female.

In this study, I assessed the efficacy of remote radio-telemetry data-loggers for use in fisher den research. Data-loggers have the potential to collect unparalleled data on fisher den ecology and behavior while minimizing disturbance to denning fishers that traditional den research methodology may generate through frequent visits to dens by researchers. Use of remote data-logging devices requires only one visit by the researcher to a den site while the female is present, and all subsequent visits to maintain data loggers can be conducted while the female is away from the den, reducing potential research-related disturbances to the focal study animals. I evaluated the ability of the data-loggers to not only record fisher den attendance patterns, but also to estimate litter sizes, which is a goal that many fisher den research project managers commonly attempt by using remote cameras or tree climbing.

Additionally, I described the environmental variables that influence fisher den attendance patterns and established baseline data that in the future may be compared with the behavioral patterns of female fisher denning near areas of anthropogenic activities that may cause disturbance and alter their behavior. Although I originally intended to collect data on fishers in close proximity to anthropogenic disturbances, timber harvest did not occur as planned so no denning focal animals were disturbed by these activities. Although timber harvest did occur within three focal female's home ranges during the denning season, these females either did not exhibit denning behavior or failed in their denning attempts shortly after parturition (potentially attributed to extreme weather

events and/or inexperience). One female whose home range overlapped with planned fuels-management and road maintenance activities in the southern Sierra Nevada also did not exhibit denning behavior. I encourage future research to collect data regarding anthropogenic disturbances and denning behavior where opportunities exist, although it may take years of data collection as part of long-term monitoring projects to obtain a sufficient sample size to draw conclusions.

Finally, I quantified potential disturbances to radio-collared denning fishers caused by researcher presence at the den site. Future long-term studies should address whether or not anthropogenic activities including timber-harvest-related and fuels-management activities influence fisher denning behavior and reproductive efforts. Once disturbance to den attendance behavior has been quantified, these data can be used to determine whether females disturbed by anthropogenic activities have higher den failure rates, lower survival rates, or successfully wean fewer kits than undisturbed females. These data could be used to guide forest managers across the fisher's range on the west coast to develop best management practices that properly balance socio-economic needs and fisher conservation.

METHODS

Study Areas

Fishers were studied at 4 sites in California, USA: the Hoopa Valley Indian Reservation (HVIR), Stirling, Sugar Pine, and Kings River study areas (Figure 1). At each of these sites, fishers were captured and marked annually with radio-collars for demographic, habitat, and den ecology research.

On the northernmost study area, the HVIR, fishers were radio-collared and intensively studied since 2004. Fishers on the HVIR are part of the contiguous northern California and southern Oregon population. The HVIR comprised approximately 367 km² within the Klamath physiographic province (Küchler 1977) and contained approximately 35,410 ha of commercial timberland (Higley 2012). Forests were generally dominated by Douglas-fir and tanoak (*Notholithocarpus densiflorus*), and California black oak (*Quercus kelloggii*), Oregon white oak (*Quercus garryana*), madrone (*Arbutus menziesii*), and canyon live oak (*Quercus chrysolepis*) at lower elevations. Forested areas included a mixture of mature old-growth and early-seral forests due to past and present forest management practices (Higley 2012).

Timber harvest began on the HVIR in the 1940s under management of the Bureau of Indian Affairs (Higley 2012). In 1994, the Tribe developed and implemented its own FMP, and timber harvest was an important economic factor to the Hupa¹ people.

¹ Hupa refers to the indigenous people/culture, while Hoopa refers to the locality.

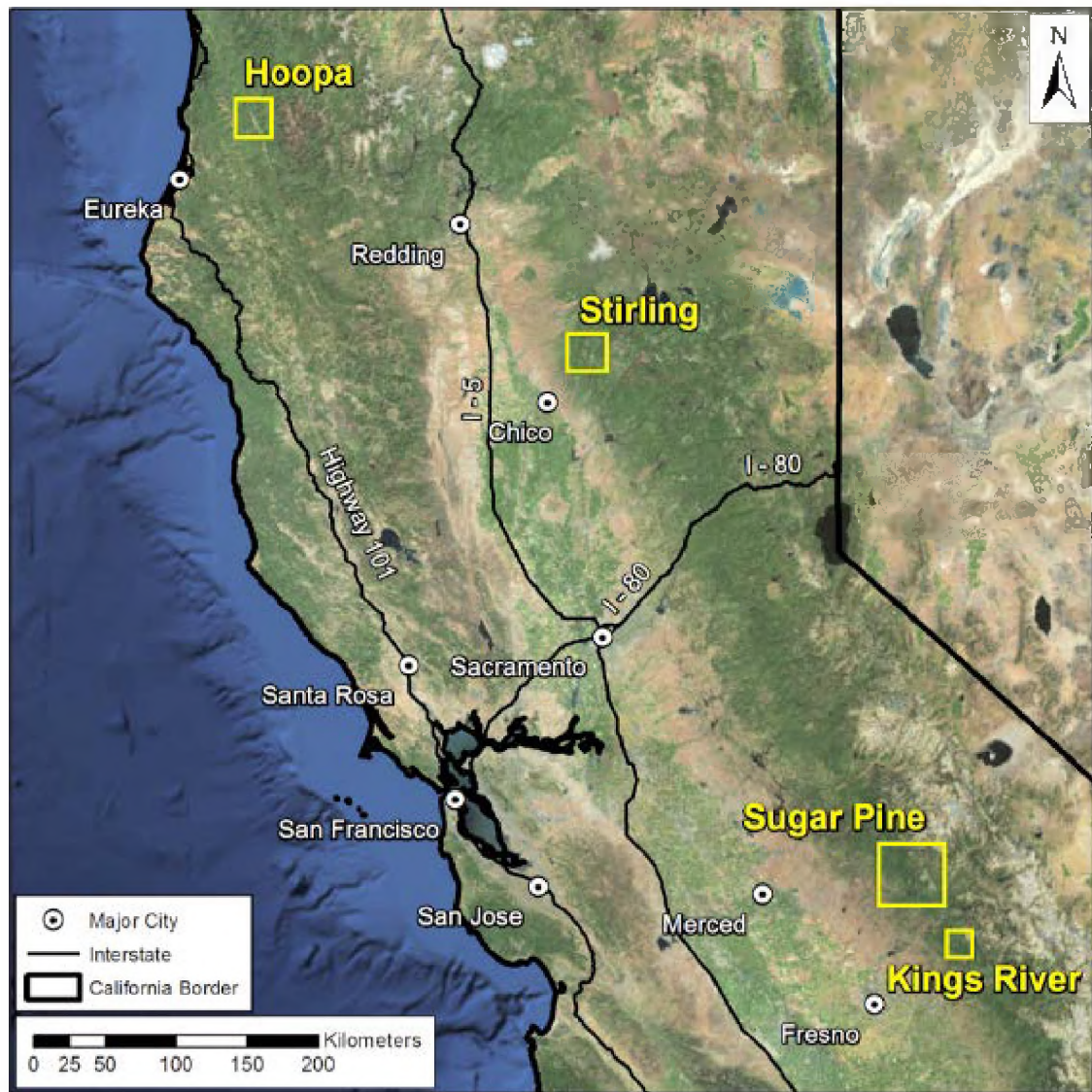


Figure 1. Locations of the four study areas where fisher den attendance data were collected, March-June 2014 and March-June 2015, California, USA. Extents of box outlines represent the extent of den locations where den attendance data were recorded within each study site.

The main objective of the Tribe's current Forest Management Plan was to balance economic gain from timber harvest with the sustainability of important tribal resources and the protection of culturally important species, such as the fisher.

The Stirling study area occurred primarily on the 648 km² Stirling Management Area of SPI timberland. Habitat on the Stirling site consisted primarily of second-growth Douglas-fir and pine (*Pinus* spp.) mixed conifer forests, with some hardwoods including *Quercus* species. Forty fishers were reintroduced to this area in the northern Sierra Nevada mountain range between 2009 and 2011 (Powell et al. 2013). The reintroduction effort was part of a Candidate Conservation Agreement with Assurances between SPI and the USFWS, where released fishers were monitored 7 years post-reintroduction to document survival, reproduction, habitat use, and causes of mortality (Powell et al. 2013). During the fisher breeding season (defined by SPI as mid-February to mid-May), up to 25% of the Stirling Management Area's yearly volume harvest may be taken, though no vegetation disturbance activities may occur within ¼ mile of a known fisher den site (Sierra Pacific Industries and US Fish and Wildlife Service 2008).

The Sugar Pine and Kings River study areas encompassed land primarily in the Sierra National Forest in the southern Sierra Nevada mountain range. Fishers in this population were separated by over 400 km from the northern Sierra reintroduced population (Spencer et al. 2015) and may have been isolated from other populations for thousands of years (Tucker et al. 2012). It is estimated that this population may contain fewer than 250 adult individuals (Spencer et al. 2011). Dominant tree species included mixed conifers and hardwoods, including incense cedar (*Calocedrus decurrens*), white fir

(*Abies concolor*), ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), giant Sequoia (*Sequoiadendron giganteum*), black oak, live oak (*Quercus* spp.), California bay (*Umbellularia californica*), and white alder (*Alnus rhombifolia*; Sweitzer et al. 2015). The Sugar Pine and Kings River study areas were subject to fuels-management treatments, including both mechanical fuels reduction and prescribed burns, detailed in the Sierra Nevada Forest Plan (USDA Forest Service 2004). Zielinski et al. (2013) estimated the footprint of southern Sierra fuels-management to be 7.4 ha of disturbance/year/km². Although Zielinski et al. (2013) demonstrated some tolerance of fishers to fuels reduction practices, little is known about how these practices may disturb denning female behavior. Sweitzer et al. (2016) found that local persistence of fisher declined by 24% in areas with restorative fuels reduction and recommended that fuels reduction techniques be minimized in suitable fisher denning habitat. Den cavities have been shown to accumulate levels of carbon monoxide hazardous to fisher neonate during springtime prescribed burns (Thompson and Purcell 2016), posing a more immediate risk than behavioral disturbances to adult females.

Capture Methods

Fishers were captured from September through February in live traps (model 207, Tomahawk Live Trap Company, Tomahawk, Wisconsin, USA) baited with chicken and modified with wooden nest boxes for safety, stress reduction, and shelter from the elements (Wilbert 1992, Seglund 1995). Animals were captured and handled following protocols for each respective study area approved by the Humboldt State University

Animal Care and Use Committee (No. 13/14.W.74-A), the North Carolina State University Animal Care and Use Committee (No. 2014 12-037-O), and University of California Davis Animal Care and Use Committee (No. 16302). Captured fishers were anesthetized with a combination of ketamine hydrochloride (40 mg/kg) and midazolam (0.5 mg/kg), or with Telazol (7 mg/kg). Females of reproductive age (older than 1 year at time of capture) were fitted with VHF radio-collars (Holohil model MI-2M, Holohil Systems Ltd., Carp, Ontario, Canada, or Telonics model MOD-125, Mesa, Arizona, USA), with each collar weighing 34-53 g, approximately 1-2.7% of the weight of an adult female fisher.

Radio-Telemetry Data-Loggers

Radio-telemetry data-loggers were constructed using a modified handheld VHF/UHF radio (BaoFeng, Quanzhou City, Fujian, China), a HOBO® Event logger (Onset Computer Corporation, Bourne, MA, USA), and a relay coil interface. The units were powered using an external 12V battery and were housed in a weatherproof hard-sided container (MTM Survivor Dry Box with O-Ring Seal, Small, MTM Molded Products Co., Dayton, OH, USA). Units were modeled after a design published by Callo et al. (2002) but were modified to suit the needs of this study (Appendix A). The HOBO® event loggers recorded presence/absence data every second based on whether or not the handheld radio was receiving a signal from the female's radio-collar.

Data-Logger Validation

Units were tested prior to deployment in the field and received signals from the radio-collars to an average distance of 44.4 m (SE= 3.3 m). Controlled conditions while testing the units on flat land do not likely reflect the range of environmental conditions experienced in the field. Slope, vegetation, humidity, the vertical position of the fisher on the landscape (i.e., in a tree or on the ground), and variations in radio-transmitter strength likely all influence the actual distance from which the radio-telemetry data-loggers receive signals. Additionally, distances that the receiver would pick up the collar differed depending on whether the fisher was exiting the receiving range or was entering receiving range. Fishers needed to be closer to the radio-telemetry data-loggers when returning after having been absent for the data-loggers to initially receive the signal.

To assess the accuracy of the units to record presence signals only when the females were very near the dens, field technicians recorded independent assessments of fishers' locations on the HVIR each time we heard or located them using ground-based radio-telemetry techniques during the denning season. Technicians recorded whether or not the female was suspected to be present at the den and the time. I then quantitatively compared these assessments with the data-logger records to determine the percentage of records where both data-loggers and technicians concurrently determined the fisher to be either present at or absent from the den.

Den Location and Monitoring

From mid-March through mid-June 2014 and 2015, radio-marked females were monitored daily using ground-based radio-telemetry techniques to determine whether or

not they were displaying denning behavior. When a female's location (determined by triangulation) was similar for two consecutive days, she was suspected to be denning and was located by walk in techniques (following the radio signal on the ground). Her location was isolated to a single tree, and a remote radio-telemetry data-logger unit was deployed within 10 m of the tree and concealed under duff and debris. In addition, a HOBO® pendant logger was hung approximately 1.5 m above the data logger unit to record ambient temperature. If this position was exposed to persistent direct sunlight, the data logger was moved to a nearby partially shaded location to more accurately reflect stand conditions. HOBO® pendant loggers were programmed to record ambient temperature at intervals of 15 minutes on the hour, in order to sync temperature data with summarized den attendance data. Females were defined as "denning" if they were located in the same structure on 3 or more consecutive days (as recorded by a remote data logger).

Every 7-9 days, a technician visited the den while the female was determined to be away (based on radio-telemetry signals) to replace external 12V batteries that powered the units and to download data from the HOBO® event loggers. Data-logger maintenance continued until the female was suspected to have moved to a new den tree. A fisher was suspected to have moved to a new den tree when she was located inactive away from the known den by triangulation or when the data-logger showed that she was no longer utilizing the tree. Matthews et al. (2013) found successive dens on the HVIR to be an average of 385 m apart, a distance that is conspicuous when using triangulation techniques and from which the data-logger would not be able to record a signal from the

female at the new tree. Once located in the new den structure, the data-logger was redeployed and maintained until the female was suspected to have moved again. Females were monitored for up to 8-12 weeks until they either stopped exhibiting denning behavior or until they moved dens too frequently to be monitored, which occurs as kits exceed weaning age.

Litter Size Estimates

Number of kits was estimated for each den tree by examining the patterns in the den attendance data on the final day of use for each tree. Females would often leave the tree for a short time, then return for approximately 5 minutes before leaving again. Thus litter size was estimated by counting the number of return trips the female made to the tree during a move, as recorded by the data logger. I assumed that the first excursion from the den after a long presence interval indicated the movement of a first kit and that any brief (approximately 5 minute) returns following the first excursion indicated the movement of an additional kit. Additionally, the number of kits inside of the first den tree where parturition occurred (the natal den) was not estimated unless the tree was climbed after the female moved to check for deceased kits, as kit abandonment and natural kit mortality has been documented in California fisher populations (Higley, unpublished data; USDA Forest Service Pacific Southwest Research Station, unpublished data). Although kit mortality/abandonment also occurs in maternal dens (Higley, unpublished data), if a litter size was estimated when the female moved from her previous den, I was able to determine litter size for each successive maternal den.

For the Stirling, Kings River, and Sugar Pine study areas, remote cameras were used to obtain a second estimate of litter size. Three remote cameras were positioned around the base of each fisher den tree to capture images of females moving kits to new den locations. Litter size estimates from remote cameras were compared with estimates from remote radio-telemetry data-logger to assess the efficacy of utilizing the data-loggers for obtaining kit counts.

Preparing Den Attendance Data

Remote radio-telemetry data loggers recorded the presence or absence of a radio-collared female every 1 second while deployed. Since the radio-collars did not transmit a constant signal and the timing of the transmission did not line up with every second that the data-logger was recording, it was necessary to summarize the datasets prior to performing any statistical analyses. Presence/absence data were summarized in 5-minute intervals. Females were considered to be present for the entire 5-minute interval if the data-logger recorded her as present for greater than 50% of the duration of that interval. The exact proportion of presence records vs. absence records for this 50% threshold was variable among each collar, as each collar had a slightly different pulse rate. Data were also assessed visually for apparent problems with the data logger. The most frequent problem was the appearance of gaps in the data as a result of a faulty relay-interface connection. For datasets that appeared unrealistic due to frequent gaps (e.g. that showed a fisher coming and going from her den multiple times per hour) but where presence-absence blocks were still visually apparent, a female was assumed to be present during

the entire den attendance block including during the gaps in the data that were equal to or shorter than 30-minute intervals. Faulty datasets that did not have obvious presence-absence blocks were excluded from further analyses.

Environmental Variables

Environmental variables at den trees were recorded as predictors for den attendance. Diameter at breast height (DBH) was measured for each den tree while the fisher was absent. Ambient temperature data were recorded by a HOBO® pendant logger hung near each den tree, as described on page 18. Precipitation was also used as a predictor variable for den attendance, however these data were impractical to obtain at each den site. Instead, precipitation data were obtained from National Ocean and Atmospheric Administration (NOAA) databases for the Stirling and Sugar Pine study areas, from the nearest respective weather stations in De Sabla and Fish Camp, CA. Jim Ladwig, a Hoopa Tribal Forestry employee, recorded precipitation data for the Hoopa study area in the Hoopa Valley. Precipitation data for the Kings River study areas were obtained from the U.S. Forest Service Pacific Southwest Research Station. The Kings River Experimental Watershed project crew collected these data in the upper Providence Creek drainage of Sierra National Forest.

Another environmental variable used to predict den attendance patterns of fishers was the solar exposure at each den site. Solar radiation may interact with the den tree to mitigate the influence of ambient air temperatures. For example, a female fisher may be able to leave a sunny den site sooner on a cold morning than another female fisher that

dens in a stand with dense canopy cover, where little sunlight reaches through to the section of the tree with the den cavity. Direct sunlight may warm the surface of the den tree, providing an insulating effect and reducing heat loss inside the den cavity.

Measures of solar insolation were calculated using Geographic Information System (GIS) techniques and remotely sensed data. To calculate solar insolation at the den sites, I used Digital Elevation Models (DEMs) generated by either satellite data or Light Detection and Ranging (LiDAR) data, and the Area Solar Radiation tool in ArcMap (version 10.1.1, ESRI, 2012). This specific tool assumed bare-ground cover and clear skies. For the Hoopa study area, where LiDAR information was available, a second solar insolation value was calculated to account for canopy density.

To account for uncertainty both in the process of determining a den tree using radio-telemetry signals and in the error of the handheld global positioning system (GPS) units, all den locations were buffered by 10 m, and the area within this buffer was used for solar insolation calculations rather than the point itself. Solar radiation values (in watt hours per m²) were then calculated using a variety of tools built into ArcMap.

For the Stirling and Sugar Pine study areas, 10-m DEMs were acquired online from the United States Geological Survey (USGS). For the Hoopa and Kings River study areas, a 1-m DEM was generated using LiDAR point cloud data. DEMs were masked with 30-m buffers around den sites and then used as an input for the Solar Radiation tool in ArcMap. Solar radiation was calculated for each den tree, at 1-day intervals for the entire duration of the denning season in each respective study area. Calculations of insolation for each day were necessary, as the models of den-attendance patterns have

predictor variables that are input on a daily scale to model the daily proportion of time for each den, and solar insolation values change over time.

The solar radiation outputs resulted in three rasters: total solar insolation, direct solar insolation, and diffuse solar insolation. Each raster had multiple bands representing the values associated with each calendar day. The next step was to calculate the mean value for each solar radiation raster/band, associated with each 10-m buffer. Each data set from each raster was first extracted using the Composite Bands tool and Python scripting (Python Software Foundation, Wilmington, DE, USA), so that it could be input into the Zonal Statistics tool. A model was then built in ArcMap that would iterate through solar radiation rasters to calculate the zonal mean values for insolation, attach the data set name to the zonal mean table, and then append all zonal mean values into one large master table in a Microsoft Access database. These solar insolation values represented a bare-ground model, where canopy density was not accounted for.

For the Hoopa study area where LiDAR-based canopy information was available, a 5-m resolution raster representing canopy density above 2 m was extracted from the raw point cloud, using program FUSION (U.S. Department of Agriculture, U.S. Forest Service Pacific Southwest Research Station). I then masked the resulting canopy raster by the 10-m den buffers, and extracted an average canopy density value for each den using the zonal statistics tool. This canopy density value was then used to calculate sub-canopy solar insolation values for each den tree on a daily basis. Sub-canopy solar insolation was calculated using methods described by Bode et al. (2014):

$$TotSR_{subcan} = DiffSR_{subcan} + DirSR_{subcan}$$

where $TotSR_{subcan}$ is the total sub-canopy solar insolation value, $DiffSR_{subcan}$ is the diffuse sub-canopy solar insolation value, and $DirSR_{subcan}$ is the direct sub-canopy solar insolation value. Diffuse sub-canopy solar insolation was calculated by a linear regression formula described by Gendron et al. (1998):

$$DiffSR_{subcan} = 1.024 \times DiffSR_{bare} \times (1 - CC) + 0.01719$$

where $DiffSR_{bare}$ represents the diffuse solar radiation value from the bare-ground model calculated using ArcMap's solar radiation tool, and CC represents the canopy cover (as a proportion) at the den tree. Direct sub-canopy solar insolation was calculated by:

$$DirSR_{subcan} = (1 - CC) \times DirSR_{bare}$$

where $DirSR_{bare}$ represents the direct solar insolation value calculated for the bare-ground model using ArcMap's solar radiation tool.

Statistical Analyses

Den Attendance Model

Daily proportion of time spent at the den was modeled as a function of den tree characteristics that have been shown or were suspected to influence insolation inside of tree cavities, including DBH, hardwood or conifer type, live or dead (Coombs et al. 2010); daily precipitation total; daily minimum ambient temperature; daily solar radiation values; number of days since parturition (kit age); study site; and relevant interaction terms. Hereafter, predictor variables will often be abbreviated (Table 1).

Litter size was excluded as a predictor variable as an estimate was unavailable for many den trees. Parturition was assumed to occur on the first day of den use for the purposes of this study. For den tree characteristics influencing insulation, interaction terms were included for tree type and DBH but main effects of tree type and DBH were excluded. It seems likely that tree type and DBH do not directly influence fisher den attendance patterns, but instead they influence den attendance indirectly through interaction with ambient temperature values. Daily den attendance records with missing values for any one predictor variable included in the models were removed prior to model fitting so that the number of observations would be consistent between models for comparison purposes.

The data were fit to generalized linear mixed effects models with a Gaussian distribution using package lme4 (Bates et al. 2015) in program R (version 3.2.1, R Foundation for Statistical Computing 2014). FisherID and TreeID were considered as random effects for the models. A nested random effects structure of TreeID nested within FisherID was chosen, as it was the most biologically relevant random effects structure and appropriately represented the study design. Study site was included as a fixed effect in all models, as estimating parameters of a model with study site fit as a random effect would have limited model inference due to study site having only 3 levels. Because of their geographic proximity, connected fisher populations, and limited number of observations, the Sugar Pine and Kings River study areas were categorized as a single

Table 1. Predictor variable abbreviated names and descriptions for models of fisher den attendance.

Variable Name	Variable Description	Random or Fixed Effect
FisherID	Unique fisher identification number	Random
TreeID	Unique den tree identification number	Random
Site	Study area (HVIR, Stirling, or southern Sierra)	Fixed
KitAge	Number of days since suspected parturition	Fixed
C.H	Classification of den tree as a conifer or a hardwood	Fixed
LT.SN	Classification of den tree as a live tree or a snag	Fixed
DBH	Diameter at breast height of den tree (cm)	Fixed
MinT	Daily minimum temperature at a den tree (°C)	Fixed
Precip	Daily total precipitation (cm) at a weather station closest to the study area	Fixed
BareSR	Daily solar insolation (watt hours per m ²) at a den tree assuming bare ground cover	Fixed
SubCanSR	Daily solar insolation (watt hours per m ²) at a den tree beneath the canopy cover and above 2 m	Fixed
WalkIn	Categorical variable (yes/no) denoting whether or not a fisher was walked in on by a researcher on that date	Fixed

study site, hereafter referred to as the southern Sierra site.

The most biologically relevant full model included the following fixed effects: study site; interaction terms between study site and MinT, BareSR, & DBH; MinT; BareSR; whether the tree was a hardwood or conifer; whether the tree was a live tree or snag; DBH of the den; interaction terms between MinT and BareSR, the hardwood/conifer category for the den tree, the live tree/snag category for the den tree, DBH of the den tree; KitAge; daily precipitation total; and whether or not the fisher was walked in on by researchers that day [DailyPresence $\sim (1|\text{FisherID}/\text{TreeID}) + \text{Site} + \text{Site}:\text{MinT} + \text{Site}:\text{BareSR} + \text{Site}:\text{DBH} + \text{MinT} + \text{BareSR} + \text{C.H} + \text{LT.SN} + \text{DBH} + \text{MinT}:\text{LT.SN} + \text{MinT}:\text{C.H} + \text{MinT}:\text{DBH} + \text{MinT}:\text{KitAge} + \text{MinT}:\text{BareSR} + \text{KitAge} + \text{Precip} + \text{WalkIn}$]. Numerical predictor variables were centered around the mean and were standardized to make regression estimates more meaningful and more easily interpreted, as well as to make effect sizes directly comparable.

The response variable was scaled to represent the daily percentage of time a female fisher spent at the den in order to make interpretation of predictor variable effect sizes more clear. I developed an *a priori* fixed effects candidate model set containing only biologically relevant variables and interactions and compared models using an information theoretic approach (Burnham and Anderson 2003). To prevent potential confounding effects from researcher disturbance, the categorical variable denoting whether or not a researcher had walked in on a fisher that particular day was included in all models. Multiple variables that were highly correlated ($r > 0.6$ or $r < -0.6$) were not incorporated together within a single model.

Relative support of each model was evaluated by comparing AIC_c values (Hurvich and Tsai 1989). Since random effects were constant across all models, AIC_c was calculated using a true maximum likelihood approach instead of restricted maximum likelihood. Top models were defined as those within two AIC_c values of the model with the lowest AIC_c value (Burnham and Anderson 2003) and then were averaged using the zero method (Nakagawa and Freckleton 2010).

Fit of the final averaged model was assessed using marginal and conditional coefficients of determination (R^2), where marginal R^2 relates to the variance explained by fixed effects and conditional R^2 relates to the variance explained by both fixed and random effects (Vonesh et al. 1996). Fit was also assessed visually by looking for patterns in the plotted residuals, by using quantile-quantile plots of residuals, and by plotting a histogram of the residuals.

Although the response variable was a proportion, I chose not to log-transform the dataset in order to preserve the model interpretability and to avoid biases in parameter estimates (Faraway 2005). Log transformation would have required adding an error term to zero values of predictor variables.

Temporal Patterns in Den Attendance

Daily den attendance was divided into four time periods: crepuscular morning, daytime, crepuscular evening, and nighttime. Crepuscular time periods were defined as the time between one hour before and after sunrise or sunset. The proportion of time that females spent at the den during each time period was plotted against number of days since parturition. Days where fishers had been walked in on by researchers were excluded

from this analysis, and only days with complete 24-hour periods of data were included. Only data collected in 2015 were used for this analysis to preserve comparability between study areas. I then generated a local regression line and 95% confidence bands using the LOESS method (Cleveland 1979), with the smoothing parameter constant for all times of day and study locations (span = 0.5). LOESS regressions were generated using package ggplot2 (Wickham 2009) in program R (version 3.2.1, R Foundation for Statistical Computing 2014).

Additionally, I extracted the time at the beginning of excursion events, where fishers left the den for periods of longer than 30 minutes, and homing events, where fishers returned to the den after an absence of longer than 30 minutes. For these analyses, I excluded days where fishers had been walked in on by researchers to avoid confounding effects, whereby a walk in event may have altered the behavior of a female and the time that she left or returned to the den. I also excluded data collected in 2014 at the HVIR, to preserve comparability between study areas and to avoid potentially confounding environmental differences between years. I then plotted the times of the beginning of excursion and homing events as a function of kit age, number of hours from sunrise and sunset, and number of hours from the time at which daily minimum and maximum temperatures occurred. Finally, I generated local regression lines and 95% confidence bands using LOESS methods, with smoothing parameter held constant for study locations (span = 0.5), to describe the temporal patterns of excursion and homing events in relation to environmental cues.

RESULTS

Over the two denning seasons in 2014 and 2015, 36 individual female fishers were monitored. The dataset consisted of 1456 total observations from 86 unique den trees (Appendix B), where an observation was defined as a complete 24-hour period where den attendance data was recorded for a female and no predictor variables were null. More females were monitored on the HVIR for a longer period of time than at the other study sites, and the DBH of den trees on the HVIR was generally larger than the other sites (Table 2). Due to the low number of individual fishers monitored at the two southern Sierra Nevada study sites, the datasets from Kings River and Sugar Pine were combined into a single site hereafter referred to as the southern Sierra site. Individuals in both of these study areas are considered to be part of a single contiguous population, and environmental conditions are similar across the two study areas, so I felt it was reasonable to pool the datasets into a single site representing the southern Sierra Nevada population.

Data-Logger Validation

During the 2014 and 2015 den seasons on the HVIR, there were 289 written records where field technicians documented the date, time, and suspected location of focal females based on radio-telemetry signals or triangulations. Of these, 280 (97%) were consistent with records of den presence/absence based on remote radio-telemetry data-loggers.

Table 2. Sample sizes and diameter at breast height (DBH) of trees and standing dead trees (snags) selected as dens by female fishers used to evaluate den attendance patterns during 2014-2015 in California, USA. Observations were defined as full 24-hour periods of den monitoring with no null predictor variables for the models.

Site	Dates Monitored	Female Fishers	Den Trees	Den DBH \pm SE (cm)	Observations
Hoopa	7 April-9 June 2014 & 19 March-10 June 2015	15	47	97.5 \pm 32.3	719
Stirling ^a	19 March-17 June 2015	11	22	85.8 \pm 26.4	425
Kings River ^b	31 March-15 June 2015	6	11	79.5 \pm 22.5	209
Sugar Pine ^b	28 March-4 June 2014	4	8	75.4 \pm 15.1	103
Southern Sierra total ^b	28 March-15 June 2015	10	19	78.4 \pm 25.6	312
Total		36	88		1456

^a Stirling Fisher Project Team, unpublished data; do not cite without permission

^b USDA Forest Service Pacific Southwest Research Station, unpublished data; do not cite without permission

Litter Size Estimates

Across the Stirling, Kings River, and Sugar Pine study areas, there were a total of 43 den trees where remote cameras and data-loggers were both deployed to estimate litter sizes. Remote cameras recorded female fishers moving kits at 22 (51.2%) of the dens, while data-loggers recorded apparent kit moves at 29 (67.4%) of the dens.

There were 18 dens where both remote cameras and data-loggers simultaneously recorded females moving kits. On 13 (72.2%) of those occasions, the number of kits estimated from remote cameras was identical to the number of kits estimated based on the remote radio-telemetry data-logger patterns. Of the remaining 5 occasions where estimates were not identical, remote camera estimates were incorrect on 3 (16.7%) occasions compared with data-logger estimates. On these 3 occasions, remote cameras recorded females moving a single kit while data-loggers estimated two kits, but then remote cameras later recorded females moving two kits at successive den trees. The remaining 2 occasions where data-logger and remote camera estimates differed occurred for the same female at 2 den trees. The data loggers estimated that the female had 2 kits while the remote camera estimated only 1, and it is uncertain which estimate was closer to truth.

Den Attendance Models

Twelve variables were used to generate models for den attendance in fishers (Table 1). When models including a sub-canopy solar radiation effect were added to the model list, these models did not appear to improve the fit, and the sub-canopy solar

radiation models were not among the most competitive models. Thus models including sub-canopy solar radiation were dropped from the candidate model set for final analyses.

Model selection resulted in two competitive models ($\Delta AIC_c < 2.0$) for the den attendance of fishers in California (Table 3). Both of the competitive models included the fixed effects of kit age (number of days since parturition), minimum temperature, an interaction term between minimum temperature and kit age, precipitation, a walk-in effect, bare-ground solar radiation, study site, an interaction term between study site and minimum temperature, and an interaction term between site and solar radiation. The most competitive model did not include an interaction between solar radiation and minimum temperature, while the second-ranked model did include the interaction term.

Model-averaged coefficient estimates suggest that kit age had the largest influence on the percentage of time a fisher spends at the den each day (Table 4). As kit age increased by 1 standard deviation (20.0 days) from the mean kit age (37.3 days), the percentage of time a female spent at the den decreased by 12.4% when all other predictor variables in the model were centered at the mean (Appendix C). Daily minimum temperature value also had a large effect on den attendance, whereby percentage of time spent at the den decreased as minimum temperature increased when all other predictor variables in the model were centered at the mean. Precipitation had the opposite effect on den attendance; increased precipitation resulted in an increased percentage of time spent at the den. For every 1 standard deviation (0.4 cm) increase in precipitation, the percentage of time a female spent at her den increased by approximately 0.8%, or 12 minutes, assuming all other variables were centered at the mean. A walk-in event by a

Table 3. Model selection table for the optimal fixed effects structure of fisher den attendance patterns. All models had a random effects structure of (1|FisherID/TreeID). Models shown have a cumulative AIC_c weight < 0.95. Variables are listed in descending order of presence in models. K represents the number of parameters. Data were collected April-June 2014 (HVIR only) and March-June 2015 (all sites) in California, USA.

Model	K	ΔAIC _c	Weight
(1 FisherID/TreeID) + KitAge + MinT + KitAge:MinT + Site + Site:MinT + WalkIn + BareSR + Site:BareSR + Precip	16	0.000	0.299
(1 FisherID/TreeID) + KitAge + MinT + KitAge:MinT + Site + Site:MinT + WalkIn + BareSR + Site:BareSR + Precip + BareSR:MinT	17	0.200	0.270
(1 FisherID/TreeID) + KitAge + MinT + KitAge:MinT + Site + Site:MinT + WalkIn + BareSR + Site:BareSR + BareSR:MinT	16	2.977	0.067
(1 FisherID/TreeID) + KitAge + MinT + KitAge:MinT + Site + Site:MinT + WalkIn + BareSR + Site:BareSR	15	3.030	0.066
(1 FisherID/TreeID) + KitAge + MinT + KitAge:MinT + Site + Site:MinT + WalkIn + Precip	13	3.198	0.060
(1 FisherID/TreeID) + KitAge + MinT + KitAge:MinT + Site + Site:MinT + WalkIn + BareSR + Site:BareSR + Precip + C.H + C.H:MinT + LT.SN + LT.SN:MinT	20	3.749	0.046
(1 FisherID/TreeID) + KitAge + MinT + KitAge:MinT + Site + Site:MinT + WalkIn + BareSR + Site:BareSR + Precip + BareSR:MinT + C.H + C.H:MinT + LT.SN + LT.SN:MinT	21	3.869	0.043
(1 FisherID/TreeID) + KitAge + MinT + KitAge:MinT + Site + Site:MinT + WalkIn + BareSR + Site:BareSR + Precip + DBH + DBH:MinT + DBH:Site	20	3.904	0.042
(1 FisherID/TreeID) + KitAge + MinT + KitAge:MinT + Site + Site:MinT + WalkIn + BareSR + Site:BareSR + Precip + BareSR:MinT + DBH + DBH:MinT + DBH:Site	21	4.031	0.040
(1 FisherID/TreeID) + KitAge + MinT + KitAge:MinT + Site + Site:MinT + WalkIn	12	6.697	0.011

Table 4. Model averaged coefficient estimates for all models with $\Delta AIC_c < 2.0$. Data were collected April-June 2014 (HVIR only) and March-June 2015 (all study sites) in California, USA. Variables are listed in descending order of scaled effect size.

Variable	β Coefficient	Adjusted Std. Error	Lower 95% Confidence Interval	Upper 95% Confidence Interval	z value	Pr(> z)
(Intercept)	50.510	2.142	46.312	54.709	23.578	< 0.001
KitAge	-12.383	0.645	-13.647	-11.119	19.199	< 0.001
WalkIn-Yes	5.572	1.621	2.395	8.749	3.437	< 0.001
MinT	-2.906	0.748	-4.371	-1.441	3.887	< 0.001
KitAge:MinT	1.509	0.439	0.648	2.370	3.436	< 0.001
Precip	0.799	0.359	0.095	1.503	2.226	0.026
BareSR	-0.582	0.914	-2.373	1.208	0.637	0.524
Site <i>SSierra</i>	0.183	3.685	-7.040	7.406	0.050	0.960
Site <i>Stirling</i>	-1.807	3.396	-8.462	4.848	0.532	0.595
MinT:Site <i>SSierra</i>	-0.369	1.201	-2.723	1.984	0.308	0.758
MinT:Site <i>Stirling</i>	1.226	0.976	-0.687	3.139	1.256	0.209
BareSR:MinT	-0.285	0.427	-1.464	0.265	0.667	0.504
BareSR:Site <i>SSierra</i>	0.307	1.424	-2.485	3.098	0.215	0.830
BareSR:Site <i>Stirling</i>	-2.464	1.303	-5.018	0.091	1.890	0.059

researcher also resulted in increased den attendance between 2.4-8.7%, or 35-125 minutes.

The averaged top model supported an interaction between minimum temperature and kit age (Appendix D). As kit age increased, the effect of minimum temperature on den attendance was reduced. Although the averaged model also supported bare-ground solar radiation and an interaction between solar radiation and minimum temperature, the confidence intervals of the effect sizes of these predictors broadly overlapped 0. When an interaction between site and solar radiation was introduced, the effect of solar radiation varied among sites. Solar radiation appeared to influence fisher den attendance at the Stirling study site, but it did not have a strong effect on the den attendance of fishers on the HVIR or southern Sierra study sites (Appendix E).

Results from the averaged model did not strongly support a difference in den attendance of fishers based on the study location. The effect size for each study site was small, and confidence intervals for these effect sizes overlapped broadly between sites. However, as previously stated, study site may be important in predicting fisher den attendance when including a solar radiation variable.

Marginal and conditional R^2 values suggested that the fixed effects explained much of the variance in the top models (Table 5). Nearly 47% of the variance in the top models was explained by the fixed effects alone, while 67% of the variance was explained by the combined fixed and random effects.

Table 5. Marginal and conditional R^2 values for the top models of the daily percentage of time that fishers spent at the den. Data were collected April-June 2014 (HVIR only) and March-June 2015 (all study sites) in California, USA.

Model	Marginal R^2	Conditional R^2
(1 FisherID/TreeID) + KitAge + MinT + MinT:KitAge + Site + Site:MinT + WalkIn + BareSR + Site:BareSR + Precip	0.466	0.669
(1 FisherID/TreeID) + KitAge + MinT + MinT:KitAge + Site + Site:MinT + WalkIn + BareSR + Site:BareSR + Precip + BareSR:MintT	0.465	0.667

Temporal Patterns in Den Attendance

The proportion of time that female fishers spent at the den for each 24-hour period was remarkably similar in all study areas (Figure 2). Fishers generally spent 80-90% of their time at the den the first week following parturition. Daily den attendance dropped to less than 50% by the time kits were 20-40 days old. General trend lines showed den attendance leveled off at ~30% by the time kits were being weaned at 56-70 days old.

Overall, the temporal patterns of fisher den attendance were similar among the three regions in California (Figure 3). Fishers mostly spent a large proportion of time at the den during crepuscular morning hours, regardless of the kit age. Proportion of daytime den attendance was high close to parturition dates but steadily declined as kits aged. For all regions, crepuscular den attendance dropped steeply as kits aged.

Temporal patterns of fisher den attendance between study areas differed during the nighttime hours. On the HVIR, nighttime den attendance started high, dropped steadily, and fell below 50% during the time at which females began to wean kits (56 days). In contrast, at the Stirling site, nighttime den attendance dropped sharply when kits were 20 days old, then fell and remained below 50% by the time kits were 30 days old. In the southern Sierra, nighttime den attendance dropped sharply in the first 20 days after parturition, then rose slightly until kits were 30 days old, and then steadily declined until kits were of weaning age.

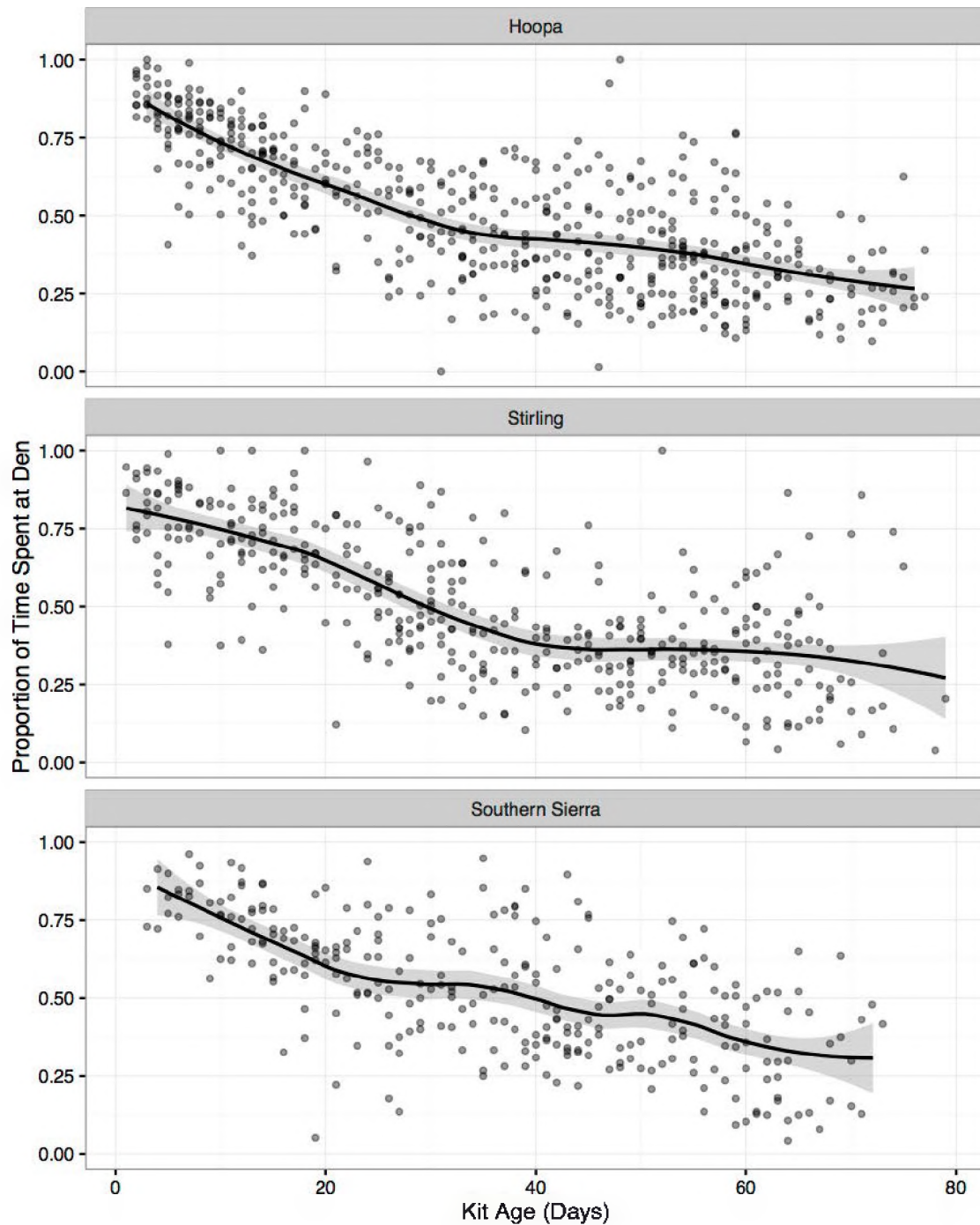


Figure 2. Proportion of time that females were present at the den per 24-hour period as a function of kit age. Local regression lines were generated using LOESS methods. Gray shading represents 95% confidence bands. Data were collected March-June 2015 in California, USA.

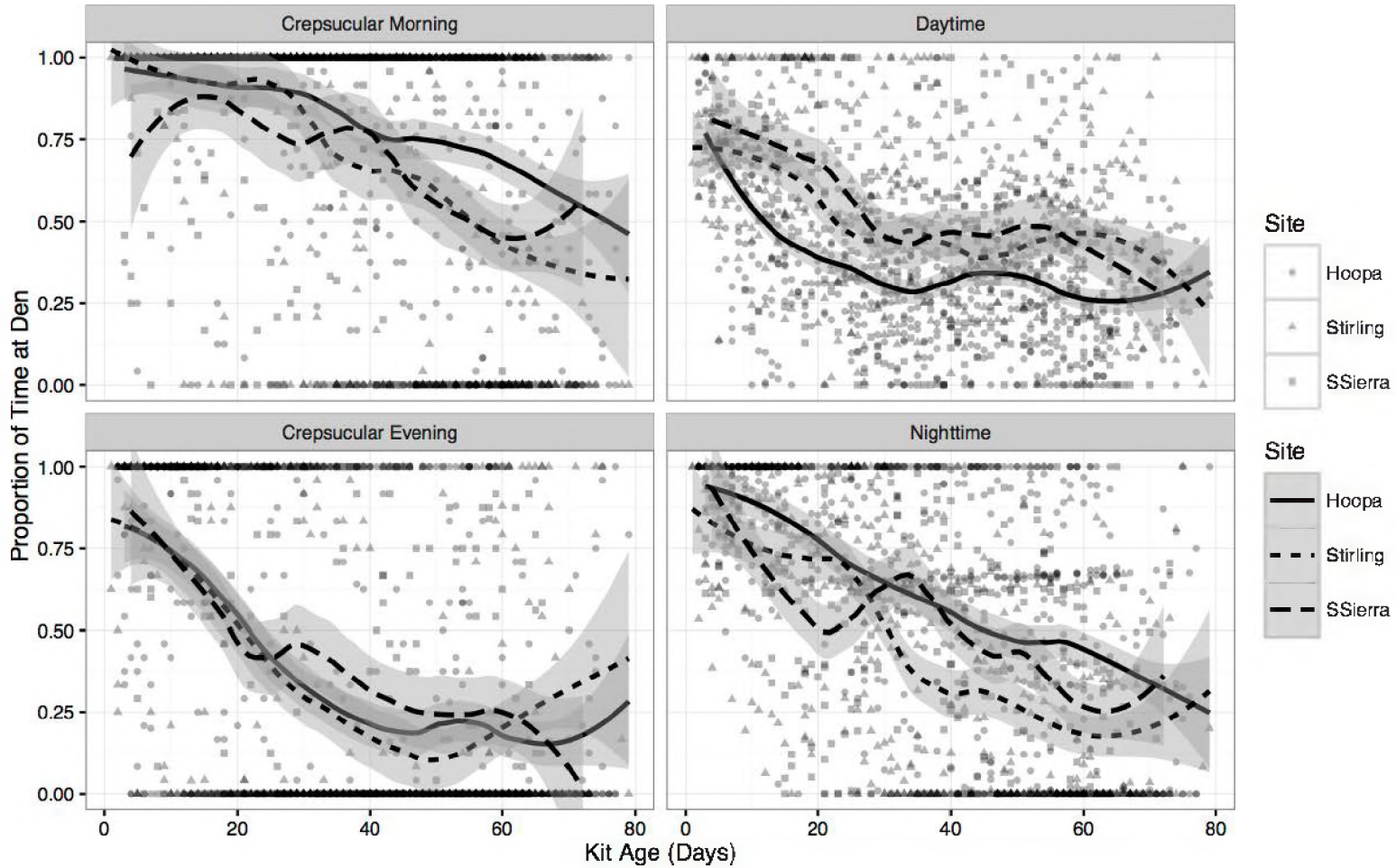


Figure 3. Proportions of time fishers were present at the den during different times of day, for each respective study site. Local regression lines were generated using LOESS methods. Gray shading represents 95% confidence bands. Data were collected March-June 2015 in California, USA.

Although overall the proportion of time females spent at the den during a day or any given time of day was similar across all study sites, there were slight differences in the timing of excursions lasting longer than 30 minutes (Appendix F). For all study areas, few excursions began between 00:00 and 06:00. Temporal patterns in excursions were more likely related to biologically relevant factors, such as sunrise and sunset or minimum and maximum temperature occurrences rather than directly to the time.

On the HVIR, fishers left the den most consistently in the early to late morning hours, less than 5 hours following sunrise (Figure 4). Timing of excursions away from the den did not change relative to sunrise time, though as kits aged they did occur sooner before sunset. At the Stirling study site, most excursion events occurred 5-10 hours following sunrise (Figure 4). However, as kits aged these excursions away from the den occurred increasingly further from sunrise, in contrast to the pattern exhibited on the HVIR. Timing of excursions at the Stirling site remained relatively stable in relation to sunset as kits aged. In both the HVIR and Stirling study areas, some excursions away from the den did occur before sunrise or after sunset when the kits were young, but these events declined in frequency as kits aged and as excursions lengthened.

Fishers in the southern Sierra followed excursion timing trends similar to Stirling, in that they most often left within 5-10 hours after sunrise, and excursion timings trended further from sunrise as the kits aged (Figure 4). This trend, however, was not as strong as at the Stirling site, as there was more variation in the timing of excursions. When the southern Sierra data were separated into the two individual sites (Kings River and Sugar Pine), fishers on the Sugar Pine study area showed very different excursion timings from

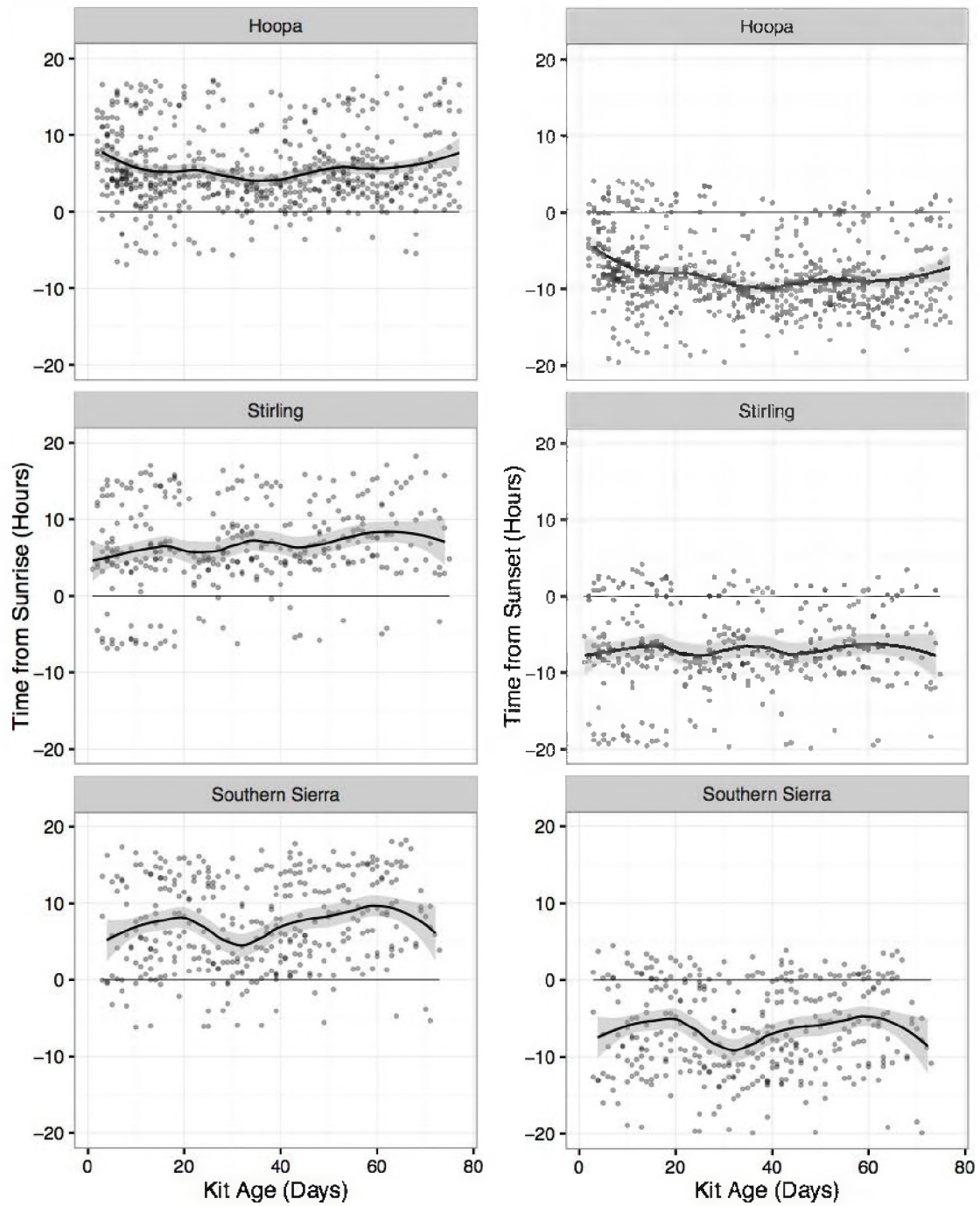


Figure 4. Timing of excursions away from the den lasting longer than 30 minutes, relative to sunrise (left) and sunset (right). Local regression lines were generated using LOESS methods. Gray shading represents 95% confidence bands. Data were collected March-June 2015 in California, USA.

all other study sites, including Kings River. Most excursion events for fishers on the Sugar Pine study site occurred either shortly following sunrise or preceding or following sunset by approximately 2-4 hours, with fewer excursions occurring midday. I suspect that this contrasting pattern at Sugar Pine may be due to the low sample size and due to unequal sampling effort per individual, whereby trends at the Sugar Pine site later in the denning season may have been driven heavily by the patterns of a single female.

Fishers on the HVIR began excursions shortly after the time that daily minimum temperatures occurred, and excursions rarely began after the daily maximum temperature had been reached (Figure 5). In contrast, excursions on the Stirling and southern Sierra study sites were not closely associated with the occurrence of daily minimum temperatures. Although almost all excursions occurred after the daily minimum temperature, most excursions at the Stirling and southern Sierra sites began in close association with the occurrence of the daily maximum temperature.

The timing of homing events (i.e., fisher female returning to the den after an absence of 30 minutes or greater) did not display a strong pattern for any study location in relation to sunrise or sunset or to the times at which the daily minimum and maximum temperatures occurred. There was evidence of a slight trend for the HVIR and Stirling study areas, in that homing events generally shifted from evening and nighttime hours to early morning hours as the kits aged.

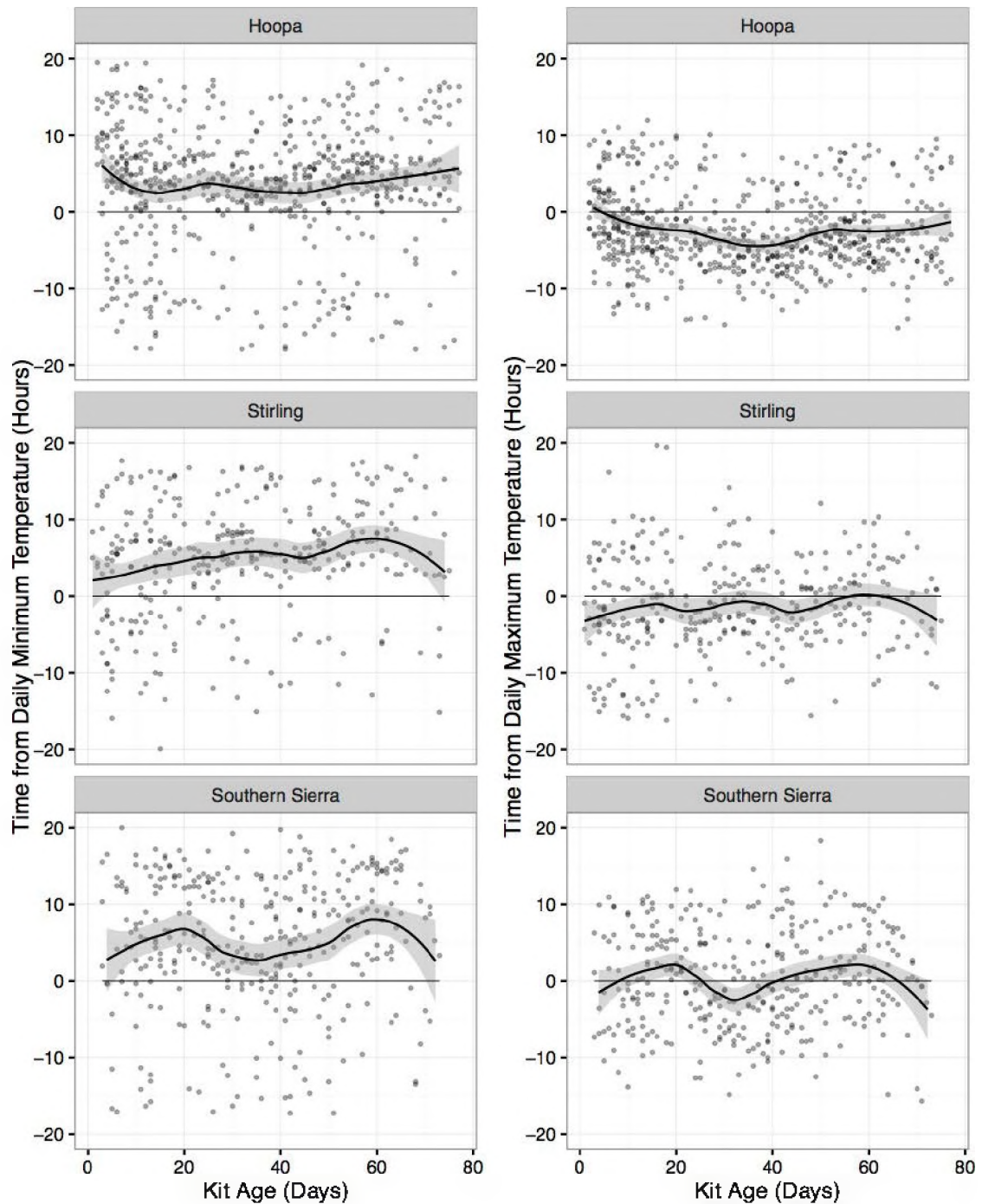


Figure 5. Timing of excursions away from the den lasting longer than 30 minutes, relative to the time that daily minimum (left) and maximum (right) temperatures occurred. Local regression lines were generated using loess methods. Gray shading represents 95% confidence bands. Data were collected March-June 2015 in California, USA.

DISCUSSION

Homemade radio-telemetry data-loggers were effective and accurate tools for recording den attendance patterns of and for estimating litter size of fishers. Kit age, daily minimum temperature, precipitation, and solar radiation were the biological and environmental variables supported in den attendance models as influencing the proportion of time that females spent at the den per day. Research disturbance also influenced den attendance, as the presence of a researcher at the den site caused fishers to spend 35-125 minutes longer at the den. Fishers were present at their dens greater than 50% of the time during the first 4 weeks following parturition. Proportion of time fishers were present at the den, as a function of kit age, did not vary regionally. Fishers were also generally present at the den throughout crepuscular morning hours regardless of kit age. Den attendance during daytime and nighttime hours varied regionally. The timing of the beginnings of excursions away from the den were closely correlated with the occurrence of daily maximum temperatures in the southern Sierra and at Stirling, but excursions began soon after the daily minimum temperature occurred at the Hoopa study site.

Efficacy of the Radio-Telemetry Data-Loggers

Remote radio-telemetry data-loggers recorded den attendance data with a high degree of accuracy, as evidenced by the comparison between data-logger and written telemetry records kept by technicians. Data loggers are an improvement over traditional

den research methods due to their low cost and their ability to record den use with a greater degree of precision. More specifically, data on the duration of use of the den tree is recorded exactly and continuously, as compared to walk-in based methods that are unlikely to pinpoint when a female leaves the den for the day to forage or even moves her kits to a new den tree. Data loggers also show promise in their use for estimating litter size for fishers. They recorded apparent kit moves more frequently and kit counts with greater accuracy than remote cameras.

Other studies have found success utilizing homemade technologies for wildlife research applications. Bass et al. (2012) successfully developed an antenna system to read PIT tags in estuarine environments, in which commercially available technologies do not function well due to the saline and other challenging properties of the environment. Researchers have even developed their own advanced GPS radio-collar systems where technological advances in commercial products have not kept up with research demands (Clark et al. 2006). Technologies built for non-wildlife purposes, such as drones, have also been successfully adapted for use in wildlife research (Jones et al. 2008). The data-logging units presented here were adapted from technologies described by Callo et al. (2002) and Ivan (2000), who successfully used similar technology to record gray catbird (*Dumetella carolinens*) nest attendance and American marten (*Martes americana*) track-plate avoidance. Homemade technologies can both reduce the cost and increase the accuracy of wildlife research.

The data-logging units, however, did not operate without error (Appendix A). Sources of error for the devices occurred in the form of technological glitches in the radio

software, manufacturing error when building the components, and user error when operating the units. By far, the largest source of confusion and frustration when operating the devices in the field was caused by a software glitch in the handheld radios. For some radios, when the battery saving setting was turned on, the squelch opened up in pulses and produced static, creating a false signature on the HOB0® data-logger that made it appear as if the female fisher was present when in fact she was not. Luckily, the pulse rate of the static differed significantly from the radio-collar pulse rate, so the data were still usable. The simple solution for this glitch is to turn off the battery save mode, but this requires that the units be maintained and batteries replaced more regularly (as often as every 5 days).

Another major source of difficulties in interpreting the data arose when the connection between the handheld radio and the relay was not solid. This resulted in small gaps in the data while the fisher was present at the den. Observations of patterns in the data can be used to fill in these gaps. For example, it is not likely that a female leaves her den on five occasions within a 1-hour period. The best way to prevent this is to use pre-soldered headphone jack connections, which are less susceptible to strain with frequent movement of the cables. Thorough testing of the equipment prior to deployment in the field should also prevent poor solder connections from compromising the data.

Despite having to overcome these challenges when I tested this homemade technology, the benefits greatly outweighed the drawbacks and occasional frustrations. These units were at least 10 times less costly than radio-telemetry data-logging units offered by wildlife professional technology companies. Materials for the homemade

units cost \$230 per unit, while professionally built technology often costs \$3,000 per unit. A single unit was also less expensive than the combined costs of three or four remote cameras placed around the den tree to estimate litter size. Further, they yielded rich datasets on female denning behavior that could not have been obtained through traditional fisher den research methods.

Den Attendance Model

Kit age had a clear influence on the den attendance of fishers at all study sites. Overall, as kits aged, females spent less time at their dens. This pattern makes biological sense for several reasons. As kits grow older, their energetic demands increase (Powell and Leonard 1983). Thus, the mother's energetic demands also increase and she must spend more time away from the den foraging in order to meet those increasing demands. Once kits reach 8 weeks of age, they are weaned from the mother's milk to solid foods (Powell 1993). At this point, the mother likely needs to spend time away from the den travelling and foraging to bring back solid food items for the kits to consume.

Kit age interacted with daily minimum temperature in the final averaged model. The effect of daily minimum temperature on den attendance is diminished as kits age (Appendix C). As kits age, they grow larger in size and grow thicker fur, improving their ability to thermoregulate. As a result, the mother fisher is less tied to her den during times with colder ambient temperatures because she does not need to be in the den cavity to keep the kits warm. However, it is difficult to disentangle the effects of thermoregulatory capabilities and of increased energetic demands as kits age.

Precipitation also appears to be an important variable that influences fisher den attendance. The female may need to remain with the kits inside of the cavity to keep them dry during a rainfall event, as some precipitation may seep into the den cavity.

Solar insolation appeared to be an important influence on the proportion of time females spent at the den, although this variable did not appear to impact all study areas equally. For all study areas, percentage of time spent at the den decreased as solar insolation values increased. Increasing solar radiation values may mitigate the effects of ambient temperatures. Wintering forest birds, for example, have been found to roost in areas of higher solar radiation in order to minimize thermoregulatory costs (Villén-Pérez et al. 2013). While the influence of solar radiation on den attendance was similar between the HVIR and southern Sierra sites, the effect appeared to be greatest for fishers residing in the Stirling study area (Appendix D). The median value and spread of the solar insolation variable were similar between Stirling and the HVIR, so it is unclear why the effect of solar radiation would be greater at Stirling. It is possible that a difference in canopy cover between sites may be responsible for this interaction. Fishers at the Stirling study site also experienced greater fluctuation in daily minimum temperatures than at other study areas, which may increase the importance of solar radiation in predicting fisher den attendance.

One important note is that the bare-ground solar radiation measures did not accurately reflect the solar insolation value at a den site. Fishers select for den site locations at a three-dimensional scale: the location on the landscape and the vertical location of the den cavity on the tree. The solar radiation values based on the built-in

ArcMap tool reflected only the solar radiation value at ground-level assuming no canopy cover. Thus there was no reflection of the microsite of the den cavity in the solar radiation calculations. Even though my sub-canopy solar radiation values incorporated the canopy cover into the values, they assumed that all den cavities were at the same height. A better approach to calculating solar radiation would be to calculate a bare-ground solar radiation value using a digital surface model of the tree tops, then to calculate a sub-canopy solar radiation value that incorporates the canopy cover above the cavity height for each den tree. This may improve estimates of effect size for the solar radiation term and relevant interactions in the models. However, cavity heights for fisher den trees are often unknown as cavities are not always visible and multiple cavities may be present in the tree.

Although the final averaged model suggested that daily minimum temperature interacted with bare-ground solar insolation, the direction of the interaction was not clear as the 95% confidence interval largely overlapped 0. Thus, this interaction term was not well supported by the model. Solar radiation values generally increased as the kits aged due to prolonged daylight hours as the calendar year approached summer solstice. Daily minimum temperature also tended to increase as the kits aged and the season changed. This correlation was a confounding factor when interpreting the effect of solar radiation and relevant interaction terms.

There were other variables that were not measured that could have accounted for some of the variation in the models not explained by the combined fixed and random effects. The presence of a potential predator in the vicinity of the den could have

influenced a female's den attendance patterns, similar to the way a researcher's presence did. Research has shown that common voles (*Microtus arvalis*) respond to predator presence at nest sites with increased vigilance, nest-guarding behavior, and adaptive foraging strategies that minimize nest predation risk (Liesenjohn et al. 2013, 2015). Effects of predator presence on fisher den attendance could, in part, be accounted for by placing remote cameras around the den site. However, the scope of those cameras would be relatively small compared to the scope within which a fisher may detect a predator. Cameras may also fail to detect some visitors, as they often fail to detect the denning fisher even when multiple cameras surround the den tree.

Another variable that may influence den attendance is wind. Wind increases thermoregulatory demands (Chappell and Iii 1984), which mammals may compensate for behaviorally by changes in activity and/or nesting in a buffered shelter (Körtner and Geiser 2000, Terrien et al. 2011, Klug and Barclay 2013). Thus, wind may increase fisher den attendance behavior. Wind was not accounted for in my study, as we did not have instruments to document wind speed at each den site. Future studies should incorporate data loggers that record microsite-level wind speed values, if funds are available.

It is also possible that prey populations influence a fisher's den attendance patterns. Natal den attendance patterns in pine marten (*Martes martes*) are reported as being influenced by activity and availability of prey (Kleef 2000, Kleef and Tydeman 2009). Prey abundance may influence the amount of time a fisher spends away from the den foraging. If prey is more abundant and foraging success greater, a reproductive

female fisher may spend less time away from the den to meet her (and her kits') energetic requirements. The distance to foraging patches may also influence den attendance patterns. A female who forages in a patch further from the den may spend more time travelling to and from the patch, and as a result will spend less time at the den than a female who forages in a patch that is closer to her den. Finally, prey behavior and foraging success may be altered by environmental conditions, as mentioned previously in the discussion of precipitation. Some environmental conditions that may influence prey behavior, such as moon phase (Brown et al. 1988, Hughes and Ward 1993, Griffin et al. 2005), were not parameterized in my models. Changes in prey behavior due to environmental conditions may consequently influence predator foraging behaviors (Zielinski 1986, Rockhill et al. 2013).

Similarly, it is possible that predator populations and activity patterns may also influence fisher foraging behavior. Primary predator species for female fisher in California include bobcat, mountain lion (*Puma concolor*), and coyote (*Canis latrans*; Gabriel et al. 2015). Female fisher in California are most frequently preyed by bobcats (Wengert 2013). Denning female fisher may be more active under environmental conditions that favor predator avoidance, such as low moonlight or high cloud cover at night (Rockhill et al. 2013). Bobcat predation risk in California is highest in open and brushy habitat types (Wengert 2013). Predation risk may also influence fisher habitat use and foraging success rates, thereby influencing the amount of time that a fisher spends away from her den acquiring prey.

Finally, it seems likely that litter size could have a strong influence on fisher den attendance patterns. Energetic demands increase with litter size (Millar 1978, Kounig et al. 1988, Sikes 1995), so presumably a female would spend less time at the den and more time away foraging to meet those higher demands if she had more kits. Additionally, the effect of daily minimum temperature may be mitigated by multiple kits huddling together in the den, which would reduce heat loss even when kits are not yet able to thermoregulate (MacArthur and Humphries 1999). I chose to exclude this variable in my models in order to maintain a larger sample size to detect other effects, as several fishers did not have any kit counts associated with their datasets. If litter size estimates are available for more fishers in the future, I recommend incorporating litter size as a variable in the models. I also recommend incorporating an interaction term between litter size and daily minimum temperature.

Research Disturbance to Denning Fishers

Results from the final averaged model indicate that researcher walk-ins have an effect on fisher den attendance. Studies have reported similar impacts on nest guarding behavior of desert tortoises in response to human interactions whereby researchers were perceived as a potential nest predator (Agha et al. 2013). Fishers spent 2.4-8.7% more time at the den on days when they were walked in on by a researcher. This translates to an additional 35-125 minutes present at the den, an effect size that may appear relatively small in the scale of a 24-hour period. While it seems that a single walk-in event is unlikely to severely impact a denning fisher's ability to meet her energetic requirements,

it is possible that consecutive walk-ins on a female to confirm a den tree could have a cumulative effect strong enough to impact a female's energetic balance.

Frid and Dill (2002) establish that animals perceive human-caused disturbance stimuli as a predation risk. Both predation risk and disturbance stimuli have been shown to divert time away from fitness-enhancing activities, including foraging and parental care, by inciting behavioral responses to the perceived risk (Lima and Dill 1990, Lima 1998, Steidl and Anthony 2000). Carey (2011) found that investigator disturbance to shearwater (*Puffinus tenuirostris*) nests resulted in decreased chick mass and size, as a result of parental care behavior being diverted away from chicks or decreased body condition of the parent as a result of disturbance-induced stress. Repeated human-induced disturbances not only impact short-term behaviors of animals, but they also have long-term cumulative effects on behavioral budgets, reduce energy intake, and increase energetic demands of the disturbed animals (Williams 1966, Lusseau 2003, Christiansen et al. 2010). Thus, denning female fishers may be at even greater risk from repeated behavioral disruptions caused by research-related walk-ins.

Temporal Patterns of Fisher Den Attendance

Several trends were apparent in the temporal patterns of fisher den attendance across all study areas. Understanding these patterns is critical in determining the potential effects of management activities (such as mechanical thinning, road improvements, or fuels reduction) on denning fishers.

In all study areas, fishers tended to spend a large proportion of crepuscular morning hours present at the den, regardless of kit age. Crepuscular morning hours appeared to be particularly important for fishers to tend to their dens. Daily minimum temperatures typically occurred during the crepuscular morning or late night hours. This suggests that fishers may be tied to their dens during the coldest part of the day, likely to aid in the thermoregulation of kits. This pattern is consistent with that of fishers in British Columbia reported by Weir and Corbould (2008), where den tending periods generally occur during the coldest parts of the day.

Another prevalent pattern is that when the kits were young, fishers were most frequently away from the den during the daytime and crepuscular evening hours. As kits aged, females spent more time away from the den at night. This again suggests that fishers may be tied to the den during the coldest parts of the day, especially when kits are young, but that the need for females to help thermoregulate kits may decrease as kits age and develop. This pattern is also supported by the interaction term between kit age and daily minimum temperature in the den attendance models.

Regardless of the time of day, fishers spent the majority of the day tending to their dens during the first 4-6 weeks after parturition, though den attendance steadily declined as kit age increased. This decline in den attendance as kits age has also been reported by Leonard (1980), Powell and Leonard (1983), and Weir and Corbould (2008), and is attributed to the increased energetic demands of nursing and rearing kits as they age and grow.

The timing of excursions away from the den lasting longer than 30 minutes was similar but showed slight variations between study sites. Excursions away from the den generally trended further away from sunrise as kits aged at the southern Sierra and Stirling study sites, while excursions occurred closer to sunrise as kits aged on the HVIR. Variations in temporal patterns of fishers in California may be due to regional prey differences and the temporal activity patterns of those prey items. Activity patterns of American martens have been found to be correlated with prey availability and activity (Zielinski et al. 1983).

Golightly et al. (2012) found that fishers in the Klamath Bioregion had a more diverse prey base than fishers in the southern Sierra Nevada and suggested that fishers forage opportunistically. Reptiles appear to be present in fisher scat at a higher rate in the southern Sierra than on the HVIR (Zielinski et al. 1999, Golightly et al. 2012), which might explain the trend of fishers in the southern Sierra leaving den sites later in the daytime than fishers on the HVIR. Diet analyses are not yet complete for fishers on the Stirling study site, though preliminary analyses suggest that fishers have a diverse prey base including many species common to the other two study locations (Powell et al. 2014).

Variation in temporal patterns of fisher den attendance between the two southern Sierra study sites is likely due to small sample size and unequal sampling effort of individuals. Variation between study sites may also be due to differences in ambient temperature. Both daily minimum and maximum temperatures tended to be lowest at den sites in the southern Sierra, followed by the Stirling study area. Ambient temperatures

were more moderate on the HVIR. Cooler ambient temperatures may result in fishers spending a higher percentage of time at the den during morning hours, when daily minimum temperatures tend to occur.

The times that females began excursions away from the den closely coincided with the times that daily maximum temperatures occurred on the Stirling and southern Sierra study sites. Similarly, Weir and Corbould (2008) found a strong correlation between the timing of excursions from dens and the timing of daily maximum temperatures, but no relationship between the timing of excursions and ambient temperature. Fishers on the HVIR did not follow this pattern in that most excursions began prior to daily maximum temperatures and instead tended to occur shortly after the daily minimum temperatures occurred. The more moderate temperatures at den sites on the HVIR could explain this regional difference between temporal patterns of fishers. Alternatively, activity patterns of prey in response to daily minimum and maximum temperature may differ between sites due to differing relative availability or abundance of prey species.

Future Study Directions

The most important focus of future studies should be to include denning female fishers that are in the proximity of anthropogenic disturbances, including but not limited to timber-harvest and fuels-management related activities. The primary focus of this study was to establish a baseline for environmental factors that influence fisher denning behaviors with which to compare denning behavior of fishers that may be impacted by

anthropogenic disturbance. The environmental and den tree variables found to be important here should be included in future model sets that include disturbances, to account for potential factors that may confound the effects of disturbances. Ideally, future studies will also define at what distances from fisher dens anthropogenic activities constitute a disturbance and will focus on whether or not research activities and other disturbances may cause female fishers to relocate den sites more frequently than they otherwise would.

Additionally, future studies should focus on more accurately capturing the solar insolation values for dens. More accurate reflections of solar radiation may further refine estimates of solar radiation effects and their interaction with daily minimum temperature. The inclusion of these effects in the top averaged model suggests that solar radiation may be an important factor influencing fisher denning behavior and should be further studied.

Although my study revealed that research activities alter the behaviors of denning fisher, it is still unknown whether frequent research-related disturbances may cause a female to move to a new den site. Future studies should address the frequency of den moves in relation to the frequency of researcher walk-ins to the den site.

Finally, future studies should not focus solely on behavioral perturbations of denning female fishers. Instead, they should strive to link behavioral changes, reproductive success, and kit survival rates to quantify how various disturbances (research-related or land-management-related) may impact fisher populations.

RECOMMENDATIONS

My research suggests that walk-in events, where researchers approach a radio-collared female fisher at her den tree, alter the female's behavior. As a result of a walk-in, she may spend up to 125 minutes more at the den that day than she otherwise would have without researcher disturbance. This increase in time at the den reduces the amount of time a female can spend foraging, and may impact the ability of the female to meet the energetic demands of raising kits. Multiple consecutive walk-ins have the potential to impact a female's ability to successfully rear kits. I therefore recommend that walk-ins to the den while the female is present there be minimized, and that researchers not use multiple consecutive walk-ins to confirm den trees. Instead, I recommend that researchers monitor potential dens and continued use of dens with remote cameras or preferably with remote radio-telemetry data-loggers, and that those technologies be maintained in the field while the radio-collared fisher is away from the den. If multiple walk-ins are necessary to confirm a tree as a den, I recommend that researchers space those walk-in events out several days between events.

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PERSONAL COMMUNICATIONS

Facka, A. 2015. North Carolina State University, Department of Applied Ecology.

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APPENDICES

Appendix A. Construction methods and trouble-shooting guide for remote radio-telemetry data loggers.

Part I: Building Components for a Remote Radio-Telemetry Data Logger Unit



Caylen Cummins, January 2016

Section I: Constructing the relay-interface

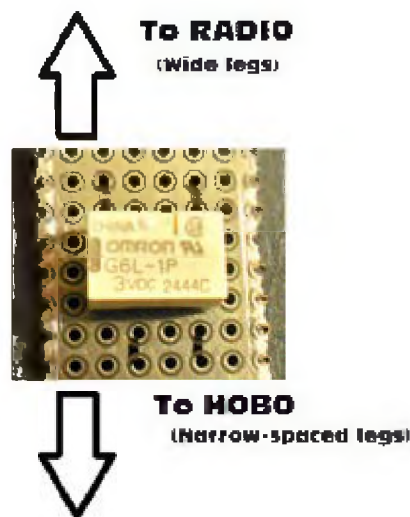
Equipment needed:

- Low signal relay, 3VDC (Mouser Electronics Part# 653-G6L-1P-DC3)
- Gray wire & 2.5mm jack that comes with the HOBO® UX-90M data logger
- 3' 2.5mm mono male/male cable (e.g. YCS Basics from Amazon)
- Circuit board/Perfboard with no solder pad connections
- Reaming tool (optional; not necessary for most circuit board)
- Laminate/plastic scoring tool
- Flush wire cutters
- Soldering iron & electronic-grade solder
- Solder/flux paste
- Hot glue stick
- Wire stripping tool
- Vice grip (optional, but recommended)

Step 1- Use the laminate scoring tool to score and break the circuit board to size. Circuit board should be cut to be at least 8 x 6 dots.

Step 2- Place the relay on the top of circuit board piece (the side with no solder pads), such that the relay runs length-wise along the shorter dimension of the board and is almost centered along the longer dimension. Carefully bend the legs slightly inward to hold the relay in place.

Step 3- On the top side of the board, mark the position of the relay legs. This is where the wiring will be inserted.

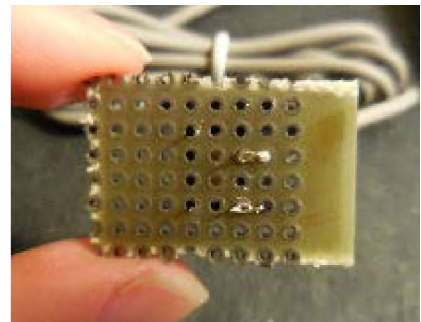


Step 4- Cut the 3' 2.5mm mono jack cable in half. Strip ~1/8" of insulation off the lead of each wire. Once cut in half, this cable can be used for 2 separate relay interfaces. The gray wire that came with the HOBO® logger is used for the other side of the relay interface.



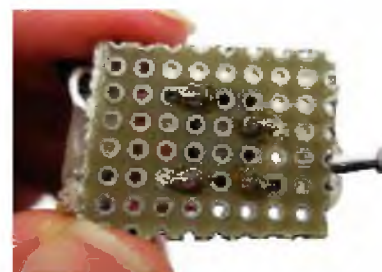
Step 5- Tin the ends of the wires from the 2.5 mm mono cable, by briefly heating them and adding a small amount of solder. This will make it easier to get the wires through the circuit board. The wires from the grey HOBO® cable come pre-tinned.

Step 6- Place the ends of each wire through the holes where the relay legs are on the top side of the board, with one hole for spacing between the wires and relay. Ream the holes, if necessary, so that the insulation will fit through the holes. Bend the lead wires so that they wrap around each associated leg once, and fold the lead back on itself. Trim any excess wire.



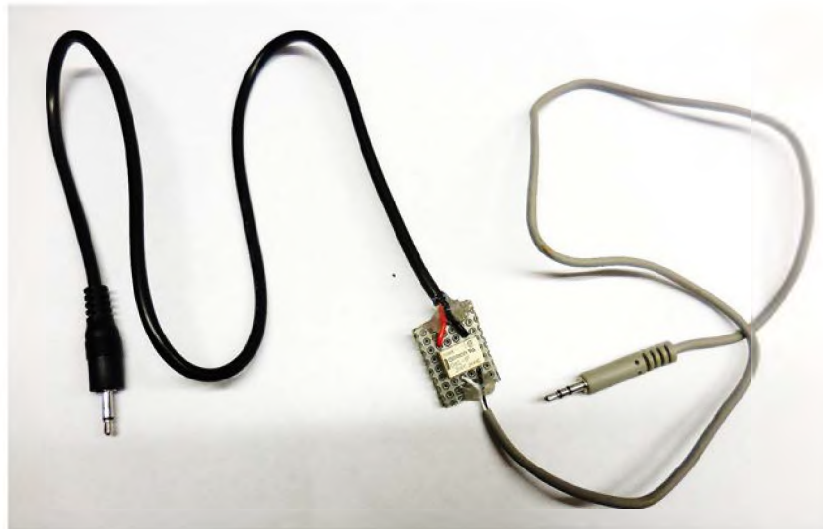
Note: It does *not* matter which lead wire goes to which leg, as there is no polarity. It also does *not* matter which jack is on which end of the relay, as the jacks are the same size and will fit into both the radio and data logger. If you would like to keep the wiring consistent so that the gray wire is always connected to the HOBO® logger, attach the gray wire leads to the legs that are spaced closer together. This is the output end of the relay. What will matter will be which end of the relay you plug into the radio (the end of the relay with wide spacing between the legs).

Step 7- Solder the connections between each wire and the relay legs. Clip off the excess legs of the relay.



Step 8- Label the wires with masking tape, or use a color-coding system. The wire connected to the closely spaced relay legs (right side of the picture) should be labeled “data” or “logger”. The wire connected to the widely spaced relay legs (left side of the picture) should be labeled “radio”. The HOBO® data logger will not record data if it is connected to the wrong end of the relay.

Step 9- Test the relay with a power source on the radio end and a power meter on the other end to ensure connections are solid. Use hot glue to firmly attach the wire in place on the circuit board, to prevent future wire stress/breakage. Congratulations, the relay interface is now complete!



Section II: Modifying the radio

Equipment needed:

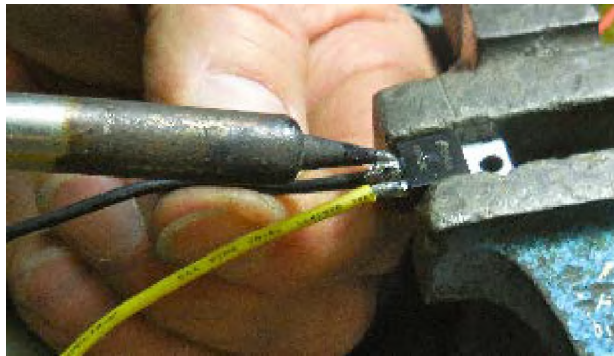
- BaoFeng® UV-5RA radio
- Linear Voltage Regulator (Mouser Electronics® Part #511-L7808ABV)
- Single lead wire, one red, one black, and one other color
- Heat shrink tube, to fit the wire of your choice
- Blue spade fittings for battery connections
- Soldering iron & electronic-grade solder
- Solder/flux paste
- Wire stripping tool
- Crimping tool
- Flush wire cutter
- Zip tie or waxed string
- Screwdriver

Note: When referring to the “left” or “right” side of the radio, this manual will refer to left and right looking at the backside of the radio (where the battery would normally slide in. Positive battery connections will use red wiring, and negative will use black.

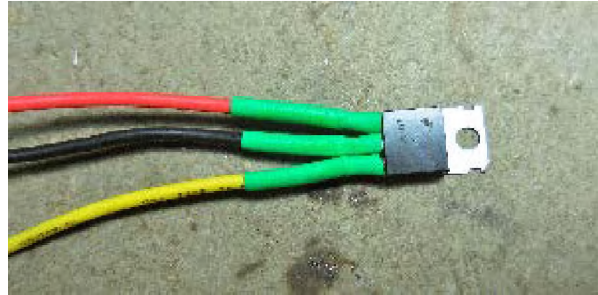
Step 1- Trim half of the leg length of the voltage regulator chip. Place the regulator chip in the vice grip, with the legs protruding.

Step 2- Cut one piece of red wire approximately 6 inches long and strip about 1/2” from each end. Repeat with the black wire. Repeat also with the other colored wire, but cut the length to approximately 3 inches instead of 6.

Step 3- Tin one end of each wire with solder. Using a soldering iron, attach the red wire to the top leg of the voltage regulator chip, the black to the middle leg, and the other color wire to the bottom leg.



Step 4- After the wires are firmly soldered to the chip, slide an inch of heat shrink tube over each wire and chip leg. Apply a heat source (e.g. lighter) to shrink the tube around the wires/legs.

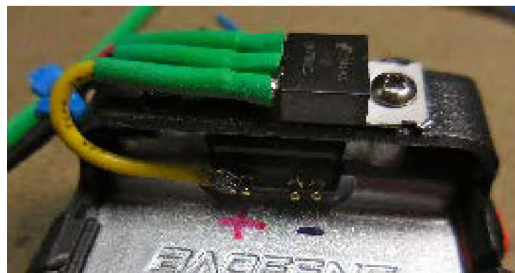


Step 5- Unscrew the right screw toward the top of the radio. Screw the regulator chip in, with the wires coming off to the left.

Step 6- Secure the red and black wires against the metal rectangular slot on the left side of the radio, with a zip tie or string. This will reduce stress on the wire connections.



Step 7- The third color wire will connect to the battery connection knobs on the left side of the radio. Trim this wire shorter if necessary, and strip 1 cm off the end. Tin the end of the wire. Solder the wire to the brass knob furthest to the left on the radio.



Step 8- Strip ~2cm off the ends of the red and black wires. Double the wire back on itself.

Step 9- Crimp spade fittings onto the ends of each wire. Make sure the knob in the crimp is pressing against the bottom side of the spade fitting (the bottom side being the closed side of the spade).



Step 10- The radio modification, except for the antenna, is complete! Connect it to a power source to be sure it works.

Section III: Building an antenna

Equipment needed:

- Flexible, thin, single-lead wire
- Female SMA to female SMA coupler joiner
- Hot glue stick
- Soldering iron & electronic-grade solder
- Solder/flux paste
- Wire stripping tool

Note: Antenna modification may vary based on your project's needs. Determine the radius with which you want the data-logger to receive and record a signal. For our purposes, we chose a length that will receive within 51 meters (on flat terrain). You may lengthen or shorten the wire to determine the right length for your antennas. One method of determining the length you need is to place a metal tube over a certain length of the wire antenna to effectively shorten & lengthen the antenna before you make the actual cut.

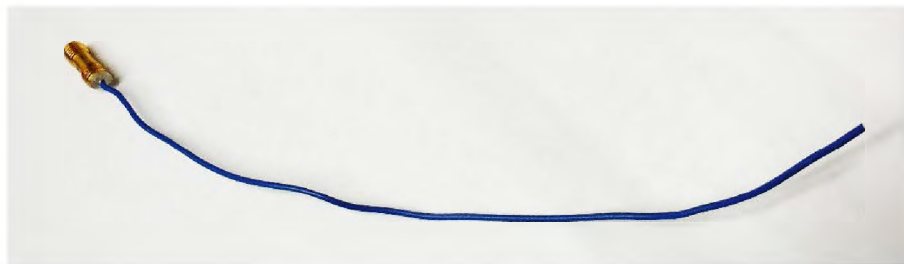
Step 1- Clip a long piece of the flexible, thin wire. Strip less than 1 cm off one end of the wire, and tin it with solder.

Step 2- Solder the wire into the small hole of one side of the coupler joiner.

Step 3- Screw the coupler joiner into the antenna slot and test the device to ensure that the connection is solid.

Step 4- Use hot glue to fix the wire more permanently into the coupler joiner.

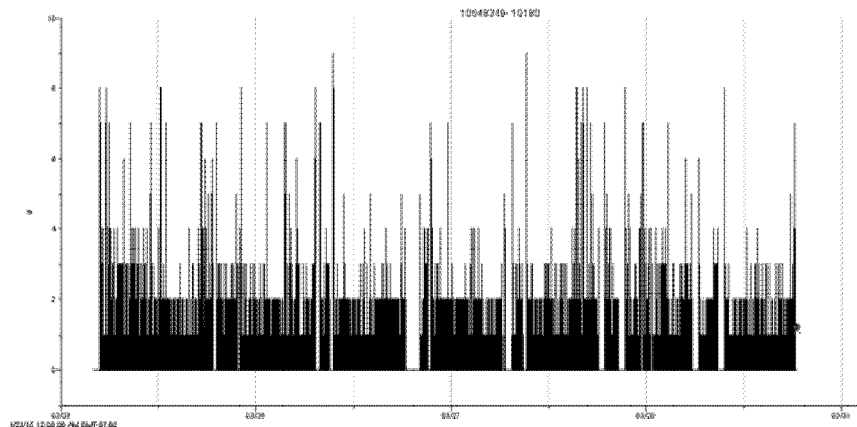
Step 5- Trim the wire to your desired length.



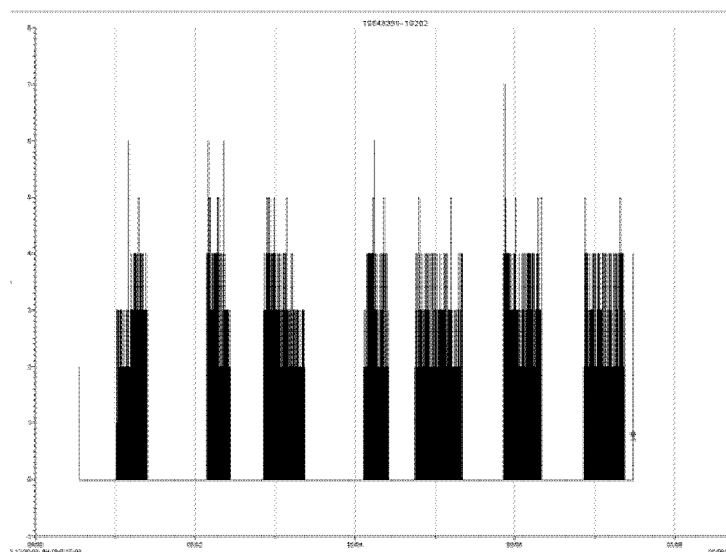
Part II: Common Problems: A Trouble-Shooting Guide for Remote Radio-Telemetry Data Logger Units

What HOBOTM Files Should Look Like

Before we dive into potential problems with the data-logging units, let's take a look at what the raw data should look like so that you can recognize when there might be a problem with the unit. Data are graphed in HOBOWare® by date/time on the x-axis and by counts on the y-axis. Counts greater than 0 indicate the female was present at the den. Ideally, raw data should look something like this:



Or like this:



What HOBOWare® Files Should Look Like (Cont.)

Note that in the first example, it is early in the season so the fisher is spending most of the time at the den. The second example is later in the season.

It doesn't matter how tall the spikes in the data are, or that the spikes are different heights. The spikes can be thought of as relative signal strength, but what really matters is whether the "count" is zero or a number higher than zero.

When you look at these two examples, you can see that the "presence" blocks are relatively solid when you look at them below the 1 on the y-axis. There might be a few small gaps early in the denning season, and typically there will be large gaps later in the season.

Note: Sometimes HOBOWare® has errors when plotting the data, and a line will appear above the 1 on the y-axis but not below it. Don't worry about this error, the data is still there.

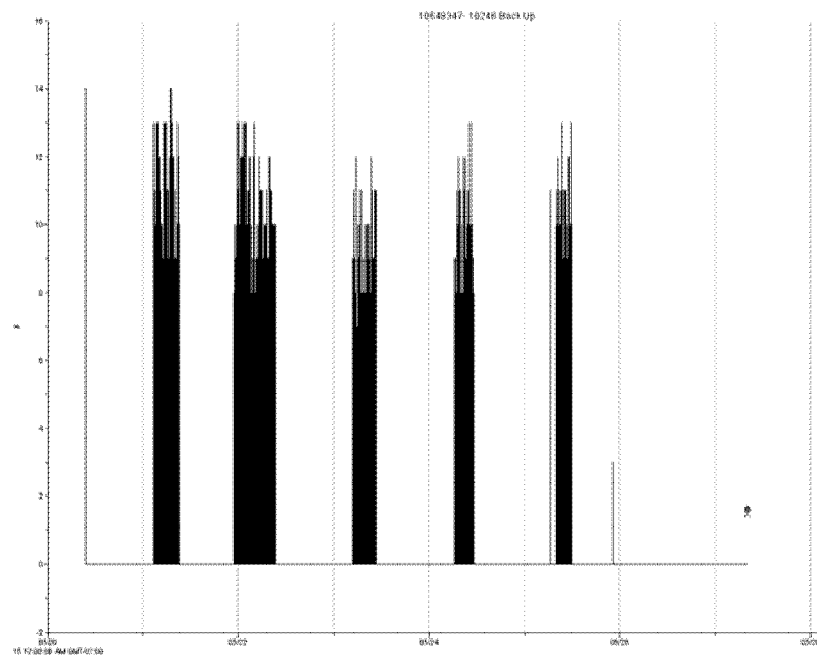
You might have a problem with your data logger if:

- The data is blank with all counts equaling zero.
- The data is mostly blank with just a few black lines here and there, or the data looks sporadic and shows no obvious patterns.
- There are a lot of gaps in the dataset. This might not be totally apparent until you zoom in on the data a bit. A few gaps here and there are normal, but a lot of gaps lasting 10+ minutes could indicate a problem.
- The data looks like the first graph, but it is late in the season and you wouldn't expect the fisher to spend the majority of her time at the den.

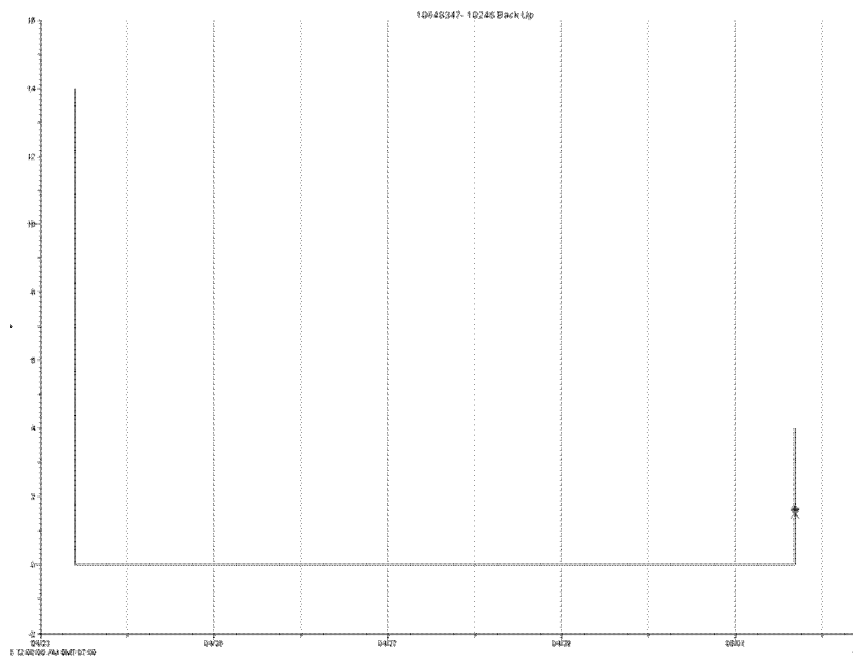
This guide will walk through each of these examples plus a few more, and how to fix them.

Problem: The file is blank (or partially blank) but the fisher is definitely still using the tree.

Data files will look like:



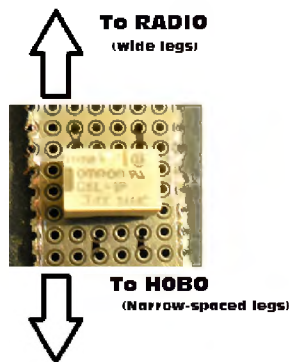
Or like:



Problem: The file is blank (or partially blank) but the fisher is definitely still using the tree. (Cont.)

Let's start out with an obvious potential problem:

- 1) **Did the 12V battery fail prematurely**, or is there potential that someone accidentally swapped the battery with a dead one? It's easy to make this mistake when you're carrying around several batteries in a vehicle.
 - a. If the battery was dead to begin with, the data file will be totally blank. There will be no spike (a single count above zero) at the beginning of the file, when someone plugged the radio in to the new battery.
 - b. If the battery died prematurely, there will be data and then it will suddenly stop, as in the first graph pictured. Often a failing battery can leave a weird pattern in the data (slowly declining spikes, or conversely, sharply rising spikes due to the squelch opening up) before it goes blank.
 - i. Note: This funky pattern only occurs if the animal is present while the battery is failing.
 - ii. *Always look at the screen of the radio when you go to check it in the field.* If the screen is off, the 12V battery failed, and this needs to be noted so the dataset can be cropped to the last known signal.
- 2) If the file is totally blank...
 - a. **Check the direction that the relay is plugged in.** The jacks are identical and will fit both the radio and the HOBO® logger, but there is only one correct way to arrange it:



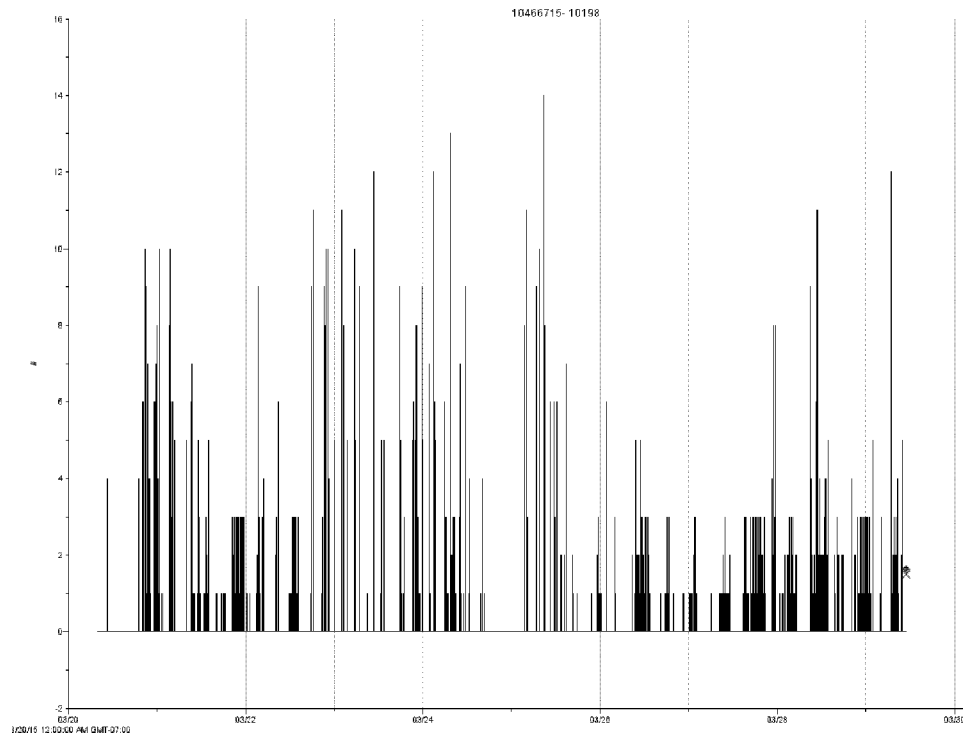
If the relay is plugged in correctly, and you tune the radio to the National Weather Service Station (or a collar with you), you should be able to hear some noise coming from the white relay when you put your ear up to it. If the plug-in is reversed, there will be no noise.

Problem: The file is blank (or partially blank) but the fisher is definitely still using the tree. (Cont.)

- b. **Check the battery connections.** Sometimes the wires in the battery spades become loose and don't make a solid connection.
 - i. Plug in the radio, turn it on, and move the radio around quite a bit. If the radio is turning on and off while you do this, it's probably a bad battery connection.
 - ii. Identify which connection it is by tugging on the wires at the battery terminal one at a time to see which wire triggers the radio to shut off. Clip off the bad spade, strip the end of the wire, and crimp on a new spade. It helps to make a better connection when you double up the wire inside of the spade.
- c. **Check that the frequency in the radio is correct.** It's easy to accidentally push a button and change the frequency (or the frequency mode). Prevent this by holding down the pound key: this will lock the radio buttons.
- d. **Check the "Beep" mode setting.** Some of the radios have a glitch in the software: if the "Beep" setting is turned OFF, and a button is pushed on the radio (even the lock button), the radio will stop receiving a signal.
 - i. It's a good idea to test each radio for this glitch before putting them in the field, or to just leave the Beep mode ON for all radios. Leaving beep on will cause some little spikes in the dataset whenever someone maintains the radio in the field, but it should be obvious what the spikes are and won't get confused with "presence" data.

Problem: The file is mostly blank and seems to be picking up the radio-collar only some of the time.

The file will look like this:



- 1) **Check the antenna.** Is it completely screwed on? Did the wire fall out?
- 2) **Check the relay jack connection.** The most likely culprit of this gappy data problem is a worn connection/ a short in the headphone jack that plugs into the radio. This wire can get stressed when it's bent frequently or for long periods of time. It can also be difficult to solder a headphone jack connection, so it's best to use pre-soldered jacks.
 - a. Tune the radio to the weather station or a known collar. While listening to the relay, pinch and move the wire around at the base of the headphone jack connection.
 - i. If at some point while you are moving the wire around, the ticking or noise from the relay stops, this means the connection is bad. You'll need to replace the cable & headphone jack (refer to the building manual).
 - ii. If this doesn't produce any results, move around the cable at the base of the relay. There could be a short on this end, too.

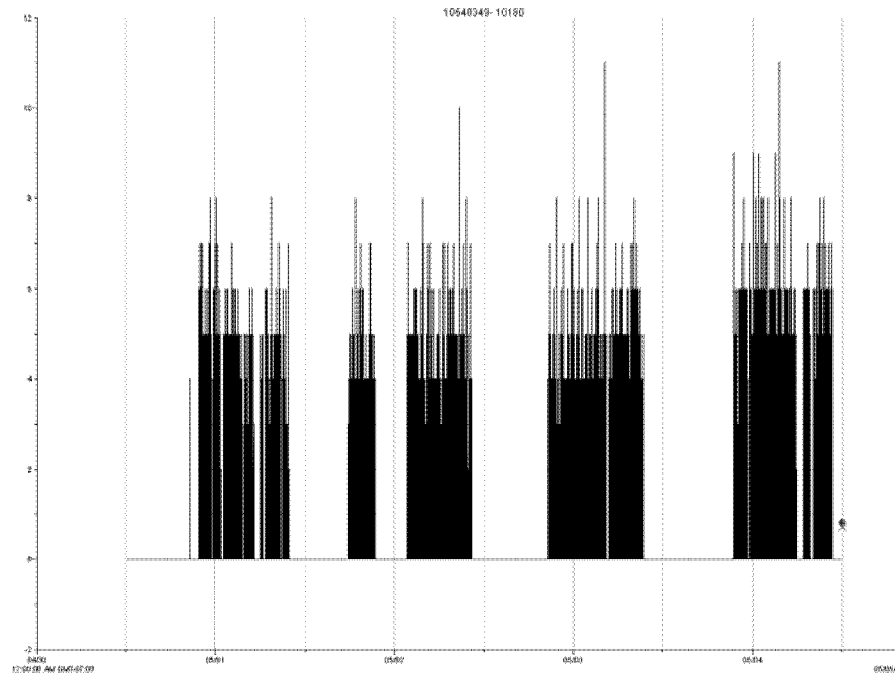
- iii. You can also connect the HOBOTM end jack to a battery tester to see if the electrical pulses are transferring all the way through the relay set-up.
- 3) **Try turning the volume knob up.** Generally I try to keep the volume low on the radios, because increasing the volume on the radio makes the ticking from the relay louder, which might increase the chance of a bear finding the unit. However, it is possible that when the volume is very low, the electrical signal put through the speaker/headphone jack of the radio might not be strong enough to trigger a response from the relay.
 - a. Note: turning the volume up very high may also drain the 12V battery sooner.
- 4) **Try placing the unit in a different spot.** It's best to place the unit on the same side as the cavity and slightly out from the base of the tree.
 - a. Sometimes the signal gets blocked by the den tree itself. This tends to happen with larger DBH trees and high cavities.
 - i. For example, one den tree in Hoopa was a 70" DBH Douglas fir, ~150 feet tall with the cavity located in the far upper reaches of the tree. When the data logger was placed near the base of the tree, it was not getting a consistent signal. However, when the data-logger was moved to the opposite slope of the draw (~40m from the base of the tree, but higher up and in direct line of sight from the cavity), it was able to pick up clear signals.
 - b. Keep in mind that moving the data logger too far away from the tree might skew where the unit is picking up the signal when the animal is on the ground & leaving or returning.
- 5) **Verify that the fisher didn't move to a nearby tree.** If the data was solid, and then becomes gappy within the same dataset, this might be the problem.
 - a. The range of the units is not exclusively limited to 30-40 meters. This is generally the range when an animal is on the ground. However, if an animal moves to a tree that is nearby, it is possible for the data logger to still pick up the signal, especially if the cavity is up high.
 - i. In Hoopa, we have had successive dens that were only ~100 meters apart and the data-logger did not pick up the signal when the fisher moved. However, we have also had dens that were ~100 meters apart where the data logger continued to pick up a signal (some of the time) after the fisher moved. In these cases, dens were

generally line-of-sight (not blocked by major topographic changes) and the cavity of the new den was high.

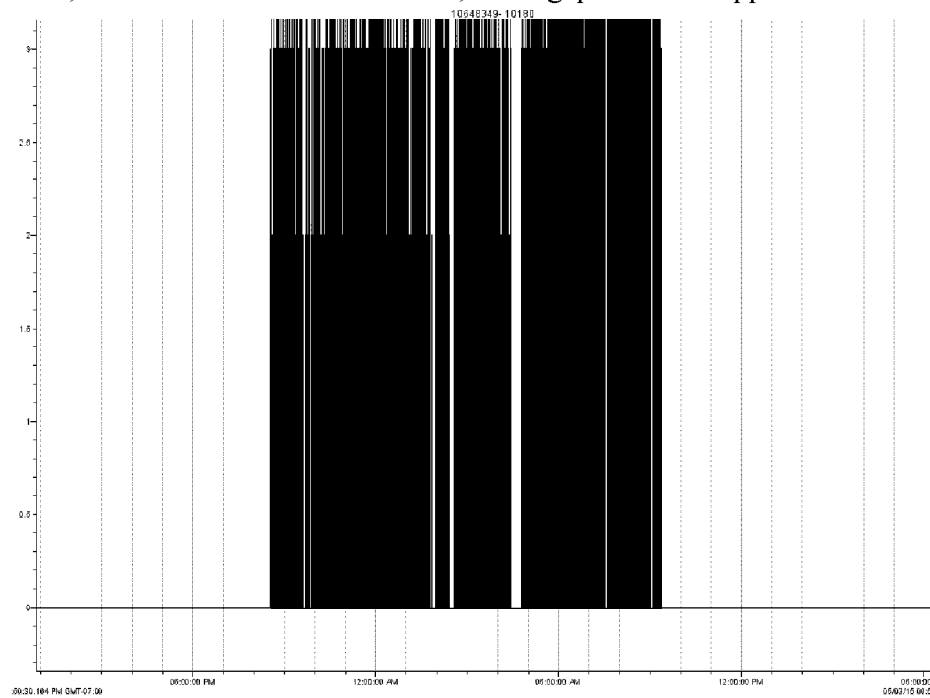
- 6) **If all of the above fails, swap out the radio.** Some of the radios are glitchy and just don't function the way that they are supposed to. One radio that we purchased for the Hoopa project, for example, only picks up the signal every other pulse of the collar.
- 7) **One last thing you can try (hasn't been verified to fix anything)...** I've noticed that sometimes the radios don't seem to receive a signal as well after a button has been pushed on the radio. In fact, some radios have a known glitch where if the "beep" setting is turned off, they stop receiving signals altogether once a button has been pushed. It's generally a good idea to turn the radio off and then on again after you've pushed any buttons and are ready to leave the radio in the field.

Problem: The dataset is mostly solid but has multiple unrealistic gaps.

The file will look like this:



Same dataset, zoomed into the third column; more gaps become apparent:



Problem: The dataset is mostly solid but has multiple unrealistic gaps. (Cont.)

Some of these gaps are okay and are to be expected. Looking at the 2nd, zoomed in graph, most of these gaps are very small (5 minutes or less). The larger gap in the second graph is about 20 minutes and is more questionable.

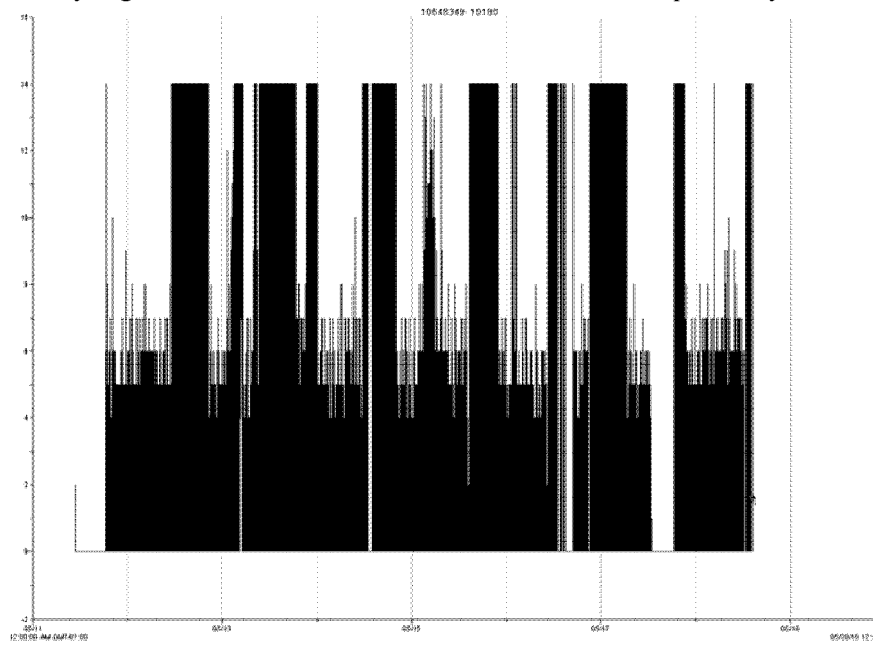
Could the fisher have been gone for 20 minutes and come back? Sure. But when you look at the first column of the first graph and when you look at the other gaps in the dataset, it's pretty apparent that the data logger is just failing to pick up the signal some of the time while the female is present. It seems highly unlikely that the female left her den briefly 10 times throughout the day.

To figure out whether it's a problem with the unit, or if the female is genuinely absent, just look at the patterns in the data. Are multiple days gappy? How many gaps are there in each "column" of data? How have previous datasets at this same tree looked?

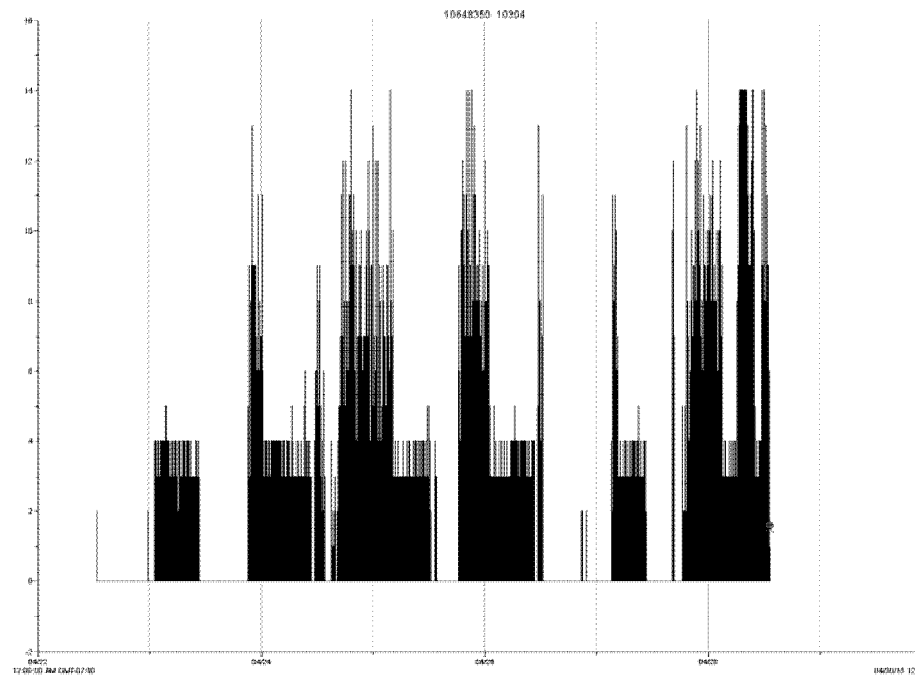
- If there's only a gap like this once or twice throughout the whole dataset, it's probably fine and those are probably genuine absences.
- If there are multiple gaps in a single "presence block" and it seems unlikely that a fisher is coming and going from her den that frequently, it's probably a problem with the unit.
 - Look at the previous section for potential solutions to the gaps (pages 7-9).

Problem: The dataset shows her being at the den most of the time, but it's late in the season and she shouldn't be there so often. **OR:** The data shows her as being present during a time when an observer was present at the den and knew for a fact she was not there.

This is definitely a glitch in the radio software. Your data will probably look like this:

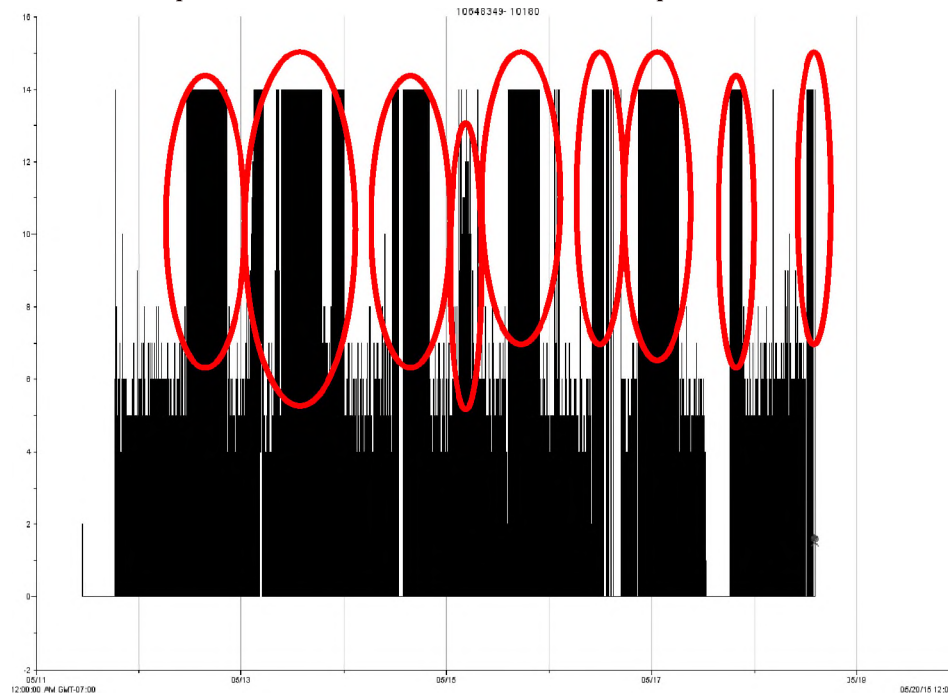


Or like this:



Problem: The dataset shows her being at the den most of the time, but it's late in the season and she shouldn't be there so often. **OR:** The data shows her as being present during a time when I was present at the den and knew for a fact she was not there. (Cont.)

Your first cue to the problem should be these random tall spikes in the data:

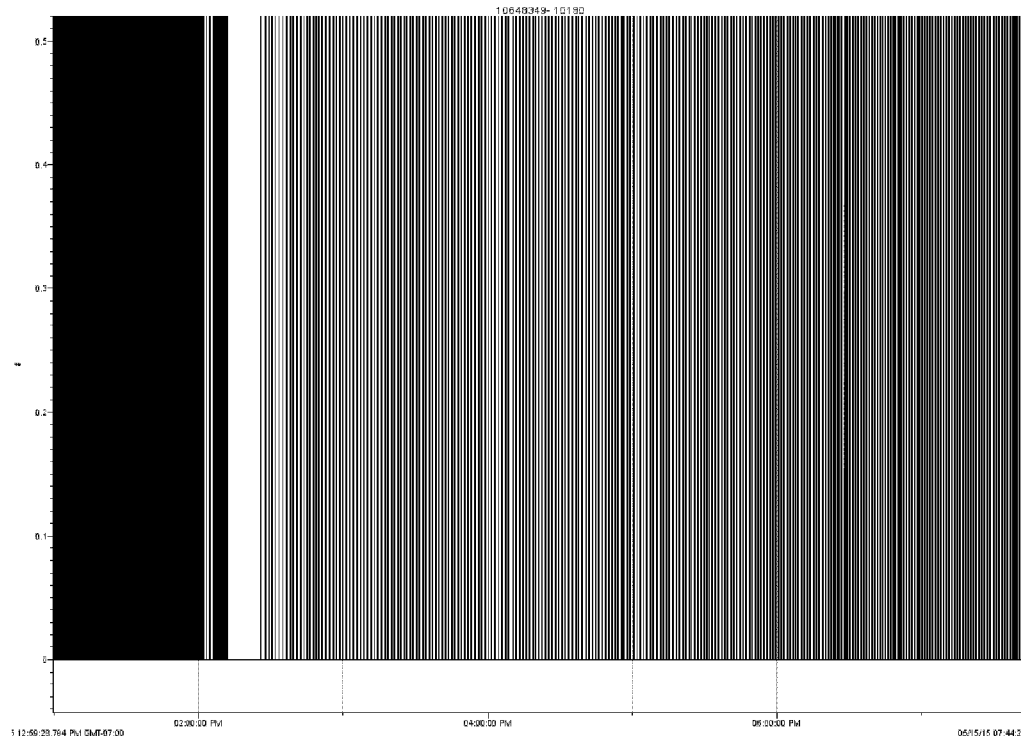


Note that these spikes do not have to be present for this glitch to be present. They won't be apparent if your dataset generally has high count values when the fisher is present.

What you really need to do to find this glitch is zoom in on the dataset (~6 clicks zoomed in on a desktop PC). Continue onto the next page...

Problem: The dataset shows her being at the den most of the time, but it's late in the season and she shouldn't be there so often. **OR:** The data shows her as being present during a time when I was present at the den and knew for a fact she was not there. (Cont.)

This is the same dataset, zoomed in:



You'll see that those tall spikes are not actually solid at all. On the left side of this graph is data when a fisher is truly present at the den. After she leaves, the data shows pulses, but they start off slowly and become more rapid as time goes on. Rarely do they ever reach the same pulse rate as a fisher collar, so most of this data is actually salvageable.

This occurs because of a glitch in the radio software. When the "Battery save mode" is turned on (any number displays in the settings), some of the radios start opening up the squelch in pulses while the battery save mode is running. When the squelch opens all the way (Squelch=0), the radio picks up only static, and that static noise triggers the relay & data logger.

The solution: Turn the **battery save mode OFF**. The bad news is that the battery might drain in as few as 5 days with the save mode turned off. *Note:* This static pulsing problem may not be apparent at the first dens of the season: the problem cropped up for us in mid-April.

Problem: When I press a button, the radio stops receiving any signals.

This problem is caused by a glitch in the radio software.

The solution: Turn the **“Beep” mode ON**. You can also turn the radio off then on again before leaving (lock the screen before you turn the radio off/on, though). But it’s more fool-proof to leave the setting turn on, and leaving it on isn’t going to mess up the data.

Problem: The radio won’t turn on even though it’s connected to a new 12V battery.

This could be caused by one of two things: the battery connection is bad, or the voltage regulator chip is blown.

- 1) **Check your battery connections first.** With the radio turned on, move each battery connection wire independently to see if the screen flashes on at any point. If it does, clip the bad spade off and replace it.
 - a. If the wires seem well connected at the spades, check the connections at the voltage regulator chip by flexing them a bit. If the screen flashes on, it’s one of the connections on the chip end that will need to be re-soldered (shrink wrap can be easily cut off and out of the way).
 - b. If the screen doesn’t flash, it’s the voltage regular chip that is the problem. Move onto step 2.
- 2) **Replace the voltage regular chip.** You can use the same wires that are already attached. Just solder them to a new regulator chip by following the unit construction manual.

Appendix B. Total numbers of unique den trees where fisher den attendance data were recorded in the three study regions, by tree type and by species. Species are listed from most in descending order of prevalence. Data were collected March-June 2014 and March-June 2015, California, USA.

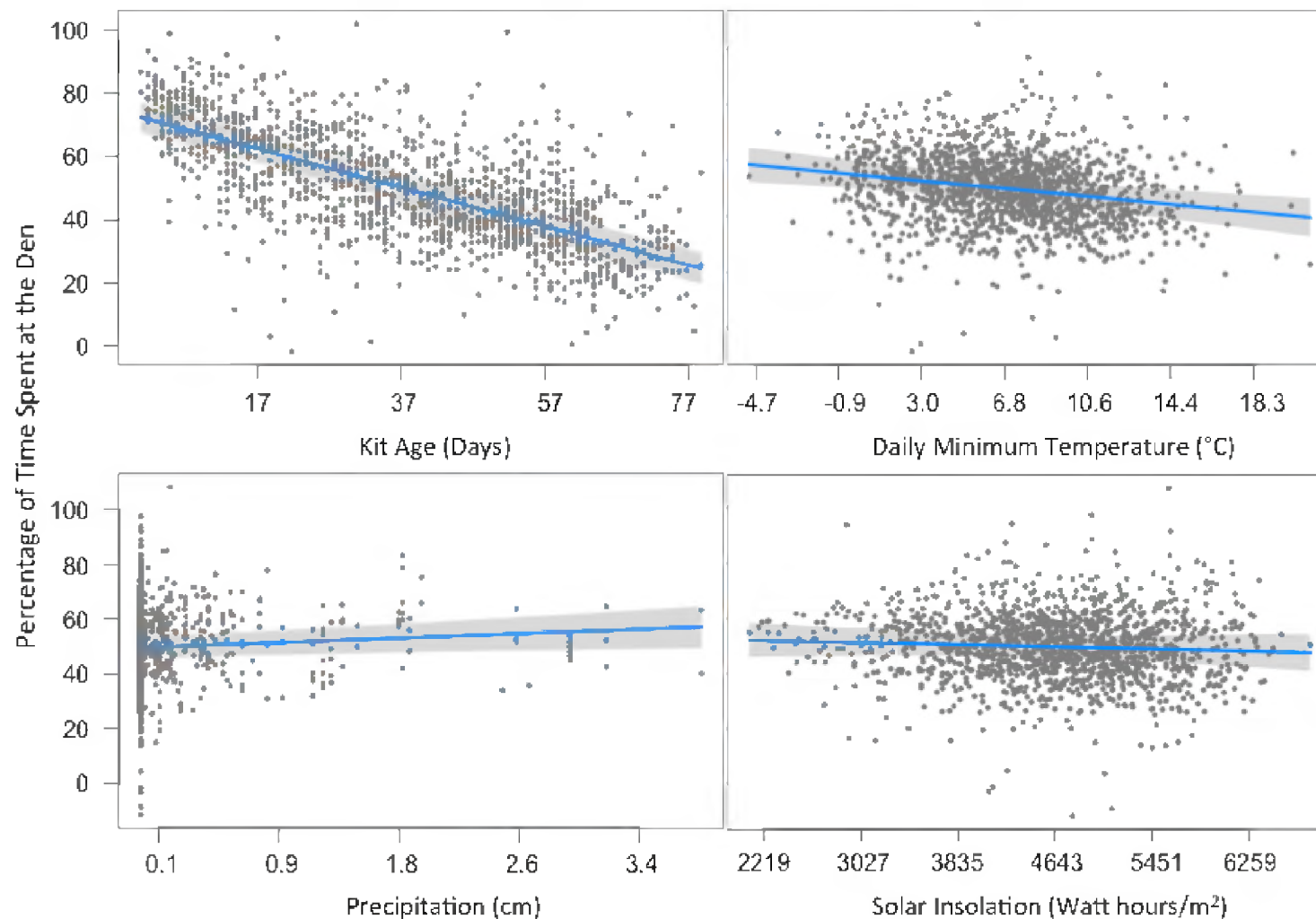
Tree Type and/or Species	HVIR ^a	Stirling ^b	S. Sierra ^c
Live Trees	37	16	14
Tanoak (<i>Lithocarpus densiflorus</i>)	26	-	-
Black oak (<i>Quercus velutina</i>)	1	13	7
Douglas fir (<i>Pseudotsuga menziesii</i>)	5	1	-
Chinquapin (<i>Chrysolepis chrysophylla</i>)	4	-	-
White fir (<i>Abies concolor</i>)	-	-	4
Incense cedar (<i>Calocedrus decurrens</i>)	-	1	2
Sugar pine (<i>Pinus lambertiana</i>)	-	1	-
Red alder (<i>Alnus rubra</i>)	1	-	-
White alder (<i>Alnus rhombifolia</i>)	-	-	1
Snags	10	6	5
Douglas fir (<i>Pseudotsuga menziesii</i>)	6	1	-
White fir (<i>Abies concolor</i>)	-	-	4
Incense cedar (<i>Calocedrus decurrens</i>)	-	3	-
Tanoak (<i>Lithocarpus densiflorus</i>)	2	-	-
Unknown conifer species	-	2	-
Black oak (<i>Quercus velutina</i>)	-	-	1
Port Orford cedar (<i>Chamaecyparis lawsoniana</i>)	1	-	-
Sugar pine (<i>Pinus lambertiana</i>)	1	-	-
Total Unique Trees	47	22	19
Total Females Monitored	15	11	10

^a Hoopa Valley Indian Reservation

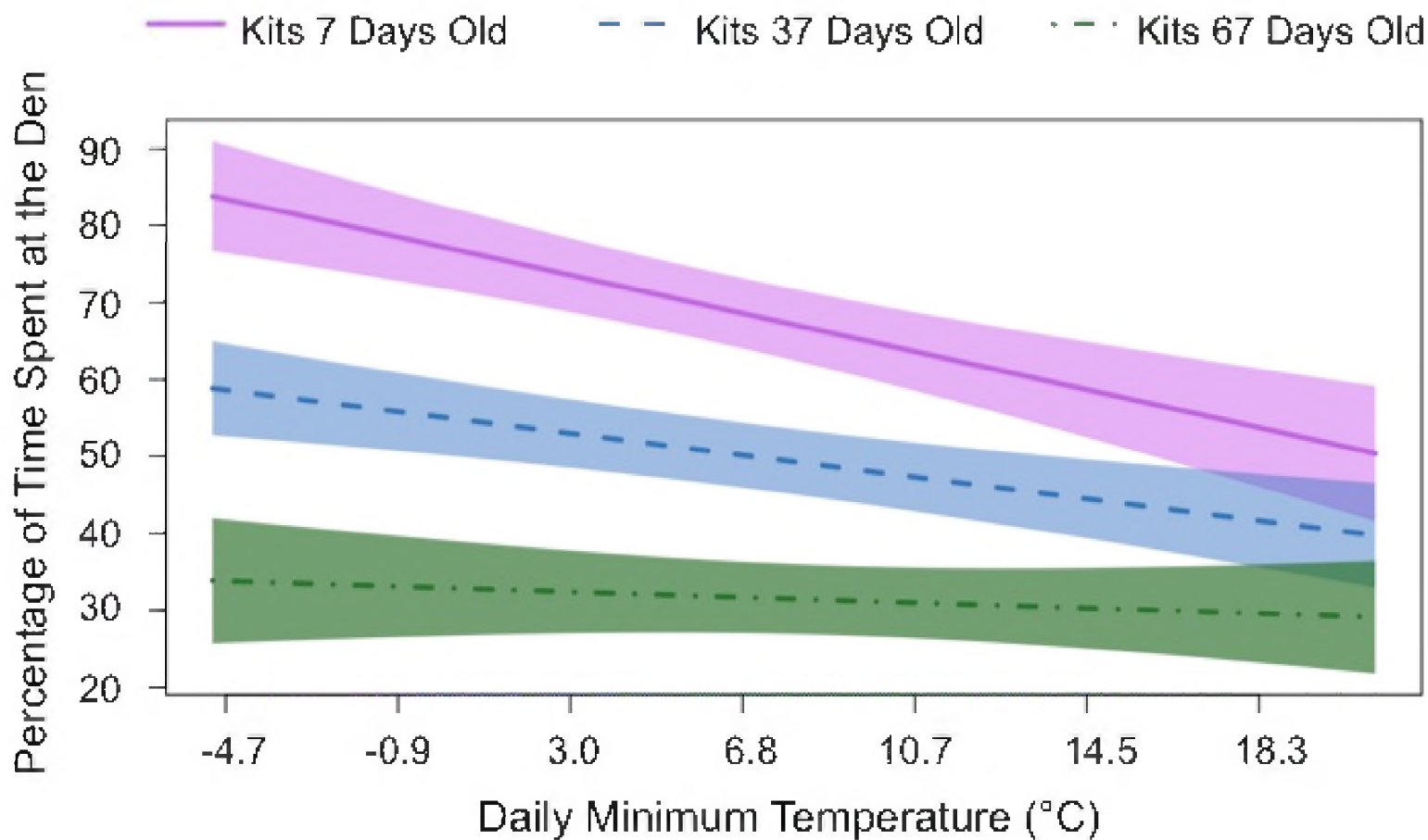
^b Stirling Fisher Project Team, unpublished data; do not cite without permission

^c USDA Forest Service Pacific Southwest Research Station, unpublished data; do not cite without permission

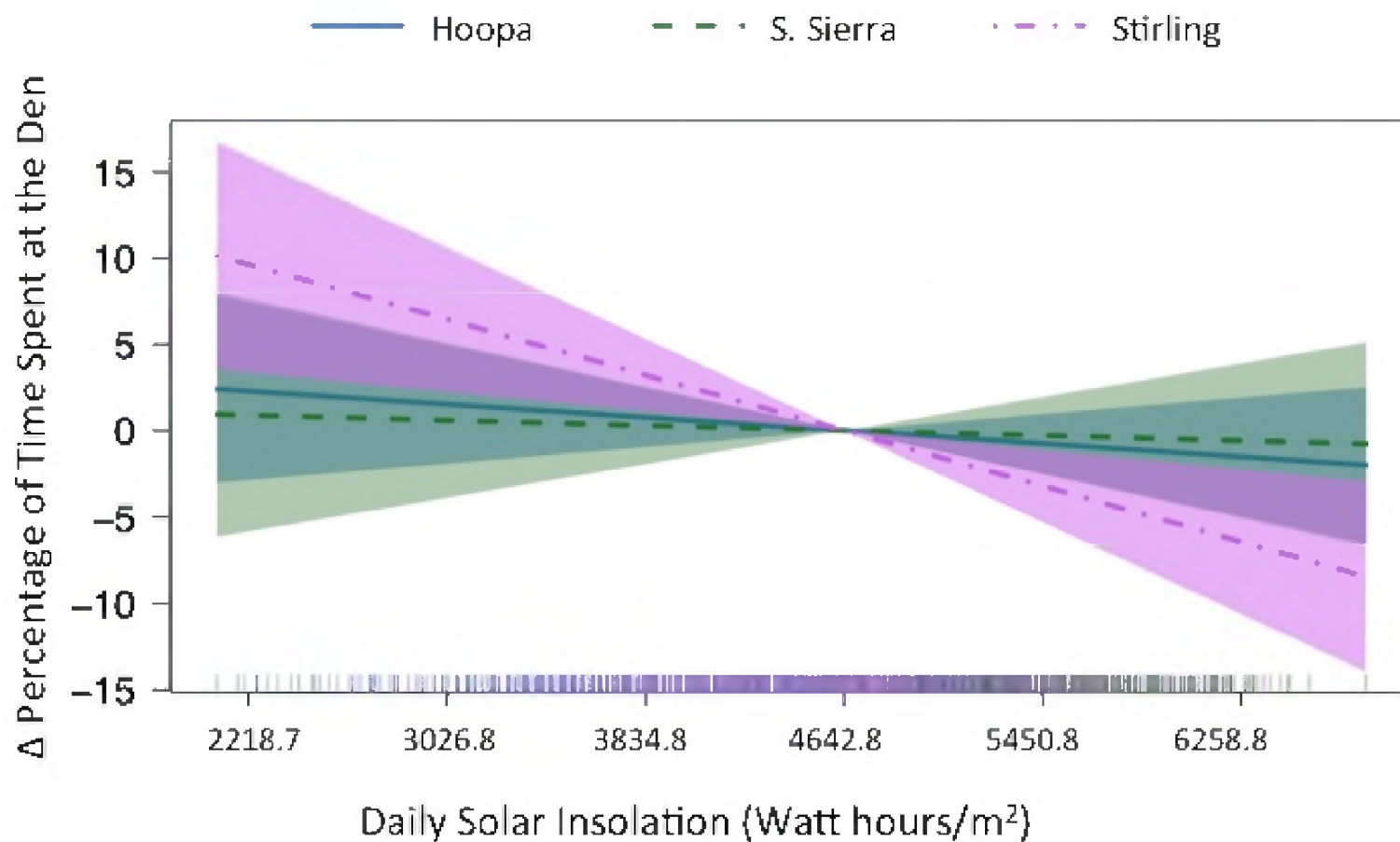
Appendix C. Effects of numerical predictor variables on fisher den attendance. Shading represents 95% confidence bands. Regressions were fit using the highest-ranking model, using median values of all other predictor variables.



Appendix D. Interaction term between minimum temperature and kit age, showing the change in percentage of time spent at the den as a function of daily minimum temperature and number of days since parturition. Shading represents 95% confidence bands. Regressions were fit using the highest-ranking model, using median values of all other predictor variables.



Appendix E. Interaction term between solar insolation and study site, showing the change in percentage of time spent at the den as a function of solar insolation for each study area. Shading represents 95% confidence bands. Regressions were fit using the highest-ranking model, using median values of all other predictor variables.



Appendix F. Timing of excursions away from the den longer than 30 minutes, as a function of kit age. Data were collected March-June 2015 in California, USA.

