

**Den, rest site, and movement characteristics of
Pacific fisher (*Pekania pennanti*) in the southern Oregon Cascades**

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Executive Summary

Fishers (*Pekania pennanti*) are a forest-obligate mesocarnivore of conservation concern in the western United States. Human activities resulting in direct mortality or the degradation of suitable habitat led to the extirpation of fisher throughout much of their historic range. In an effort to control porcupine (*Erethizon dorsatum*) damage to forest plantations, 41 fishers were reintroduced to the Cascade Mountains near Klamath Falls, Oregon between 1961 and 1981. A population descending from these reintroductions persists on the Klamath Plateau in the southern Oregon Cascades. The Klamath Plateau is a patch mosaic of federal (Bureau of Land Management and U.S. Forest Service), state, and private lands (primarily managed for timber production). We partnered with the Medford and Lakeview Oregon BLM Districts to better understand fisher ecology and habitat elements, including space use, movement, and rest and den characteristics, in a mosaic of management objectives and intensities.

Our first goal was to evaluate space use characteristics and minimum number of individuals. We captured 16 fishers (8 females, 8 males) on 65 occasions and evaluated home ranges for 8 individuals with enough data (4 females, 4 males). Fisher home range sizes were similar to the previous study in southern Oregon Cascades and comparable to studies in British Columbia and Idaho with animals of similar body size. On average, females and male ranges in southern Oregon were 25 and 63 km² respectively during the non-breeding season, as calculated with 95% fixed-kernel estimates.

Estimated core areas were 8 and 23 km² for females and males, respectively. Home range overlap (18%) was similar to fisher research in northern California. In addition to our 16 captured fishers, we identified 10 additional individuals genetically from non-invasive hair snares. We identified 19 kits, of which 12 lived past July of their birth year, but we were not able to verify individual kits with captures or hair snares. As such, we identified 31-41 individuals: 16 captures, 10 hair identified animals which could also include any number of the 15 kits. Only 13 individuals were detected more than one year, and we presume those animals were residents.

These data combined with recent distribution survey data highlight that the persisting fisher population in the southern Oregon Cascades does not appear to be expanding since the initial reintroductions in 1961. Identifying factors limiting the expansion of this population would be prudent for regional fisher conservation.

Secondly, we documented movement behavior and report observed vegetation associations from presumed foraging locations. We summarize GPS data from 9 individuals (4 females, 5 males). During October 2015-August 2018, we obtained 61,147 high-quality locations (67% fix success overall, 70% not including denning season female data). Fisher traveled approximately 5.6-7.4 km on average daily with no significant differences between male and female daily movement distances. On average, females moved less than males. Female fishers moved longer distances daily during summer compared to fall. Males moved more variably on average during breeding periods (March-May, n=3), likely due to more extreme fluctuations in daily activity exemplified with very long distance movements (e.g., >30 km/day) followed by days with little to no activity, likely while attending female den sites waiting for an opportunity to breed. Maximum speeds were 99 and 148 meters/minute for females and males respectively. Our data suggest fishers, like martens (*Martes caurina*) and wolverines (*Gulo gulo*), are poly-phasic, moving in periods throughout the day punctuated by >1 resting bouts. Such consistent

daily movement patterns may be attributed to tasks like foraging and marking their territory perimeter. Such movements also may increase predation risk, which may be reduced in familiar areas or in locations with sufficient escape cover.

Fishers tended to travel in stands >107 years old and in stands with >60% canopy cover as estimated from Gradient Nearest Neighbor (GNN; 2012) maps. Fisher locations were in areas with an average (\pm standard deviation) of $67\% \pm 14\%$ and $62\% \pm 15\%$ canopy cover for females and males, respectively. Dominant forest age, or the predicted stand age classification from remote sensing and extrapolation, differed between some individuals (i.e., M09T), and there was no difference in estimated stand age between sexes. Fisher locations were on average (\pm SD) in stands 129 ± 40 years and 127 ± 48 years for females and males, respectively.

With modeled habitat associations, fisher use showed a positive response to canopy cover and dominant stand age and a negative response to the interaction between canopy cover and stand age, although there was little support for the interaction term and the influence of sex in the model. We interpreted the negative response to the interaction as a potential avoidance of thinned stands, potentially similar to movement characteristics by Pacific martens (*Martes caurina*). Vegetation associations likely fulfill daily and annual requirements such as access to resting or denning structures, foraging opportunities, and areas of predation avoidance.

Third, we quantified rest and den structures as well as microsites. We evaluated reproductive chronology (e.g., when fishers initiated denning) and also collected pilot data on female movements before and after parturition. From our captured 16 fishers (8 female, 8 male), we radio- tracked 13 adults (6 females and 7 males) between October 2015 and August 2018 with the goal of collecting rest and den data. We located 146 unique rest structures, 86 and 61 used by females and males, respectively.

Females used a wider variety of rest and den structure types than males. Rest and den structures were live and dead trees, and a log. Sizes ranged from 21 to 211 cm diameter at breast height (DBH). Overall, den and maternal rest sites were located in the largest structures (DBH 102 ± 22 cm, \pm SD), followed by female rest sites (97 ± 33 cm DBH) and male rest sites (90 ± 47 cm DBH). Most rest microsites (77%) were cavities or mistletoe brooms.

Although preliminary, we used a novel method to identify suspected rest zones and structures with a subset of our GPS collar data (2015-2017) and simple clustering algorithms. We tested our GPS data and derived suspected resting locations with remote cameras. With this methodology, we identified 566 unique rest zones, or forest patches that we suspected fishers to be using for resting. Remote cameras within these suspected rest zones documented fisher use, verifying our assumption that GPS clustering algorithms could be used to identify resting areas. We observed a reuse rate of 46% for the suspected rest zones estimated from GPS data collected after the suspected rest zones were initially identified, but cameras observed fishers using structures in these suspected rest zones more frequently (near 100%, but these data are in progress). Based on an extrapolation from the short period of time GPS data was collected (16-184 days), we estimate fishers in this population may use 234-557 unique rest structures per individual per year.

We documented 29 den and maternal rest structures. Female dens were restricted to arboreal structures with cavities until kits were weaned and semi-mobile, then females were documented also using ground based maternal rest structures (i.e., slash piles, logs). Den initiation, on average, was 25 March and our observed average litter size was 2.1. Females used $2.18 (\pm 0.87)$

dens/season prior to weaning kits, spending an average of 33 (\pm 17) days at natal dens and 17 (\pm 13) days at maternal dens.

The average distance traveled within a 24-hour period by denning females (n=2, 2018) did not differ from the non-denning periods; nonetheless, there appeared to be a slight difference over time. Females traveled slightly lower daily distances within the first week after giving birth and increased their average minimum daily travel distance throughout the denning season. These movement differences were not significant and had high variability, likely due to our low sample size. During denning, minimum daily distances traveled ranged from 45 to 20,325 meters. These preliminary results are the first to document female fisher movement during denning season. These data suggest denning females have a high daily movement capacity, similar to capacity during non-denning periods. During the denning season female fishers may use their entire home range, and may need to do so likely due to a high quantity of food resources required during this energetically expensive phase.

We provide a wealth of information from a relatively small sample of adult fishers in the southern Cascades of Oregon, including data from a native female that presumably emigrated from the population east of Interstate 5. In addition to the descriptions within, a movement model correlating activity with vegetation data is being produced. Other products not pursued include using these movement data to define potential corridors and used corridor widths. A potentially critical missing element of this study, requiring additional effort, was the observation of fecund adult females (2-3 kits/individual/season), but a lack of juvenile fisher captures and observations elsewhere. Barry (2018) identified extraordinarily low population growth and we speculate low juvenile survival could be a limiting factor. Monitoring the population, ideally with the ability to describe age-specific survival and causes of mortality would benefit our understanding of fisher ecology for reintroduced fishers in the Cascade Mountains.

Acknowledgements

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Background

Fishers (*Pekania pennanti*) are a forest-associated carnivore in the weasel (Mustelidae) family. In Oregon, basic information on fisher space use, habitat associations, movement, resting, and denning locations is lacking (but see Aubry and Raley 2006, Aubry et al. 2018a). We aimed to quantify movement characteristics and space use, report the types and sizes of structures used for resting and denning, and provide a platform for future research by describing aspects of fisher natural history with novel technology (miniature GPS collars).

In the Pacific states, fishers formerly resided throughout the Cascade Range and coastal mountains and within the western slopes of the Sierra Nevada Range (Powell 1993). A likely combination of trapping for fur during the early twentieth century, predator and pest control campaigns, and forest management practices resulted in population declines and range contractions across the distribution; Pacific fishers currently occupy approximately 21% of their former range (Lofroth et al. 2010). Fishers were considered extirpated in Washington until recent reintroduction efforts (Lewis et al. 2016). In Oregon, the indigenous fisher population has been reduced to a single remnant population in the Klamath Mountains in extreme southwest Oregon (Aubry and Lewis 2003). A reintroduction effort led by the Oregon Department of Fish and Wildlife from 1961-1981 established a reintroduced population in the southern Cascades with fishers sourced from British Columbia and Minnesota. The introduced populations have been genetically isolated from the smaller indigenous populations for over 40 years (Aubry and Lewis 2003). Lastly, in California fishers occupy less than 50% of their historic range in two isolated populations separated by over 500 km (Zielinski et al. 1995, Zielinski 2013). Consequently, and in light of current threats, the U.S. Fish and Wildlife Service proposed the distinct population segment historically occurring in Washington, Oregon, and California be listed as threatened under the U.S. Endangered Species Act in 2014 (USFWS 2014). Conservation efforts such as reintroductions (Lewis 2006, Lewis 2013), translocations (Facka 2016), and habitat restoration are ongoing in these states. The listing decision was withdrawn during 2016 (US Fish and Wildlife Service 2016). In 2018, litigation resulted in a court order vacating the withdrawal and remanding the decision to the Service for additional analysis. A revised listing decision is expected in fall of 2019.

It is suspected that timber harvests (e.g., Zielinski 2013), large severe fires, and rodenticides and toxicants (e.g., Gabriel et al. 2015) continue to threaten fisher populations in the Pacific states by means of habitat fragmentation, reductions in large patches of older or suitable forest, and changes in forest structure thought to be unsuitable for fisher reproduction, or reductions of individual fitness (Lofroth et al. 2010). Fishers have been described as being among the most habitat-specialized mammals in North America (Harris et al. 1982). In the Pacific states and British Columbia, Canada, fisher habitat has been described as late-successional, structurally-complex, mixed-conifer and conifer-hardwood forests with dense forest cover (Lofroth et al. 2010, Lofroth et al. 2011). Fishers use large trees and snags for resting and denning sites that provide protection from unfavorable weather and predators (Powell 1993, Zielinski et al. 2004, Purcell et al. 2009, Weir et al. 2012). It has been suggested that fishers in the West are not dependent on late-successional forests, but require closed-canopy forest with adequate prey populations and suitable structural elements associated with older forests for resting and denning (Jones and Garton 1994, Klug Jr 1997, Lewis et al. 2016).

Such discrepancies in stand use and gaps in our knowledge of fisher requirements and population ecology in the West present challenges for western forest managers, especially in Oregon where the only prior published research on fishers has been on an introduced population with larger-

bodied individuals that may behave differently compared with the smaller native individuals (Aubry and Lewis 2003, Aubry and Raley 2006, Aubry et al. 2018b). Our project objectives included: (1) Estimating the approximate size, configuration, and overlap of fisher's home ranges within the study area; (2) Describing the locations and habitat characteristics of denning and resting sites; and (3) Evaluating how fishers are moving in a mosaic of mixed forest management intensities. An additional objective added opportunistically part way through the study was to test whether data generated by GPS collars could be used to identify resting locations and structures that had been used and would potentially be re-used.

Study area

We evaluated fisher space use and movement ecology within the southern Oregon Cascade Mountain Range in an area known as the Klamath Plateau for the flat rolling, high elevation terrain (Figure i.1). Here, fishers were released in 1961 from Minnesota and British Columbia, but there was no evidence fishers were present during surveys in the 1980s-2000. Single fisher detections were confirmed in 2006 and 2008, followed by 8 detections obtained in 2013 – all from non-invasive camera and hair-snare surveys (Steve Hayner/Jeff Stephens, Bureau of Land Management, unpublished data). It is unclear whether fishers were residing at low densities or if fishers moved south from a reintroduction location (Barry 2018).

Land ownership in the area is a patchy mosaic of federal lands (Bureau of Land Management and U.S. Forest Service), state lands, and private lands (primarily commercially-owned timberlands). Thus, our study area provided a unique combination of prior fisher monitoring and a variety of forest management practices. Elevations in this mountainous region ranged from 1200-2500 m. Predominant tree species included white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*), red fir (*Abies magnifica*), ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), lodgepole pine (*Pinus contorta*), and incense cedar (*Calocedrus decurrans*). Forest vegetation types included primarily mixed-conifer stands and riparian areas. Unlike other fisher populations in California and southwestern Oregon, hardwoods were largely absent from this study area. Natural openings included perennial meadows and frozen lakes during winter. Winter mean annual snow depth for the study period was 37 cm at the Howard Prairie weather station, located at 1396 m elevation within the study area (Natural Resource Conservation Service, SNOTEL data 2015-2016). Snow persisted from November to May each year in much of the core study area. Mean annual precipitation was 77 cm for 2015 and 2016 (Natural Resource Conservation Service, SNOTEL data). Historic average annual snowfall for the Howard Prairie Dam weather station was 349 cm, and average annual precipitation was 82 cm (Western Regional Climate Center, historic data 1960-2005).

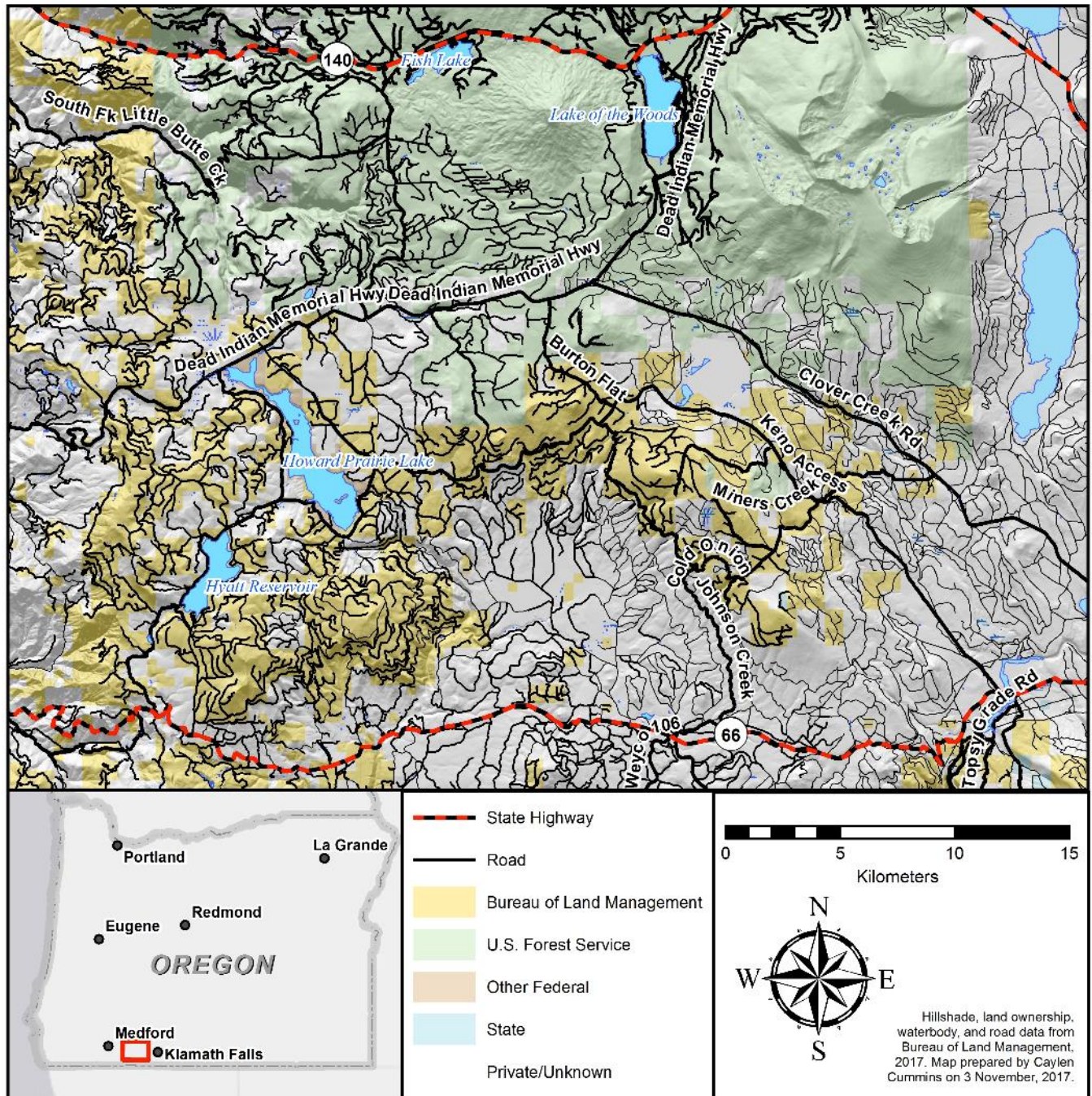


Figure i.1. Study area map. We studied rest, den, and movement ecology of fishers (*Pekania pennanti*) in the southern Oregon Cascade Mountains. The core of the study area fell between Highway 66 to the south and Dead Indian Memorial Highway and Clover Creek Road to the west, north, and east. Several individuals used areas north of the core study area, up to Highway 140.

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Objective 1: Fisher space use (2015-2017)

Introduction

The fisher (*Pekania pennanti*) is a medium-sized, forest-obligate carnivore that was historically distributed across the boreal forests of Canada, the Great Lakes and northeastern regions of the United States, the northern portion of the Rocky Mountains in the United States, and mountainous areas of Washington, Oregon, and California (Powell 1993). The fisher experienced significant population decreases and range contractions throughout North America from the mid-1800s through the mid-1900s due to widespread trapping for fur, broad-scale habitat loss, and warming after the Little Ice Age (Powell 1993, Gibilisco 1994, Lewis and Zielinski 1996, Krohn 2012). Extensive damage to managed timber plantations by porcupines (*Erethizon dorsatum*) in the 1950s prompted a multi-stakeholder collaboration to reintroduce fishers, a predator of porcupines, to the South Umpqua watershed in southwestern Oregon (Stone 1952). Eleven fishers from south-central British Columbia and 13 fishers from northern Minnesota were released north and west of Crater Lake between 1977 and 1981 (Aubry and Lewis 2003). No attempts were made to monitor either the success of the fisher reintroduction or its effects on porcupine populations (Aubry and Lewis 2003).

Aubry and Raley (2006) were the first to conduct a radio telemetry study on the ecology of fishers in the southern Oregon Cascades between 1995 and 2002. The population they studied was the result of the 1977-1981 reintroductions, and their study area was adjacent to the northern portion of our current study area. Objectives of their study included determining den and rest site characteristics, habitat use, home range size, and food habits. Results presented by Aubry and Raley (2006) offer opportunity to make comparisons between the two study periods. An extant population of fishers also exists in the Klamath-Siskiyou portion of southern Oregon and is contiguous with populations in northern California, often referred to as the Northern California-Southern Oregon population (USFWS 2014). Both Aubry and Raley (2006) and our current study, however, were focused exclusively in the southern Oregon Cascades.

On the Klamath Plateau, 11 fishers were released in 1961 from south-central British Columbia. There was no evidence fishers were present during routine federal surveys in the 1980s-2000. Single fisher detections were confirmed in 2006 and 2008, subsequently followed by 8 detections obtained in 2013 – all from non-invasive camera and hair-snare surveys (Steve Hayner/Jeff Stephens, Bureau of Land Management, unpublished data). It is unclear whether fishers were residing at low densities or if fishers moved south from a northern reintroduction location after the mid-2000's (Barry 2018).

Our objective was to describe space use. We estimated the size, configuration, and overlap of fisher home ranges to describe the population in additional detail. We summarized capture rates and minimum number of fishers known to be alive based on combined results. We hypothesized home ranges sizes would be similar to previous estimates by Aubry and Raley (2006), predicting large range sizes could be a consequence of low resource availability. Similarly, we predicted home range overlap would be minimal between same sex individuals unless resources were high, allowing for increased population densities.

Methods

We evaluated fisher space use within the southern Oregon Cascade Mountain Range in an area known as the Klamath Plateau (Figure i.1). Land ownership in the area is patchy mosaic of federal lands (Bureau of Land Management and U.S. Forest Service), state land, and private lands (primarily commercially owned timberlands). Thus, our study area provided a unique combination of prior fisher

monitoring and variable forest management practices. Elevations in this mountainous region ranged from 1200-2500 m. Predominant tree species included white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*), red fir (*Abies magnifica*), ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), lodgepole pine (*Pinus contorta*), and incense cedar (*Calocedrus decurrans*). Forest vegetation types included primarily mixed-conifer stands and riparian areas. Natural openings included perennial meadows and frozen lakes during winter. Winter mean annual snow depth for the study period was 37 cm at the Howard Prairie weather station, located at 1396 m elevation within the study area (Natural Resource Conservation Service, SNOTEL data 2015-2016). Snow persisted from November to May each year in much of the core study area. Mean annual precipitation was 77 cm for 2015 and 2016 (Natural Resource Conservation Service, SNOTEL data 2015-2016). Historic average annual snowfall for the Howard Prairie Dam weather station was 349 cm, and average annual precipitation was 82 cm (Western Regional Climate Center, historic data 1960-2005).

Non-invasive surveys: remote cameras and scent detection teams

Two remote camera survey efforts with hair snare devices for genetic samples occurred between 2013-2018. First, as part of an on-going effort the BLM opportunistically deployed cameras in areas where fishers were presumed present or in areas with potential future timber harvests. Second, Oregon State University and collaborators conducted both landscape scale and fine scale surveys during 2016. Here, we combined genetic data to uniquely identify the minimum number of individuals.

Capture and handling

All necessary permits were obtained for the described study, which complied with all relevant regulations. We captured and processed fishers using methods approved by the USDA Forest Service's Institute for Animal Care and Use Committee (Permit: 2015-003) and Oregon Department of Fish and Wildlife Scientific Take permit (Permits: 034-16, 027-17). All efforts were made to minimize suffering and discomfort during fisher live captures and throughout survey efforts. We followed recommendations by the American Society of Mammalogists (Sikes and the Animal Care and Use Committee of the American Society of Mammalogists 2016) and used capture techniques that minimized spread of potential diseases (Gabriel et al. 2012b). Our capture equipment, techniques, and procedure are described in Appendix A1.1. We collected samples in accordance with protocols for genetics, isotopes, and tissue storage (Appendix A1.1).

We radio collared adult fishers with very high frequency (VHF) transmitters (Advanced Telemetry Systems, Isanti, Minnesota, USA; M1820, 27-31g). All frequencies were approved by the Oregon Department of Fish and Wildlife and did not conflict with neighboring projects. We placed three pieces of reflective banding on the VHF antenna for individual identification with remote cameras. We obtained an estimated location using triangulation at least once a week (Appendix A1.1) and located inactive fishers to their resting or denning location (Appendix A1.2). We collected telemetry data combining triangulations and aerial telemetry for our analysis with the criteria that expected precision of each location was within 200 m of the actual location.

We deployed W500 Wildlink GPS collars (Advanced Telemetry Systems, Isanti, Minnesota, USA; 60-100g) on adult fishers opportunistically. All GPS units were tested to understand expected accuracy within the study area. We used remote downloading features to improve our data collection. Ultra-high frequency (UHF) remote downloading provided an opportunity to obtain data from a fisher while the GPS had additional battery life without capturing the individual. While on free-roaming fishers, the

GPS was programmed to estimate locations every 15 minutes or 30 minutes between attempted location attempts. Average precision was estimated as 21m on high quality locations.

Home range estimates – 95% fixed kernel

To estimate a broad spectrum of the area each fisher used, we used a conservative estimation for home ranges. We used 95% fixed kernel density methods (Worton 1989) to model life-of-monitoring home ranges for all fishers with ≥ 20 GPS locations (Powell 2000, Börger et al. 2006). Such a metric would be comparable with other prior studies using VHF telemetry. Here, we used GPS locations of female fishers collected throughout the year, excluding the denning period from March-early June. Male fishers travel greater distances during the breeding season in search of receptive females (Powell 1993, Aubry and Raley 2006). Thus we estimated male home ranges during the breeding season (1 February – 30 April) and the non-breeding season (1 May through 31 January) following Aubry and Raley (2006). We calculated fixed-kernel home range estimates using an href smoothing parameter with the adehabitatHR package (Calenge 2006) in R version 3.4.1 (R Core Team 2016). We estimated the core area of each fisher home range by computing fixed-kernel isopleths between 5 and 95% at 5% intervals with the adehabitatHR package (Seaman and Powell 1990, Bingham and Noon 1997). We used these isopleths in a regression to identify the home range isopleth in which use exceeded expected under a null model of a uniform distribution of locations (Bingham and Noon 1997). We calculated home range overlap as the proportion of the home range of one animal covered by the home range of another and as the volume of the intersection between two utilization distributions (Fieberg and Kochanny 2005, Calenge 2006, Rennie 2015).

Results

Capture rates and minimum number known alive

We captured 16 individual fishers (8 females and 8 males, Appendix A.2.1) on 65 occasions during 3,639 trap-nights (1.8% trap success) between 20 October 2015 and September 2018. We found one uncollared female kit (F04T) dead in a creek bed on 26 July 2016. Another uncollared male (M06T) of unknown age, but presumably a juvenile, was found dead by a scent detection dog team (date). We identified 10 additional individuals genetically from non-invasive hair snares (Table 1.1). We identified 19 kits, of which 12 lived past July of their birth year (Table 3.4), but we were not able to verify individual kits with captures or hair snares. As such, we identified 31-41 individuals: 16 captured and 10 hair identified animals, which could also include any number of the 12 kits (Table 1.1). We know 31 animals were mobile (captures and snares) and 13 individuals were detected more than one year. We presume those 13 animals were residents.

We primarily captured adults > 2 years, with our oldest animals estimated 5-6 years of age (Table 1.1). We captured juvenile fishers on 6 occasions (9% of captures). We witnessed a reduction of 1 kit by our field observations, witnessing F02T with 1 visible kit on 3 occasions at maternal rest sites (see also Table 3.4). Monitored adult (F01T) presumably abandoned her den during June 2018, ultimately causing the death of 3 kits despite rescue efforts. In addition, F02T was killed during summer, but had 3 dependent kits that we were unable to locate.

Home range estimates – 95% fixed kernel

We estimated home ranges from a subset of our data during a contractual period, focusing on 9 individuals (4 females, 5 males) fitted with GPS collars, captured on 16 occasions from October 2015–June 2016. During this period, collars attempted 60,029 locations and we obtained 41,127 locations with >4 satellites (3-D), equating to 67% fix success on average. We only used 3-D locations for analyses within this report and the estimated error for these locations was 21m. Later in the project, additional objectives included testing new GPS technology but we did not use such data for this analysis as the location accuracy was unknown.

Female home ranges ($n=4$) were estimated using a mean of 5,916 locations (standard deviation, $SD=2,504$; Table 3.1) and averaged 24.6 km^2 ($SD=9.9 \text{ km}^2$; Table 1.1; Figures 1.1 and 1.2). Female home range core areas were determined to be the 65% isopleth for all four individuals and averaged 8.1 km^2 ($SD=3.5 \text{ km}^2$). Mean male home ranges during the breeding ($n=3$) and non-breeding ($n=4$) seasons were estimated using means of 2,020 ($SD=884$) and 3,993 ($SD=2,672$) locations and averaged 205.5 km^2 ($SD=65.9 \text{ km}^2$) and 63.1 km^2 ($SD=26.8 \text{ km}^2$), respectively. Male home range core areas during the breeding ($n=3$) and non-breeding ($n=4$) seasons ranged between the 55% and 70% isopleths and averaged 58.2 km^2 ($SD=12.1 \text{ km}^2$) and 23.2 km^2 ($SD=11.1 \text{ km}^2$).

The proportion of female home range overlap for all females averaged 18% ($SD=16\%$, $n=12$ pairwise combinations of 4 individual female fishers). The average volume of intersection was 10% ($SD=11\%$, $n=6$ pairwise combinations of 4 individual female fishers).

Discussion

Fishers within the Klamath Plateau region of the southern Oregon Cascades persist from reintroduction efforts from 1961–1981. Based on our data, this is an extremely small population. We were able to capture 16 individuals during 2015–2018. Additionally, non-invasively collected hair samples identified 10 other individuals.

We were not able to capture all fishers in the study area, but have results consistent with other large-bodied fisher trapping projects where individuals have large home ranges. We captured 16 individuals over 2 years with 1.8% capture success. Similarly, Aubry and Raley (2006) captured 22 fishers (13 females and 9 males) during 6 years (1995 to 2001), but did not report a total number of captures or trap-nights for comparison. Weir and Corbould (2008) captured 21 fishers (15 females and 6 males) during 4 years (1996 to 2000) on 66 occasions during 9,616 trap-nights (0.7% trap success). Sauder (2014) captured 20 individual fishers between 2006 and 2010, but did not report details on capture effort or success. These results, however, offer no insight to changes in distribution or population size between Aubry and Raley (2006) and the current study or adequate comparisons to suggest similarities between study areas. One hypothesis is that the population in the Klamath Plateau was extirpated after the 1961 release and recolonized after 2006. One piece of anecdotal evidence in this regard was the prevalence of marten detections during local winter surveys from 2002–2004 but only 3 marten detections since 2009 (S. Hayner, Bureau of Land Management, unpublished data). Although martens and fishers can co-exist, fishers seem to out compete the smaller martens (Thomasma 1996, Manlick et al. 2017). Another possibility is that fishers persisted at extremely low densities. In a study by Aylward et al. (2018) of a similar species, although martens were present after reintroduction, they were not detected with systematic survey efforts. Distribution summaries and simulations evaluating population trajectories suggest this population has not expanded and has likely reduced from the prior population extent by 65% (Barry 2018). Defensible evaluations of population

trends will only come with a targeted study design and sustained, multi-year sampling (e.g., Moriarty, Tucker, and Golding. In preparation).

In regards to home range estimates, on average, females and male ranges in southern Oregon were 25 and 63 km² respectively during the non-breeding season, as calculated with 95% fixed-kernel estimates (Table 1.2). Aubry and Raley (2006) calculated 95% minimum convex polygon (MCP) home ranges estimates for adult male and female fishers. The average annual estimate for females, males during the breeding season, and males during the non-breeding season were 25 km² (n=7), 147 km² (n=3), and 62 km² (n=4), respectively (Aubry and Raley 2006). (Weir and Corbould 2010) calculated 95% isopleths of fixed-kernel utilization distributions with a smoothing parameter selected by least-squares cross-validation. They reported average annual female and male home ranges were 49 km² (SD=16 km², n=6) and 219 km² (n=2) respectively, with average core areas of 7 km² (SD =4 km², n=6) and 47 km² (n=2) respectively (Weir and Corbould 2008, Weir and Corbould 2010). (Sauder and Rachlow 2014) calculated 90% isopleths of fixed-kernel utilization distributions with a smoothing parameter selected by least-squares cross-validation. Female home ranges averaged 49.3 km² (SD =26.7 km², n=9) and male home ranges averaged 98.4 km² (SD =41.2 km², n=9, Sauder and Rachlow 2014). Despite presenting these results, we caution against making direct comparisons between studies using different telemetry technologies, sampling intervals, and home range estimation techniques (Fieberg and Borger 2012). Our results suggest, nonetheless, our fisher home ranges were larger than average estimates across western North America (18.8 km² and 53.4 km² for females and males respectively) (Lofroth et al. 2010). Although this result could be associated with our large GPS dataset compared to other studies, our study was relatively short compared to others. For instance, fishers were monitored for 730 days on average (SD = 438 days) by (Weir and Corbould 2010).

Our estimates of female home range overlap were similar to the results from the Hoopa Valley Indian Reservation (Rennie 2015). There, the proportion of annual home range overlap for all females averaged 21.7% (n=38) and the mean volume of intersection was 9% (standard error=1%). Similarly, overlap was as high as 24% with an average of 5% in north-central British Columbia (Weir and Corbould 2010).

Fisher space use in our study area was consistent with fishers in northern latitudes (e.g., British Columbia, Canada; Idaho, USA) with home ranges larger than average compared to fisher populations in North America. We were unable to assess limiting factors during our study. Future work could test whether the fisher population during our study exhibited larger than average space use with small population sizes in relation to potential limiting factors (e.g., prey densities, predator abundance, rest and den structure availability, vegetation characteristics). Although longer-term monitoring to evaluate demographic parameters would aid in our confidence, descriptions of fisher diet, potential competition using diet, and rest and den vegetation descriptions are in progress but not included within this report.

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Table 1.1. Between our work (Capture ID) and continued hair-snare and camera surveys conducted by BLM (BLM_Field ID), we identified 27 fishers between 2013-2018. Minimum age estimates were either the subtraction from the first and last records of either captures or hair snares. For captured individuals, age was the subtraction from the first known record with either a snare date (e.g., M01T) or an accurate cementum annuli result with the final record. The estimated age class was for the last record with juveniles <1 year, subadults (1-2 years), and adults capable of reproduction (>2 years).

Captured ID	BLM_Field ID	Sex	SnareRecords	TrapEvents	First Record	Last Record	Minimum_Est Age	AgeClass, LastRecord	Mortality
F01T	BLM-KL13-F1	F	34	6	2013	2018	5	Adult	-
F02T	BLM-K15-F6	F	10	4	2015	2017	2	Adult	2017
F03T	BLM-KL14-F4	F	11	5	2014	2018	4	Adult	-
F04T	-	F	-	0	2016	2016	0	Juvenile	2016
F05T	-	F	-	2	2016	2017	1	Subadult	-
F06T	-	F	-	2	2016	2018	2	Adult	-
F07T	-	F	-	4	2016	2018	2	Adult	-
F08T	-	F	-	1	2017	2017	2	Adult	-
F09T	-	F	-	1	2017	2018	1	Subadult	-
-	BLM-K13-F2	F	1	-	2013	2013	Unk	-	-
-	BLM-MED-14F	F	1	-	2015	2015	Unk	-	-
-	BLM-K16-F10	F	8	-	2016	2016	Unk	-	-
-	BLM-K16-F11	F	1	-	2016	2016	Unk	-	-
-	BLM-KL16-F9	F	2	-	2016	2016	Unk	-	-
M01T	BLM_Winema_12M	M	6	1	2011	2017	6	Adult	2017
M03T	-	M		3	2015	2017	2	Adult	-
M04T	BLM-KL13-M3	M	31	2	2013	2018	5	Adult	-
M05T	BLM-KL15-M5	M	7	2	2015	2016	1	Subadult	-
M06T	-	M	-	-	2016	2016	Unk	-	2016
M07T	BLM-KL-M07T	M	4	1	2016	2018	2	Adult	-
M08T	-	M	-	4	2016	2018	5	Adult	-
M09T	BLM-KL-M09T	M	1	2	2017	2018	1	Subadult	-
-	BLM-MED13M	M	1	-	2012	2012	Unk	-	-
-	BLM-KL15-M7	M	1	-	2015	2015	Unk	-	-
-	BLM-KL15-M8	M	5	-	2015	2016	1	Subadult	-

-	BLM-KL-M10	M	1	-	2015	2015	Unk	-	-
-	BLM-KL16-M12	M	2	-	2016	2016	Unk	-	-

Table 1.2. Locations and fixed kernel home range estimates for fishers in the southern Oregon Cascades. Male home ranges were estimated during the breeding season (1 February – 30 April) and the non-breeding season (1 May through 31 January) following Aubry and Raley (2006). Home range estimates were modeled as 95% fixed kernel isopleths using an href smoothing parameter. Core areas were estimated as the home range isopleth in which use exceeded expected under a null model of a uniform distribution of locations (Seaman and Powell 1990, Bingham and Noon 1997).

Fisher	Season	Days monitored	GPS locations	Home range (km ²)	Core area isopleth (%)	Core area (km ²)
F01T	Annual	127	7,755	34.2	65	11.3
F02T	Annual	79	5,725	8.0	65	3.0
F03T	Annual	116	7,741	28.5	65	6.7
F07T	Annual	61	2,443	27.8	65	11.3
M03T	Breeding	88	2,623	178.1	70	71.5
	Non-breeding	113	7,385	109.5	60	42.1
M05T	Non-breeding	25	1,660	45.4	55	13.5
M07T	Non-breeding	35	2,065	49.9	65	17.5
M08T	Breeding	80	2,422	296.3	70	61.0
	Non-breeding	92	4,865	47.7	65	19.8
M09T	Breeding	32	1,006	142.1	60	42.2

Table 1.3. Home range estimates for male and female fishers of similar genetic clades (e.g., not California or southwestern Oregon, but fishers from British Columbia, Minnesota, Idaho).

Study	Method	Female	Male	Core Area
Aubrey and Raley (2006)	95% minimum convex polygon	25 km ²	147 km ² (breeding) 62 km ² (non-breeding)	
Weir and Corbould (2008)	95% isopleths of fixed-kernel utilization distribution (least-squares cross-validation smoothing parameter)	49 km ²	219 km ²	7 km ² (female) 47 km ² (male)
Sauder (2014)	90% isopleths of fixed-kernel utilization distribution (least-squares cross-validation smoothing parameter)	49.3 km ²	98.4 km ²	
Klamath Plateau study	95% fixed-kernel home range estimates using an href smoothing parameter (65% core isopleth)	24.6 km ²	205.5 km ² (breeding) 63.1 km ² (non-breeding)	8.1 km ² (female) 58.2 km ² (male breeding) 23.2 km ² (male non-breeding)

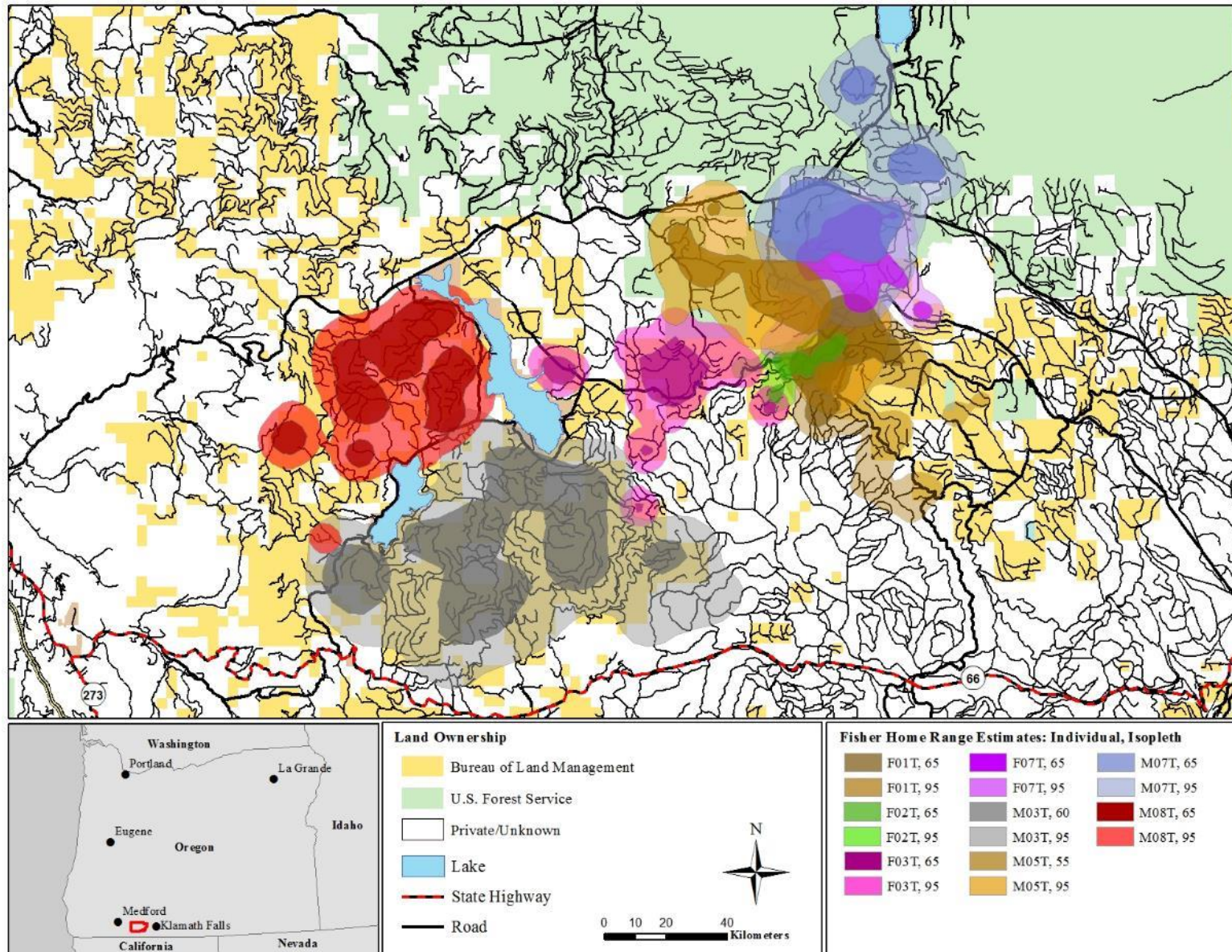


Figure 1.1. Home range (95% fixed kernel) and core area estimates for 8 fishers (4 females, 4 males) in the southern Oregon Cascades. Female home ranges were estimated through life of monitoring. Male home ranges were estimated using locations collected during the nonbreeding season (1 May through 31 January).

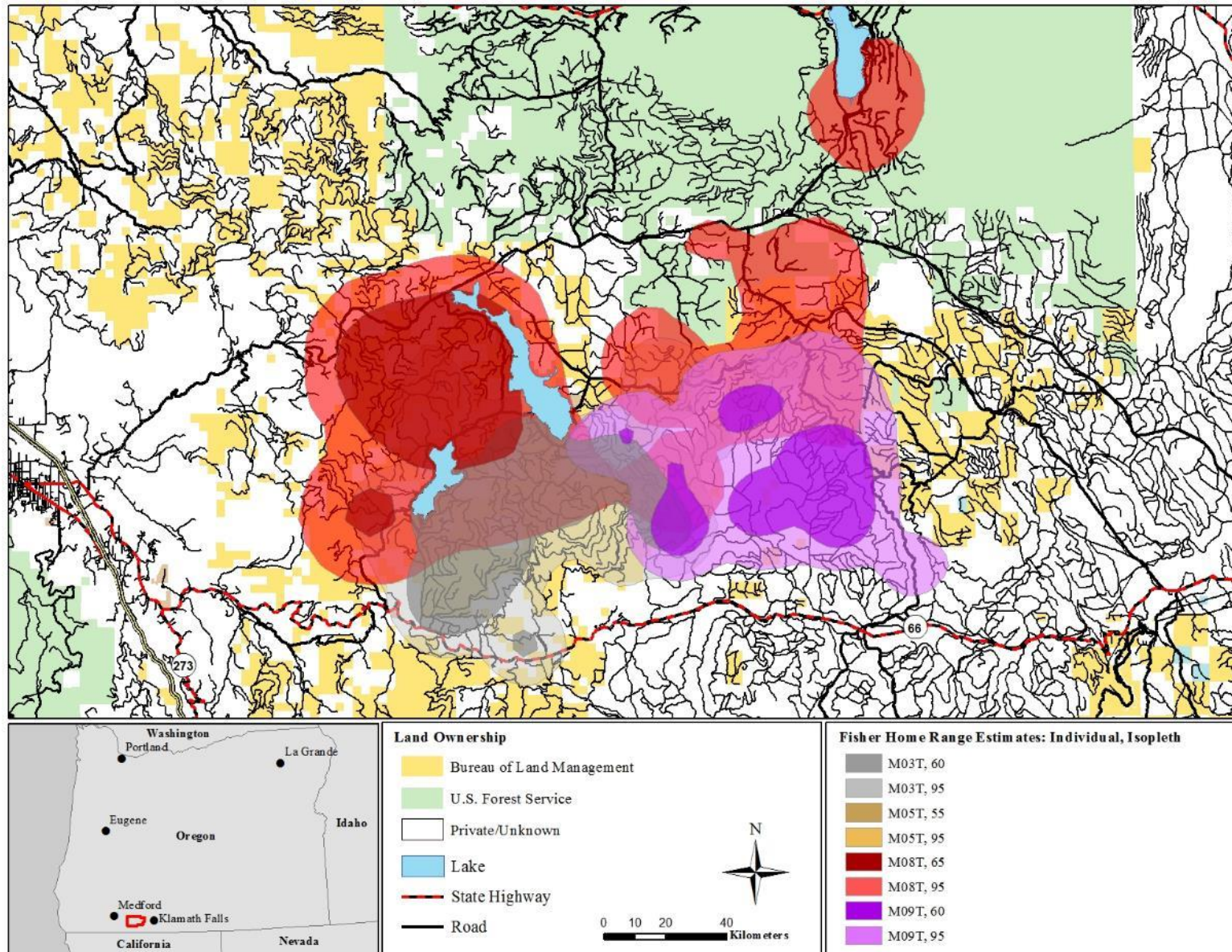


Figure 1.2. Home range (95% fixed kernel) and core area estimates for 3 male fishers during the breeding season (1 February – 30 April) in the southern Oregon Cascades (note M05 not displayed).

Objective 2: Fisher movement in a landscape mosaic

Introduction

Evidence-based forest and wildlife management rely on understanding the selection of habitat elements by species of interest. Habitat elements are selected by wildlife across a range of spatial and temporal scales (Kie et al. 2002, Boyce 2006), in a hierarchical process (Johnson 1980, Decesare et al. 2012), and are often a function of behavior (Squires et al. 2013, Olson et al. 2014, Zeller et al. 2014). Fishers (*Pekania pennanti*) in the U.S. Pacific states are associated with mid-elevation, mature forests with dense forest canopy, a diversity of forest successional stages, and complex forest structure (Lofroth et al. 2010, Raley et al. 2012). Fisher habitat selection of rest sites at fine spatial scales has been extensively studied (Lofroth et al. 2010, Raley et al. 2012, Aubry et al. 2013, Aubry et al. 2018). Less is known about the selection of habitat by fishers within home ranges.

In their reviews of fisher habitat selection within the home range, Raley et al. (2012) and Lofroth et al. (2011) reported inconsistent findings with previous studies. Most recently, Sauder and Rachlow (2014) found fishers selected larger, more contiguous patches of mature forest and reduced amounts of open areas. Similarly, Sauder and Rachlow (2015) found support for a hypothesis posed by Weir and Harestad (2003) and Raley et al. (2012) that fisher home ranges, specifically core use areas, were composed of intermediate amounts of landscape edge and high canopy forest. Forest heterogeneity within home ranges might offer an optimum between competing resources needs, specifically diverse and abundant prey species and habitat features important for reproduction and thermoregulation (Raley et al. 2012).

We evaluated habitat selection and movement of fishers at the landscape scale to further investigate the influences of forest composition on fisher space use. The diverse land ownership patterns and intensities of forest management in the southern Oregon portion of the Cascade Mountain Range offer further opportunity to investigate hypotheses of fisher habitat selection. A decade earlier in this landscape, Aubry and Raley (2006) reported larger proportions female fishers' locations in unmanaged forest when denning and resting. A majority of female fisher locations while active, however, and a majority of male fisher locations were in managed forests. Recent advances in global positioning system (GPS) technology, as employed in our study, offer more detailed spatial and temporal resolution of fisher habitat selection.

Methods

We evaluated fisher space use and movement within the southern Oregon Cascade Mountain Range in an area known as the Klamath Plateau (Figure i.1). Land ownership in the area is patchy mosaic of federal lands (Bureau of Land Management and U.S. Forest Service), state land, and private lands (primarily commercially owned timberlands). Thus, our study area provided a unique combination of prior fisher monitoring and variable forest management practices. Elevations in this mountainous region ranged from 1200-2500 m. Predominant tree species included white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*), red fir (*Abies magnifica*), ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), lodgepole pine (*Pinus contorta*), and incense cedar (*Calocedrus decurrans*). Forest vegetation types included primarily mixed-conifer stands and riparian areas. Natural openings included perennial meadows and frozen lakes during winter. Winter mean annual snow depth for the study period was 37 cm at the Howard Prairie weather station, located at 1396 m elevation within the study area (Natural Resource Conservation Service, SNOTEL data 2015-2016). Snow persisted from November to May each year in much of the core study area. Mean annual

precipitation was 77 cm for 2015 and 2016 (Natural Resource Conservation Service, SNOTEL data). Historic average annual snowfall for the Howard Prairie Dam weather station was 349 cm, and average annual precipitation was 82 cm (Western Regional Climate Center, historic data 1960-2005).

GPS data

We deployed W500 Wildlink GPS collars (Advanced Telemetry Systems, Isanti, Minnesota, USA; 60-100g), Lotek Iridium (Lotek/Sirtrack Limited, Havenlock North, New Zealand; 130g), and Lotek LiteTrack RF-40 (Lotek/Sirtrack Limited, Havenlock North, New Zealand; 50g) on adult fishers opportunistically in accordance with necessary permits (Objective 1 methods, Capture and handling). Each collar had both a very high frequency (VHF) unit with an external antenna powered by the same battery as the GPS. In addition, all GPS collars had a remote downloading feature to obtain data from a fisher without recapturing the individual. While on free-roaming fishers, the GPS was programmed to estimate locations every 15 minutes with occasional settings at a 30-minute interval between attempted location attempts.

The majority of locations were collected with W500 GPS collars. We also tested Sirtrack LiteTrack Iridium 130 (Sirtrack Limited, Havenlock North, New Zealand; 130g) collars with field trials on 2 male fishers. One Iridium collar featured Swift Fix technology while the other was equipped with standard GPS technology, and both were programmed to estimate locations at 30-minute intervals. Finally, we deployed LiteTrack RF-40 (Sirtrack Limited, Havenlock North, New Zealand; 40g) on 2 female fishers during the 2018 denning season to evaluate denning female movements. LiteTrack RF-40 collars were GPS-enabled with swift fix technology and were programmed to estimate locations at 30-minute intervals.

We tested GPS collars during hand-held trials in areas stratified by canopy cover (0-15%, 16-50%, >50%) within the study area to determine GPS accuracy and fix rates (Appendix 4). In addition, we tested individual collars for functionality before deploying them on fishers. We presumed the Wildlink GPS was operational if it was able to collect >1 location with >4 satellites accurate within 30m both during an office pre-trial and at the fisher's capture location immediately prior to deployment.

Movement and activity rates

We calculated daily distances as the sum of minimum distance moved between two consecutive locations less than 30 minutes apart. Similarly, we estimated minimum speeds as the distance traveled during a period divided by the duration between locations (only for locations <30 minutes). Speeds were calculated when the animal was presumably moving, which we defined as having locations >60m apart with activity above 15%. Daily distance rates were calculated overall and for each season. We defined seasons as periods with similar weather patterns in our study area: Winter (Dec 1-Feb 28), Spring (Mar 1-May 30), Summer (Jun 1-Sep 30), and Fall (Oct 1-Nov 30).

For the reproductive period, we defined a period for each sex. We defined denning movement when we had data between Mar 1-Jun 30 and classified non-denning as Jul 1-Feb 28 for adult females. These dates were based on the known parturition dates between Mar 3 – Apr 17 within North America and movements by females from natal to maternal dens as late as Jun 24 (Green et al. 2018). We used the dates between Mar 15- May 15 as breeding periods for males, observations in the southern Sierra Nevada occurred between Mar 29 – May 6 (Green 2017) and we speculated that some males may scout female areas, and therefore we lumped non-breeding movements between May 16 – Mar 14 for

adult males. We graphically evaluated speed and turning angles as a function of canopy cover, stand age, old-growth structural index, and occurrence of late-successional reserves.

Habitat associations

We investigated fisher habitat selection within estimated home ranges as a function of forest cover and age in a use versus availability framework (Manly et al. 2002). Specifically, we considered gradient nearest neighbor (GNN) map structure metrics canopy cover (CANCOV), old growth structural index (OGSI), and the dominant tree age within a stand (AGE_DOM) (Ohmann and Gregory 2002) as well as fisher sex. More specifically, canopy cover was derived as the percentage of cover from live trees using Landsat imagery. Old-growth structure index and calculated from the abundance of large live trees, snags, down wood, and diversity of tree sizes. Dominant age was defined as the basal area weighted stand age based on dominate and codominant trees. We also investigated fisher habitat selection as a quadratic function of dominant age, assuming there could be an age threshold and with an interaction between canopy cover and dominant stand age.

We randomly selected one GPS location per fisher per day from the sample of use locations. We generated a random sample of available locations equal to the number of use locations for each individual fisher within its 95% fixed kernel home range (See Objective 1). Values for each vegetation structure metric were extracted for each use and available location. We used generalized linear models (GLMs) and Akaike information criterion with a corrector for finite sample sizes (AICc) to model fisher habitat selection as a function of the selected habitat metrics (Burnham and Anderson 2002) in R version 3.4.1 (R Core Team 2016). We used 1,000 iterations of a bootstrap procedure for each sex to select used and available sample locations and determine the top model.

Results

Movement and activity rates

We deployed GPS collars on 9 individuals (4 female, 5 male) on 21 occasions from October 2015-July 2018. During this period, collars attempted 92,221 locations and we obtained 61,147 locations with >4 satellites (3-D) (Table 2.1). We used only 3-D locations for analyses within this report (see Table 2.1 for sample sizes). Because we only measured movements at 15 or 30 minute intervals, we expect all metrics regarding fisher movement to be minimum total estimations.

Fishers traveled approximately 6.6-km daily, with no statistically detectable differences between male and female daily movements (Figure 2.1). Specifically, during our study both males and females moved, on average, 6.2 (SD= 3.4) and 6.9 km (SD = 5.8) per day respectively. Female fishers moved longer distances daily during summer compared to fall (Figure 2.2). Males moved more variably on average during breeding periods (March-May, n=3, Figure 2.2), likely due to more extreme fluctuations in daily activity exemplified with very long distance movements (e.g., >30 km/day) followed by days with little to no activity (Figure 2.2). These periods of low daily movements may have been due to males waiting outside female dens in anticipation of a reproductively receptive female emerging.

Fishers conservatively moved an average and standard deviation of 11.3 ± 10.4 and 17.3 ± 16.6 meters/minute for females and males, respectively (Figure 2.3). Average maximum speeds (removing outliers) were 64.8 and 93.9 meters/minute for females and males (Figure 2.3). On average, male

fishers' speeds were 14.8 ± 20.2 and 11.04 ± 13.5 meters/minute during the breeding and non-breeding seasons, respectively.

Vegetation and habitat associations

Canopy cover associated with all fisher locations (>4 satellites, 3-D locations) was relatively high. There was no statistically detectable difference in canopy cover percentages in stands used by males or females, where the averages (\pm SD) $67\% \pm 14\%$ and $62\% \pm 15\%$ for females and males, respectively. Median canopy cover estimates were 67% and 64% for females and males, respectively (Figure 2.5). Dominant age within a measured pixel (GNN) differed between some individuals (i.e., M09T), but the majority of locations were in stands > 107 years (Figure 2.6). There was no difference in estimated stand age between males and females, where the averages (\pm SD) were 129 ± 40 years and 127 ± 48 years for females and males, respectively. Median stand age estimates were 124 and 123 years for females and males, respectively (Figure 2.6).

Point locations describing speed and with a vegetation attribute can be inaccurate (e.g., a fisher could have moved through stands with diverse canopy cover in the prior 15 minutes but we can only acknowledge the vegetation characteristic at the fix location). Given this caveat, speed at measured locations did not differ between locations that were less than 60% estimated canopy cover where the cut off was related to the 25% quartile for all locations (Figure 2.7). On average, both sexes moved slightly slower in areas with increased canopy cover (Figure 2.7).

Female fisher habitat selection varied significantly by canopy cover (CANCOV) and stand age (AGE_DOM), representing the top model in 985 of our 1,000 bootstrap iterations (Table 2.2). Female fisher use showed a positive response to increasing canopy cover and stand age and a negative response to the interaction between canopy cover and stand age, although there was little support for the interaction term and the influence of sex in the model (Table 2.3).

Discussion

In the Klamath Plateau, fisher movement patterns are correlated with areas hosting high amounts of canopy cover (>60%), older trees, and avoiding areas that we interpret as previously thinned. We did not measure fine scale vegetation nor did our data measure understory conditions, so our results are limited to correlations between estimated GPS locations and remotely-sensed variables at a coarse scale. We did not observe a difference in selection patterns between males and females at the home-range scale. These results are similar to patterns of fishers being associated with dense forest stands observed throughout their range (Raley et al. 2012, USFWS 2016).

Forests with high proportions of canopy cover and older dominant trees are hypothesized to provide fishers with the resources they need to increase individual fitness, which contributes directly to population persistence (Zielinski et al. 2004, Raley et al. 2012, Aubry et al. 2018b). These forests provide concealment and escape cover from potential predators, including bobcats (*Lynx rufus*) and mountain lions (*Puma concolor*) (Wengert et al. 2014, Gabriel et al. 2015). This is particularly important, considering predation accounts for 70% of known fisher mortalities throughout their range in the Pacific states (Gabriel et al. 2015). Recent unpublished data suggest coyotes (*Canis latrans*) may also consume fishers and martens in Oregon (Moriarty et al., unpublished data), with similar anecdotal reports in Hoopa and the southern Sierras, California. These forests also provide a diverse range of prey items selected by fishers, including squirrels (Sciurids) and rabbits (Leporids) (Aubry and Raley 2006, Golightly et al. 2006, Slauson et al. 2011). The availability and access to sufficient prey is

especially important for fishers, considering their high daily energetic requirements (Powell 1993). These forests also provide the microsite characteristics fishers select for daily resting bouts and raising their kits (Raley et al. 2012, Aubry et al. 2018, Chapter 2 of this report).

We observed a negative response to our characterization of thinned stands based on the remotely sensed vegetation data – but this does not represent actual thinning which has occurred throughout much of our study area to varying degrees. Fisher core use areas on other landscapes, have been composed of intermediate amounts of forest edge and high canopy forest, suggesting a level of selection for forest management activities and resulting edges between forest patches (Weir and Harestad 2003, Raley et al. 2012, Sauder and Rachlow 2015, Lewis et al. 2016, Parsons 2018). A negative response to the combination of lower canopy cover and increased forest age in this study presents an opportunity to further explore what resources (e.g., prey, escape cover, concealment cover) or what threats exist (e.g., predators) in stands that differ in age and canopy cover. Additional analyses of these data and future research could further evaluate the findings of Sauder and Rachlow (2015) indicating fishers may select for an intermediate amount of management activity resulting in forest edge between older and younger stands. It has been suggested that these edges provide increased foraging opportunities (Parsons 2018), and thinning may not allow a large increased response for vegetation (e.g., shrub cover) and small mammal communities in the same way as small openings.

Conservation planning for fishers, however, continues to rely on habitat suitability assessments based on the assumption that we can infer habitat quality (i.e., each habitat's potential contribution to individual fitness) from studies of vegetation use patterns. Several studies have challenged the assumption that habitat use patterns are a surrogate for demographic parameters and that subsequent changes in habitat suitability correspond to numerical changes in wildlife populations (Van Horne 1983, Garshelis 2000). Future research seeking to contribute to conservation planning for fishers could focus on direct linkages between habitat conditions and fisher demographic parameters.

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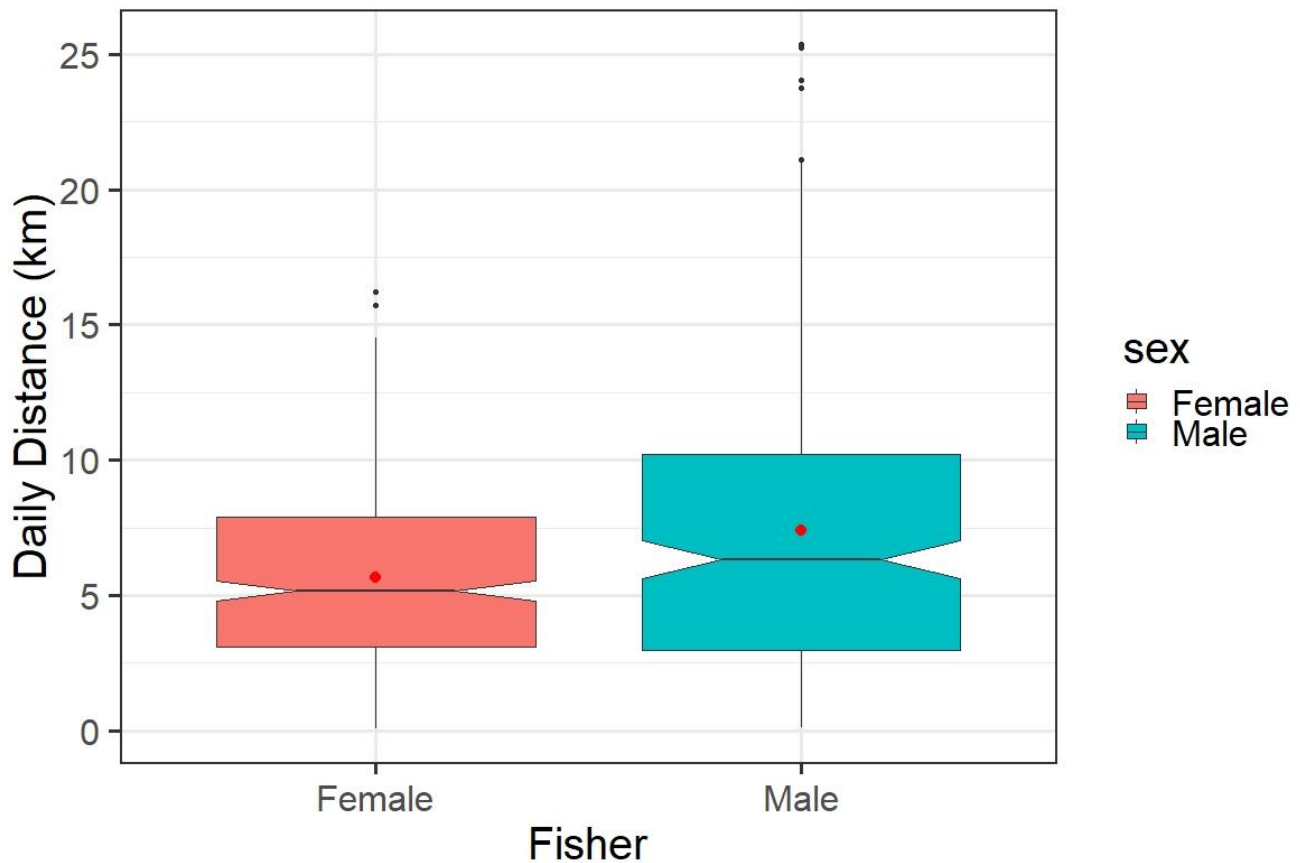


Figure 2.1. During our study females and males moved, on average \pm SD, 5.7 ± 3.3 and 7.4 ± 5.3 km per day, respectively, outside the combined reproductive season of early denning and mating (Mar 1- May 30). Median observed values were 5.16 and 6.33 for females and males, respectively. We did not observe statistical differences between sexes with the 95% confidence interval representing variation between individuals. The 95% confidence interval around the medians (notched portion of boxplots) does not overlap between sexes, but this is due to the program using the number of days (382, 252 for females and males) and not the number of individuals (4F, 5M) to calculate standard error. Average values are depicted with a red dot.

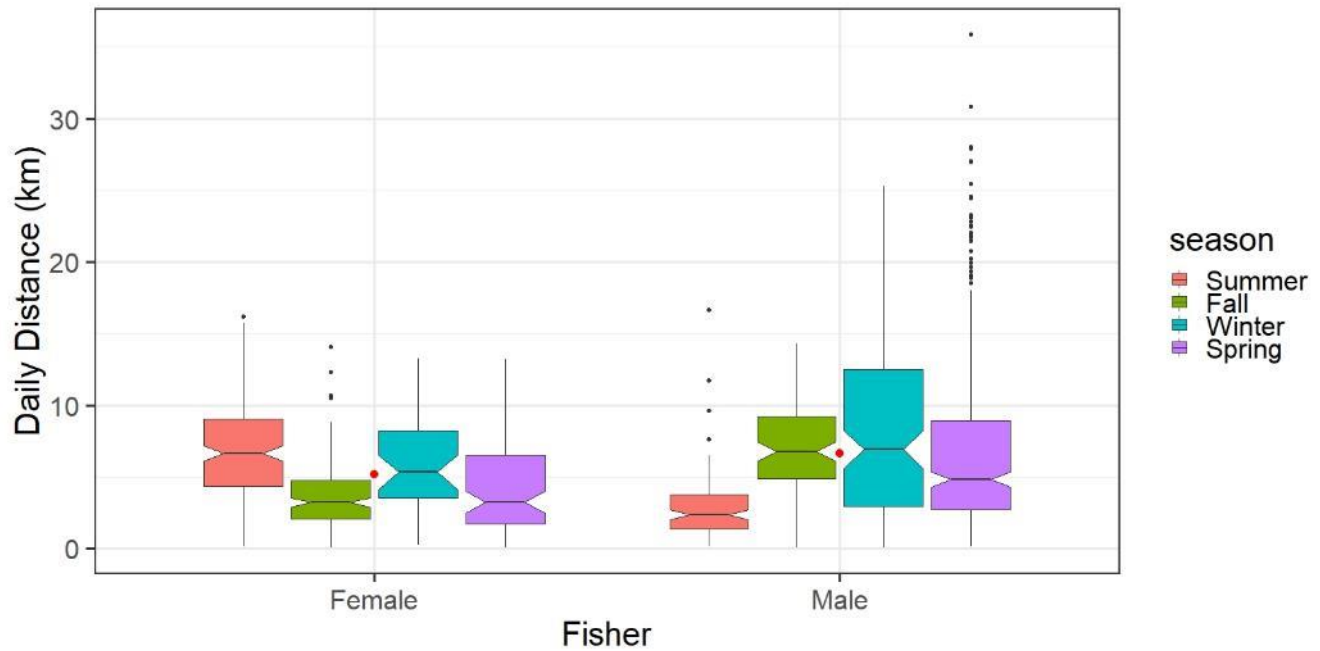


Figure 2.2. Daily movement during each season and by fisher sex while presumably not resting by restricting locations within Moriarty's Rest Zone algorithm (<15% activity, <60-m distance, and <30 minutes between consecutive locations).



Figure 2.3. A minimum estimation of fisher speeds between consecutive locations <30 minutes and while presumably not resting. The average speed (and standard deviation) between locations was 16.3 ± 11.4 and 22.0 ± 16.9 meters/minute for females and males, respectively.

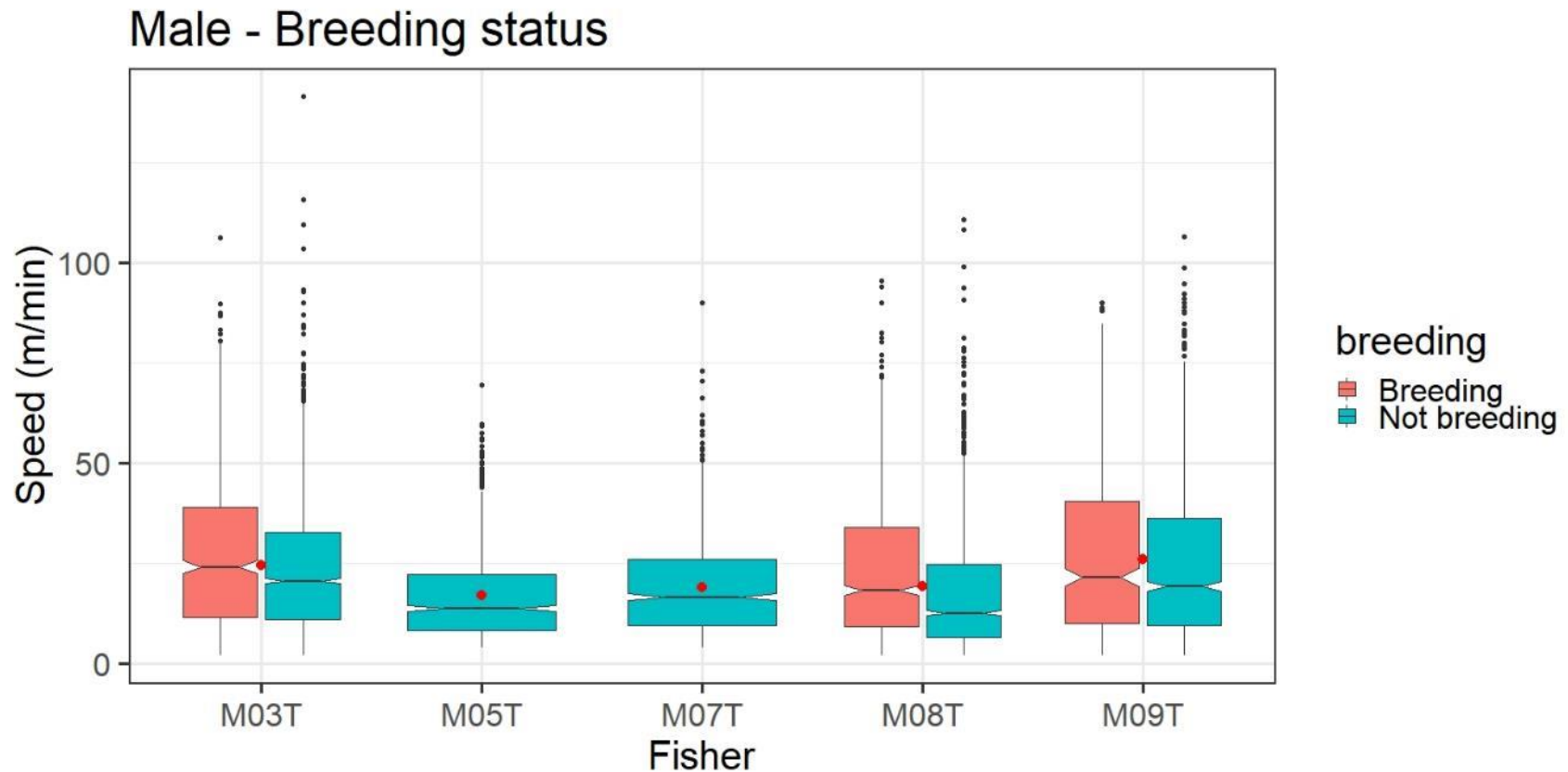


Figure 2.4. Conservative estimates of fisher movement speeds during potentially reproductive periods (March 15-May 15) and non-breeding seasons (May 16-Marc 14) between consecutive locations <30 minutes and while presumably not resting by restricting all locations within Moriarty's Rest Zone algorithm (<15% activity, <60-m distance, and <30 minutes between consecutive locations). On average, male fishers' speeds were 25.7 ± 19.2 and 20.8 ± 15.7 meters/minute during the breeding and non-breeding seasons, respectively. Maximum speeds were 106 and 141 meters/minute during breeding and non-breeding seasons. The red dot is the average overall speed for each individual.

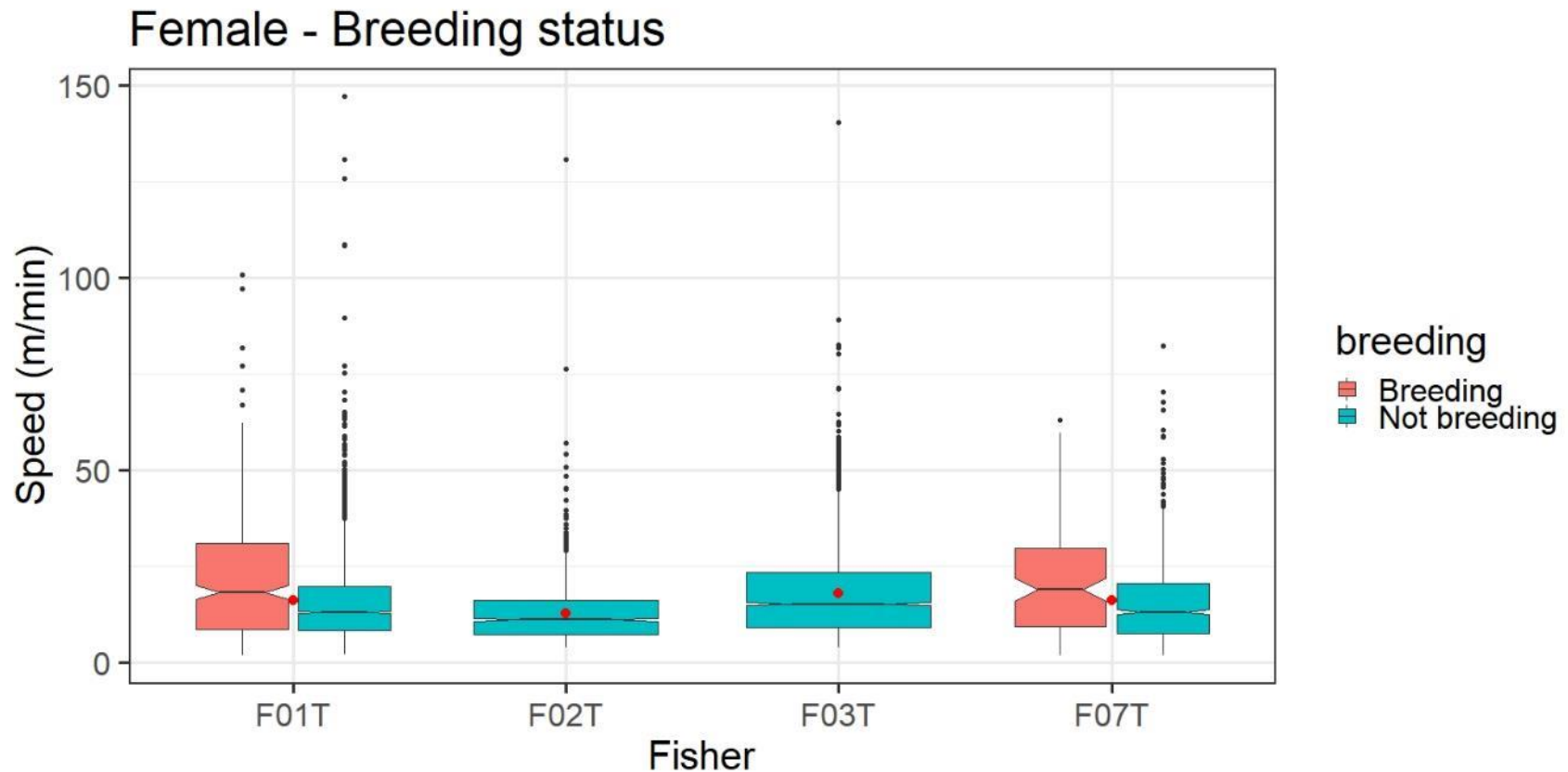


Figure 2.4b. Conservative estimates of female fisher movement speeds during early denning (March 1 – May 30) between consecutive locations <30 minutes and while presumably not resting by restricting all locations with >60-m distance, and <31 minutes between consecutive locations. Data during breeding season were with Lotek Swift collars, unlike the rest of our GPS data. On average, female fishers' speeds were 20.9 ± 15.8 and 15.8 ± 10.5 meters/minute during the early denning and all other periods, respectively. Maximum speeds were 140 and 147 meters/minute during early denning and other data. The red dot is the average overall speed for each individual.

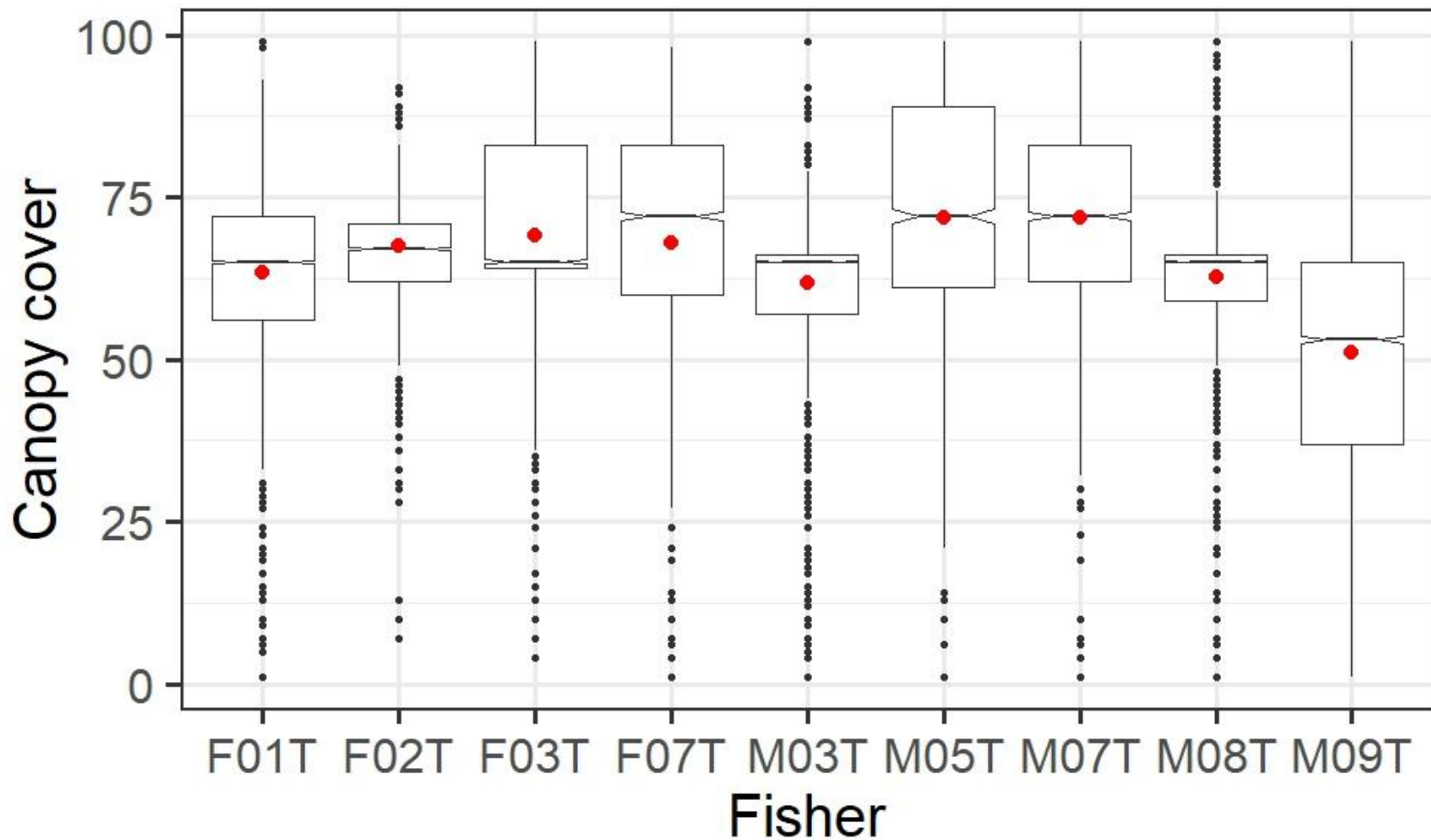


Figure 2.5. Canopy cover associated with all fisher locations (>4 satellites, 3-D locations). The average 25% quartile (or the line at the bottom of the boxplot) was 59% with the exception of M09, average canopy cover by individual shown as a red dot. There was no difference in canopy cover percentages between males and females, where the averages (\pm SD) were $67\% \pm 14\%$ and $62\% \pm 15\%$ for females and males, respectively. Median canopy cover estimates were 67% and 64% for females and males, respectively.

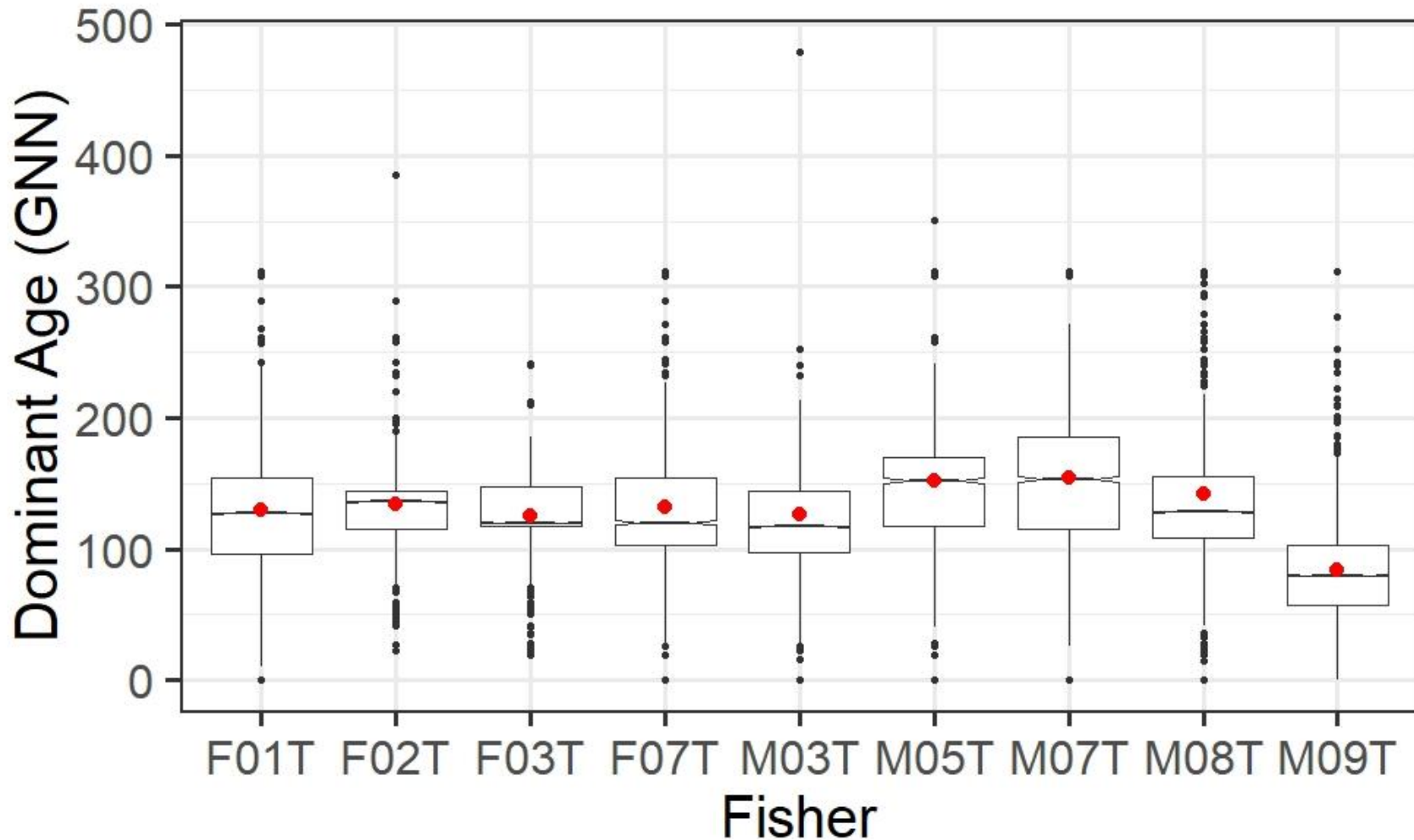


Figure 2.6. Dominant age within a measured pixel (GNN) associated with all fisher locations (>4 satellites, 3-D locations) differed between some individuals (i.e., M09T). The average 25% quartile (or the line at the bottom of the combined boxplots) was 107 years and average age is shown with a red dot. There was no difference in estimated stand age between males and females, where the averages (\pm SD) were 129 ± 40 years and 127 ± 48 years for females and males, respectively. Median stand age estimates were 124 and 123 years for females and males, respectively. Stand age can be largely inaccurate in managed forests, so this is an exploratory summary.

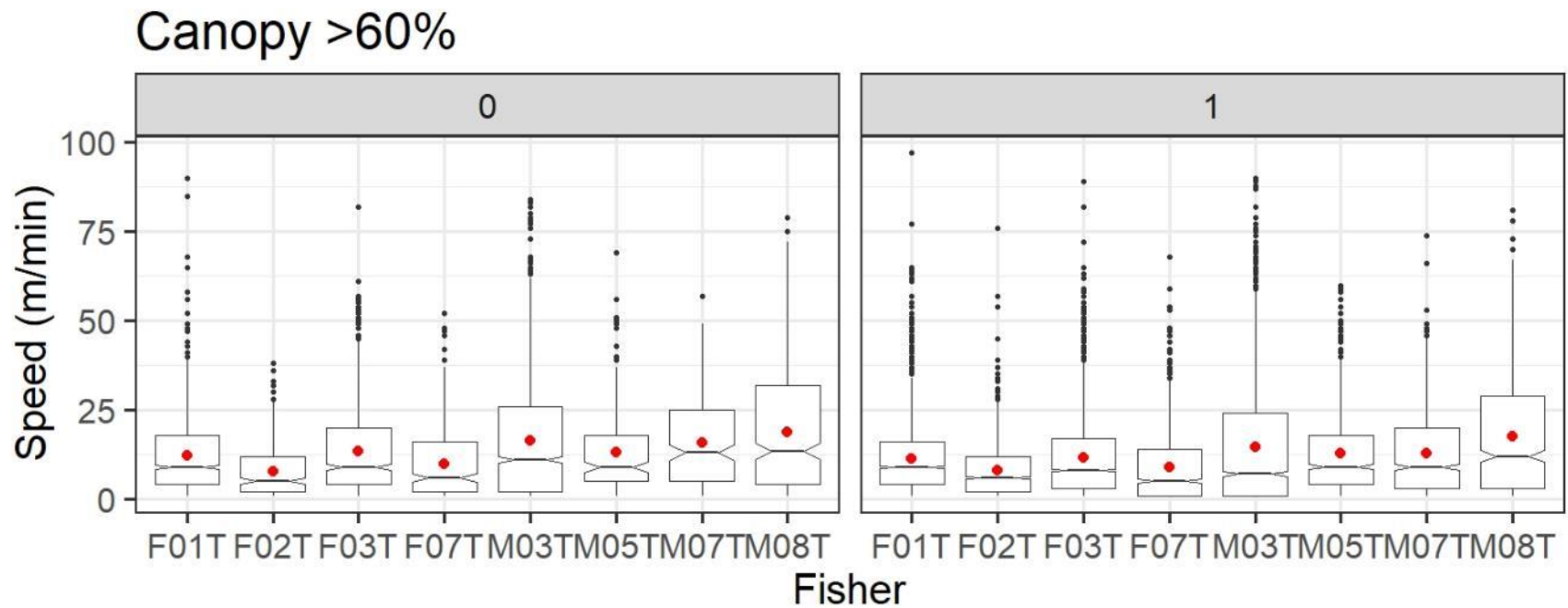


Figure 2.7. Point locations describing speed and canopy cover can be inaccurate (e.g., a fisher could have moved through stands with diverse canopy cover in the prior 15 minutes). Given this caveat, speed at measured locations did not differ between locations that were less than 60% estimated canopy cover ("0", 59% was the 25% quartile for all locations) and locations with greater than 60% canopy cover ("1"). Female speeds were on average, 11.6 ± 10.8 and 10.6 ± 10.1 meters/minute in less and more than 60% canopy cover, respectively. Male speeds were on average, 16.4 ± 16.1 and 14.3 ± 15.4 meters/minute in less and more than 60% canopy cover, respectively. As such, both sexes likely moved slightly slower in areas with increased canopy cover.

Table 2.1. We deployed GPS collars on 9 individuals (4 female, 5 male) on 21 occasions from October 2015-July 2018. During this period, collars attempted 92,221 locations and we obtained 61,147 locations with >4 satellites (3-D) that were used in various analyses and summaries.

Fisher	Deployment	Dates		Days data	Attempted Locations (n)	2-D Fix Success	3-D Fix Success	Total Fix Success
F01T	Fall15	10/21/2015	- 12/03/2015	43	4107	5%	74%	79%
F01T	Sum16a	06/27/2016	- 08/06/2016	40	3797	1%	75%	76%
F01T	Sum16b	08/18/2016	- 09/19/2016	32	3030	1%	63%	63%
F01T	Winter17	12/14/2017	- 01/17/2018	34	3244	0%	73%	73%
F01T	Spring18	03/09/2018	- 5/21/2018	73	3565	0%	30%	30%
F02T	Fall15	10/22/2015	- 11/30/2015	39	3728	4%	76%	80%
F02T	Sum16b	08/17/2016	- 09/26/2016	40	3865	1%	74%	75%
F03T	Fall15	10/25/2015	- 11/30/2015	36	3435	5%	76%	81%
F03T	Sum16a	06/27/2016	- 08/08/2016	42	4026	1%	78%	80%
F03T	Sum16b	08/23/2016	- 09/15/2016	23	2197	1%	89%	90%
F03T	Winter17	11/07/2017	- 12/03/2017	26	2457	1%	57%	58%
F07T	Fall16	11/09/2016	- 12/05/2016	26	2514	1%	45%	46%
F07T	Fall17	08/20/2017	- 09/23/2017	34	1679	0%	78%	78%
F07T	Spring18	03/07/2018	- 05/07/2018	61	2907	0%	10%	10%
M03T	Fall16	11/10/2016	- 02/01/2017	83	7945	1%	76%	77%
M03T	Winter17	02/17/2017	- 08/20/2017	184	9014	1%	84%	85%
M05T	Fall16	10/23/2016	- 11/17/2016	25	2394	1%	69%	70%
M07T	Fall16	10/18/2016	- 11/22/2016	35	3350	3%	62%	64%
M08T	Fall16	11/13/2016	- 12/18/2016	35	3362	1%	76%	77%
M08T	Winter17	02/08/2017	- 06/26/2017	138	6596	1%	72%	72%
M08T	Spring18	02/11/2018	- 07/30/2018	169	8110	0%	86%	86%
M09T	Winter17	02/10/2017	- 03/14/2017	32	1527	1%	66%	66%
M09T	Spring18	02/28/2018	- 06/25/2018	117	5614	0%	65%	65%
Average±SD				59±49	4095±2139	1.4±1.5	72±10	73±10

Table 2.2. Generalized linear models (GLMs) and Akaike information criterion with a corrector for finite sample sizes (AICc) used to model fisher habitat selection as a function of gradient nearest neighbor (GNN) map structure metrics CANCOV, OGSi, and AGE_DOM (Ohmann and Gregory 2002) and fisher sex. CANCOV and OGSi were calculated as a mean of 30 m GNN raster values over a 90 m neighborhood. AGE_DOM was calculated similarly using a 150 m neighborhood. We used 1,000 iterations of a bootstrap procedure to select daily used and available sample locations and determine the top model.

Model	Description	Iterations as top model
Use ~ CANCOV + Sex	Canopy cover of all live trees	2 (0.2%)
Use ~ OGSi + Sex	Old-growth structure index	5 (0.5%)
Use ~ AGE_DOM + Sex	Basal area weighted stand age	0 (0%)
Use ~ AGE_DOM^2 + Sex	Curvilinear relationship with stand age	8 (0.8%)
Use ~ CANCOV + AGE_DOM + CANCOV:AGE_DOM + Sex	Potential forest thinning attributes	985 (98.5%)

Table 2.3. Mean values of standardized model coefficients and percent of significance values <0.05 from the 985 bootstrap iterations resulting in the top model of fisher habitat selection as a function of gradient nearest neighbor (GNN) map structure metrics CANCOV and AGE_DOM (Ohmann and Gregory 2002) and fisher sex.

Model variable	Means of standardized model coefficients	Percent of significance values <0.05
Intercept	0.00	
CANCOV	0.33	97.1
AGE_DOM	0.29	99.6
Sex	0.14	30.5
CANCOV:AGE_DOM	-0.15	56.2

Objective 3: Fisher resting and den site use; reproductive chronology

Introduction

Rest and den structures are landscape features for fishers (*Pekania pennanti*) hypothesized to provide secure locations to avoid predators, consume prey, and reduce thermal stress. Fishers have a long, lean body profile, including a high surface to body mass ratio, shorter and less-insulating fur compared to other mammals occupying northern latitudes, and low body fat. While their body profile allows them to efficiently forage in complex environments, it also leads to rapid heat loss in cold climates (Buskirk and Harlow 1989) and subsequent high energetic requirements. Fishers, like other members of the weasel family, reduce energetic requirements by using thermally insulating structures for resting and reproduction (Taylor and Buskirk 1994). These structures are often large, old, and decadent, and fishers may use them disproportionately to their availability (Weir et al. 2012). Suitable rest and den structures within a fisher's home range, defined as the area in which an animal traverses for normal activities (Burt 1943), likely contribute to survival and individual fitness (e.g., reproductive success).

Fisher resting activities can be quantified at four spatial scales from broadest to finest: (1) the rest stand, which is a relatively homogenous forest patch containing the rest site and rest structure, (2) the rest site, which includes the vegetative and physical characteristics in the immediate vicinity of the rest structure; (3) the rest structure, which is the actual physical feature in which the fisher rests or dens (e.g., snag, live tree, log), and (4) the rest microsite location, which is the specific entry and space the fisher used within the structure (e.g., cavity in snag) (Slauson and Zielinski 2009, Joyce 2013). These scales provide a reference framework to understand fisher resting ecology, as each of the spatial scales can be used to describe fisher rest site characteristics.

At the structure scale, males and females appear to select rest structures similarly (Raphael and Jones 1997), thus identifying and describing both male and female rest structures may be equally valuable. Fisher rest structures include live trees, snags, logs, slash piles, rock piles, stumps, dense brush, and ground and snow burrows (Lofroth et al. 2010, Raley et al. 2012, Aubry et al. 2013, USFWS 2016). Of these, woody structures are often the most commonly used. In addition, used woody structures are often larger and older than available. Microsites within these structures may provide increased thermal benefits compared to more available structures, especially during times of extreme temperatures (Buskirk et al. 1989, Taylor and Buskirk 1994).

At the microsite scale within the structure, fishers rest in cavities, in interstitial spaces of woody debris and rocks, in subterranean or subnivean spaces, and on platforms including mistletoe brooms, branches, and the tops of broken tree boles. Fisher research in the southern Sierra Nevada Mountains has documented cavities as the most common fisher resting microsites (Green 2017). However, Aubry et al. (2018a) and Weir and Corbould (2008) documented a higher frequency of platforms (especially mistletoe brooms) used as rest microsites in the southern Oregon Cascades and north-central British Columbia.

Our objectives were to characterize rest and den site use at the scale of 3rd and 4th-order selection, the structure and microsite (Johnson 1980). We also summarized reproductive efforts of adult females.

Methods

We evaluated fisher rest and den ecology within the southern Oregon Cascade Mountain range in an area known as the Klamath Plateau (Figure i.1). Land ownership in the area is patchy mosaic of federal lands (Bureau of Land Management and U.S. Forest Service), state land, and private lands (primarily commercially owned timberlands). Elevations in this mountainous region ranged from 1200-2500 m. Predominant tree species included white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*), red fir (*Abies magnifica*), ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), lodgepole pine (*Pinus contorta*), and incense cedar (*Calocedrus decurran*s). Forest vegetation types included primarily mixed-conifer stands and riparian areas. Natural openings included perennial meadows and frozen lakes during winter. Winter mean annual snow depth for the study period was 37 cm at the Howard Prairie weather station, located at 1396 m elevation within the study area (Natural Resource Conservation Service, SNOTEL data 2015-2016). Snow persisted from November to May each year in much of the core study area. Mean annual precipitation was 77 cm for 2015 and 2016 (Natural Resource Conservation Service, SNOTEL data 2015-2016). Historic average annual snowfall for the Howard Prairie Dam weather station was 349 cm, and average annual precipitation was 82 cm (Western Regional Climate Center, historic data 1960-2005).

Capture and handling

We radio collared adult fishers with very high frequency (VHF) transmitters (Advanced Telemetry Systems, Isanti, Minnesota, USA; Type = 1820 28-31g) in accordance with necessary permits (Objective 1 methods, Capture and handling). We placed uniquely patterned pieces of reflective banding on the VHF antenna for individual identification with remote cameras. We located inactive fishers to their resting or denning location (Appendix A1.3).

Rest and den site - structures and microsites

Fishers were located to their resting or denning structures by homing in on radio signals until a single structure was identified as the likely source of the signal. At each structure we recorded structure type (live tree, snag, log, etc.), microsite type (mistletoe broom, cavity, etc.), and access to the microsite (broken trunk, woodpecker hole, etc.). When applicable we recorded structure species, diameter at breast height (DBH), and estimated structure and microsite height. Additionally, we recorded site characteristics including canopy cover class, tree size composition, slope, and aspect. Each structure was tagged with a unique tree marker for future relocation and identification. If a technician was uncertain whether they might have pushed an individual into a tree during radio tracking, or if a single structure could not be identified as the likely rest structure, those data were excluded from further analyses.

Reproductive ecology

Adult females were radio-tracked between March 15 and July 15 to determine reproductive status and to identify physical characteristics of natal den (where parturition occurs), maternal den (any den selected after the natal den and prior to weaning), and maternal rest structures (where kits are present with an adult female, post-weaning; defined here as first occurring on or after June 1) (Green 2017). Beginning March 15, females were monitored daily by triangulation for suspected denning behavior. If a female was located in the same area for two or more consecutive days, a technician homed in on the radio signal to identify a single structure that the signal was most likely

coming from. If the female was located in this structure for 3 or more consecutive days, the structure was identified as a den site. We deployed 1-3 remote cameras at each confirmed or suspected den site to monitor activity and estimate fecundity. We monitored females at least once per week after a den was initially located to confirm continued use of the den structure. When a female was determined to have moved to a new den site, we attempted to locate the new structure until kits were weaned and semi-mobile or until females were moving too frequently to document re-use of structures.

Denning female movements

Two adult female fishers were captured and fitted with GPS collars (Sirtrack LiteTrack RF-40, Sirtrack Limited, Havenlock North, New Zealand) in March 2018 prior to den initiation. Collars were equipped with swift fix technology and were programmed to attempt locations every 30 minutes. Data were regularly downloaded remotely until the collars were no longer functioning. To describe denning female movements, we calculated daily minimum distances traveled and maximum linear distance from the den as a function of number of days since suspected parturition (den initiation). We compared these values with daily distances traveled of the same females using GPS data from their preceding collar deployments in the fall and winter of 2017. Locations with a horizontal degree of precision (HDOP) greater than 5 were excluded from analyses, as GPS error increases with an increasing HDOP value.

Results

We captured 16 fishers (8 female, 8 male) and radio-tracked 13 adults (6 females and 7 males) between October 2015 and August 2018. We located 146 unique rest structures, 86 used by females and 61 used by males (Table 3.1). Fishers used a wide variety of rest structures; however, most rest structure microsites were mistletoe brooms (32%) or cavities (23%). The tree species most frequently used for rest and den structures (Douglas-fir, 48%, and white fir, 27%) were also the species most commonly found in the study area. Females tended to use slightly larger diameter structures than males and also used cavity rest microsites most frequently, whereas males used mistletoe broom microsites more frequently than cavities. Re-use was documented at 16 (11%) of unique rest structures based on VHF telemetry methods, primarily but not exclusively by the same individual who was originally documented as the structure (81% of re-use events).

Of the 6 females monitored, all 6 individuals denned or attempted to den at least once during the course of the study, and we documented 29 unique den and maternal rest structures. One den failure was documented during the natal den period (F01T 2017), one failure was suspected during the late maternal denning period (F08T 2018), and two failures occurred shortly after kits were weaned (F02T 2017 & F01T 2018). Mean date of den initiation was March 25, and mean litter size was 2.1 kits. Dens and maternal rest sites were located in the largest diameter structures, primarily in snags (45%) and live trees (38%) at the structure scale. Re-use of dens across years occurred at only 2 structures.

Rest and den site - structures and microsites

Females were documented using a wider variety of rest and den structures including live trees, snags, logs, slash piles, rock piles, and stumps; whereas males were documented using live trees, snags, logs, slash piles, and one natural downed woody debris pile (Figure 3.1). Rest and den structure sizes ranged from 21 to 211 cm DBH. Overall, den and maternal rest sites were located in the largest structures (102 ± 22 cm DBH, $\bar{x} \pm SD$), followed by female rest sites (97 ± 33 cm DBH) and male rest

sites (90 ± 47 cm DBH). Most fisher rest sites were located in live trees ($n=80$, 55%), but a higher percentage of fisher dens were found in snags (45%) than in live trees (38%).

Males tended to use a wider range of live tree diameters and a smaller range of logs and snag diameters than females did (Figure 3.2). This may be attributed to the differential use of rest microsites between males and females (Figure 3.3, Table 3.2). Females tended to use cavity microsites most often (29% of female rest sites) and more frequently than males, while males tended to use mistletoe brooms most frequently (49% of male rest sites).

Most rest microsites were either cavities or mistletoe brooms (77%); other microsites included interstitial spaces in downed woody debris and rock piles, broken top platforms, stick nests, branch clusters, both large and small branches, physical damage scars on the trunk, and subnivean space under logs (Figure 3.4). Female den sites were restricted exclusively to structures with cavities (live structures and snags) until kits were weaned and semi-mobile, when females were documented using both slash piles and logs as maternal rest structures (Figure 3.5).

Fisher rest and den sites were found most frequently in tree species that were most available on the landscape, especially Douglas-fir and white fir (Figure 3.6). Den structures tended to be larger than rest sites of the same species (Table 3.3). Incense cedars were used more frequently as den sites than as rest sites, although use of this species was limited to two individuals (F02T & F06T) with higher occurrences of incense cedar within their home ranges.

Reproductive ecology

From 2016-2018, we documented 29 den and maternal rest structures for fishers (Table 3.4). During the 2016 denning season, we documented the denning behavior of 3 adult females, all of which initiated dens and successfully raised kits to weaning. During the 2017 den season, we followed 4 adult female fishers, 3 of which initiated dens. One individual failed shortly after den initiation for unknown reasons, and 2 individuals successfully raised kits to weaning; however, one of the successful denning females was predated shortly after kits were weaned and the kits were unlikely to have survived on their own. During the 2018 denning season, all 4 telemetered adult females exhibited denning behavior. One individual slipped out of her collar prior to kit weaning so her success or failure is unknown. One individual is suspected to have failed in mid-May, and two individuals raised their kits to weaning age. One of the two females who denned to weaning appeared to have abandoned her kits in early June, and an attempt to rescue and rehabilitate her 3 kits was unsuccessful. This female was detected in the den area 2 days after the kits died so we know that the apparent abandonment of her kits was not a result of her mortality.

Average date of den initiation was March 25 (Table 3.5). Mean litter size was 2.11, with some apparent kit mortality prior to weaning due to unknown reasons and/or apparent complete den failure. Females used an average number of $2.18 (\pm 0.87)$ dens per season prior to weaning kits, spending an average of $33.22 (\pm 17.34)$ days at natal dens and $16.80 (\pm 12.67)$ days at maternal dens. Fishers were documented using Douglas fir, white fir, incense cedar, and red fir (Figure 3.6), ranging in size from 72 to 155 cm DBH and a mean of $102 (\pm 22)$ cm DBH, as den structures. Maternal rest structures used post-weaning for rearing kits included slash piles, white fir logs, and incense cedar live trees and snags.

Denning female movements

We captured two adult females and fit them with GPS collars just prior to the 2018 denning season. One female (F07T) wore the collar for 44 days before slipping out of it and was consequently monitored for only 21 days past suspected parturition. The collar on the second female (F01T) operated for 75 days before the GPS battery failed and was monitored 57 days past suspected parturition.

Discussion

These data suggest fishers in the Oregon Cascades use primarily larger diameter structures with cavities and mistletoe brooms. The only other study on fisher rest and den ecology in the southern Oregon Cascades reported similar findings and also reported frequent use of mistletoe brooms as resting platforms (Aubry and Raley 2006, Aubry et al. 2018a). We documented higher use of cavity rest sites for both females and males in addition to more frequent use of snags and slash piles as rest structures than reported by Aubry and Raley (2006) and Aubry et al. (2018). Similar to research in southern California, our males used platform microsites more frequently than cavities, in contrast to females (Green 2017). Both sexes have been reported to use large diameter structures surrounded by stands with structural complexity in proximity to the structure (Purcell et al. 2009, Aubry et al. 2013, Green 2017).

Retaining or recruiting a diversity of large, old structures (e.g., large woody debris, live trees) with suitable rest and den microsites will be important to maintain fisher habitat supportive of viable populations. Large snags and live trees with cavities are of particular importance because natal dens appear to occur exclusively in those structure types. It does not appear that providing slash piles, large logs, and live trees with mistletoe brooms in the absence of large snags and trees with cavities will provide for the natal dens necessary for successful reproduction. Here we did not measure tree age, but diameter is often correlated with tree age and the structures used by fishers were significantly larger than the majority of structures on the existing landscape (Fig 3.2b). Time is the most important factor in developing microsites used by fishers, as cavities formed by heart rot decay in living trees – even with inoculation – require centuries to develop a chamber large enough for a fisher (Hennon and Mulvey 2014). Cavities were the most dominantly used microsite for females and are likely disproportionately used during temperature extremes.

In addition to standing trees and snags, large woody structures provide thermal buffering during extreme temperatures and may be particularly important for maternal den sites during the portion of kit rearing post- weaning but when dependent kits are still not developed enough to climb trees. We observed fishers resting in subnivean locations associated with logs during winter (3% of all rest structures). Similarly, in other studies with smaller average tree sizes and dominated by *Populus* sp. cavity microsites, subnivean chambers within down woody material accumulations were the most heavily used microsites during winter (Weir et al. 2004). Fishers have high metabolic costs in cold temperatures (Buskirk et al. 1989, Buskirk and Harlow 1989), and the insulation that a deep snowpack adds to buried woody structures may be helpful for fishers to minimize energy expenditure in winter months.

Having access to suitable rest structures is an important aspect of fisher life history, yet the appropriate metrics for availability have yet to be determined. For example, it is still unclear how many rest structures a fisher requires over a lifetime, how rest structures should be distributed at smaller (e.g., home range) and larger (e.g., landscape) spatial scales, or what proportion of forest

within a fisher's home range can be treated with stand simplifying treatments before availability of resting refugia becomes a limiting factor. Data from the southern Sierras suggested no effect on fisher population demographic parameters or occupancy with approximately 1% of the landscape treated with thinning treatments (Purcell et al. 2018). Addressing these challenges presents the logical next step, and further research is required to answer these questions.

Information on fisher reproductive structures in the Pacific states is generally sparse; however, our data corroborates previous research (Green 2017) which indicates that reproductive locations are typically found in large diameter woody structures. Of the 22 reproductive structures that we identified, 100% were in woody structures, with natal and maternal dens found exclusively in snags, live trees, and logs. While there was no significant difference in size between fisher reproductive structures and rest structures, we suspect reproductive structures have more specific microsite elements needed for successfully rearing kits (Matthews et al. In review).

All natal dens were located in arboreal structures, including snags and live trees, within cavity microsites. Microsites such as cavities may provide optimal thermal buffering for altricial young (Maziarz and Wesołowski 2013, Green 2017) and reduce toxins like oxygen deficient conditions from smoke (Thompson and Purcell 2016). Cavities within large diameter woody structures, in particular, should offer relatively dry and well-insulated locations. Elevated cavities in snags and trees may also improve protection for non-mobile kits from predators, such as bobcats (*Lynx rufus*) and mountain lions (*Puma concolor*), compared to ground-based structures, such as logs and slash piles.

Similar to natal dens, maternal dens were largely (94%) located in live trees and snags, with cavities comprising all microsites within those structures. One late maternal den was located in a log (Table 3.4). The continued use by female fishers of secure locations for maternal dens, following natal dens, is reflected by kit development. For example, kits were typically removed from the natal den prior to being weaned or becoming mobile, and were moved between maternal dens by being "scruffed"; kits did not move between natal dens under their own power. Kits became mobile during the use period of maternal dens, but movements were limited to the immediate vicinity of the den structure in the presence of the adult female.

In contrast, maternal rest structures were more often in ground-based structures such as logs and slash piles (64%) than in arboreal structures such as snags and live trees (36%, Table 3.4). This finding is similar to some previous studies, which suggest that fishers and martens are more likely to use above-ground structures earlier in the reproductive period and ground-based structures later in the reproductive period (Wynne and Sherburne 1984, Matthews unpublished data, Moriarty unpublished data, this study, Strickland and Douglas 1987, Bull and Heater 2001, Green 2017). Ground-based structures may be less secure locations than arboreal structures, yet the reduction in security may be offset by kits becoming less dependent and increasingly mobile. This was evidenced by our observations of increased kit movement at maternal rest structures, often in the absence of the adult female.

Our study presents the first findings on fine-scale movement patterns of denning female fishers. During denning, female fishers slightly transition from a wide-ranging foraging strategy to central point foraging strategy (Higley and Matthews 2006). Despite centering their foraging on the den, we found that denning females with dependent kits still traveled great distances (over 20 km in 24-hours) and were found over 6 linear km away from their dens (see also Appendix 5).

Daily distances traveled during the denning season exceeded distances traveled prior to the denning season, supporting previous research findings that lactation increases energetic demands

(Powell 1979, Powell 1993) and that energetic demands of fishers double from the time of parturition to the time that kits are 60 days old (Powell and Leonard 1983). In addition to vulnerability from increased energetic demands, increased distances traveled and time spent foraging may increase the risk of predation to lactating female fishers (Zera and Harshman 2001). Increased travel distances as kits aged suggests that females are likely spending more time away from the den to forage as kits develop. Radio-telemetry data loggers deployed at dens on the Klamath Plateau generally support this theory, but paired GPS and den attendance data were not achievable due to relatively low successful fix rates of the GPS collars (particularly while females were in the den) and limited VHF operating schedules for the GPS collars. However, previous research reported that the percentage of time female fishers spent at the den decreased from approximately 80-90% when kits were first born to approximately 30% by the time kits were being weaned (Cummins 2016).

Fisher litters are also particularly vulnerable to mortality during the early denning period, from birth to 40 days old (Matthews et al. In Review). During this early denning period, our monitored females traveled up to 16.6 km in a single day and were found up to 6.8 linear km away from their dens. Future research could focus on expanding sample size to understand the movement patterns of denning females and how this may influence adult female survival and litter survival.

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Tables and Figures

Table 3.1. Structure types and diameter at breast height (DBH) of male and female fisher rest and den sites in the southern Cascades of Oregon.

Structure Type	Females						Males		
	Rest Sites			Dens & Maternal Rest Sites			Rest Sites		
	n	mean DBH \pm sd (cm)	%	n	mean DBH \pm sd (cm)	%	n	mean DBH \pm sd (cm)	%
live tree	43	94 \pm 37	50	11	107 \pm 28	38	38	80 \pm 46	62
snag	20	108 \pm 21	23	13	96 \pm 17	45	13	111 \pm 52	21
log	10	89 \pm 30	12	1	114	3	5	91 \pm 18	8
slash pile	10		12	4		14	4		7
rock pile	2		2						
stump	1		1						
downed woody debris							1	143	2
Total	86	97 \pm 33		29	102 \pm 22		61	90 \pm 47	

Table 3.2. Total number, average size, and percentage of microsite types found at fisher rest structures in the southern Cascades of Oregon.

Microsite	Females			Males		
	n	mean DBH \pm sd (cm)	%	n	mean DBH \pm sd (cm)	%
cavity	21	100 \pm 30	29	12	97 \pm 40	21
mistletoe broom	20	83 \pm 28	28	28	79 \pm 39	49
interstitial space	12		17	6	106 \pm 52	11
broken top	5	115 \pm 11	7	3	154 \pm 57	5
small branch	4	84 \pm 47	6			
stick nest	3	76 \pm 64	4	6	54 \pm 14	11
other	3	83 \pm 34	4			
large branch	2	149 \pm 20	3			
branch cluster	1		1	2	46 \pm 26	4

Table 3.3. Total numbers and sizes of tree species used by female and male fishers as rest and den structures in the southern Cascades of Oregon.

Species	Rest Sites			Dens & Maternal Rest Sites		
	n	mean DBH \pm sd (cm)	DBH Range (cm)	n	mean DBH \pm sd (cm)	DBH Range (cm)
Douglas fir	71	93 \pm 46	21 - 211	3	119 \pm 32	93 - 155
White fir	29	87 \pm 21	46 - 124	12	94 \pm 17	72 - 123
Red fir	8	96 \pm 20	65 - 135	3	120 \pm 19	89 - 152
Sugar pine	6	130 \pm 8	116 - 137			
Unknown	7	107 \pm 22	76 - 142			
Ponderosa pine	5	69 \pm 35	29 - 110			
Incense cedar	1	56	56 - 56	7	100 \pm 19	81 - 129
Lodgepole pine	1	28	28 - 28			
Total	128	93 \pm 39	21 - 211	25	102 \pm 22	72 - 155

Table 3.4. Summary of fisher dens from 2016-2017 in the southern Oregon Cascades. Total days indicates the number of days that an individual was known to use the structure, though there may have been days where the structure was used but not documented prior to the first use date or after the last use date. No. kits indicates the number of kits that were documented at the structure either visually or by remote camera photographs.

Fisher ID	Year	Den Type	Structure Type	Species	DBH (cm)	First use	Last use	Total days	No. Kits	
F01T	2016	natal	live tree	White fir	74	3/22/16	5/5/16	45	0	
		maternal	snag	Douglas fir	112	5/9/16	6/1/16	24	2	
		maternal rest	slash pile			6/15/16	6/15/16	1	2	
	2017	natal	snag	White fir	86	3/27/17	3/28/17	2	0	
	2018	natal	snag	White fir	86	3/25/18	4/11/17	18	0	
		maternal	snag	Red fir	119	4/17/17	6/3/17	48	3	
F02T	2016	natal	live tree	Incense cedar	115	4/28/16	5/23/16	26	2	
		maternal	snag	Incense cedar	88	5/24/16	5/29/16	6	2	
		maternal rest	slash pile			5/31/16	6/6/16	7	2	
		maternal rest	slash pile			6/13/16	6/14/16	2	0	
		maternal rest	slash pile			7/5/16	7/8/16	4	1	
		maternal rest	log	White fir	66	7/18/16	7/18/16	1	1	
	2017	natal	live tree	Incense cedar	129	3/25/17	4/22/17	29	3	
		maternal	live tree	Incense cedar	84	4/26/17	5/24/17	29	3	
		maternal	log	White fir	114	5/30/17	5/31/17	2	3	
		maternal rest	log	White fir	66	6/6/17	6/12/17	7	3	
	F03T	2016	natal	live tree	Douglas fir	155	3/31/16	6/3/16	65	2
			maternal	snag	Douglas fir	93	6/7/16	6/15/16	9	2
2017		natal	snag	Douglas fir	119	3/28/17	4/13/17	17	0	
		maternal	live tree	White fir	90	4/24/17	4/26/17	3	0	
		maternal	snag	Douglas fir	123	5/1/17	5/24/17	24	0	
		maternal	snag	White fir	73	5/30/17	6/2/17	4	1	
		maternal rest	snag	White fir	95	6/5/17	6/24/17	20	1	
F06T	2018	natal	live tree	Incense cedar	114	3/22/18	5/12/18	52	1	
		maternal	snag	White fir	90	5/17/18	6/5/18	20	1	
		maternal rest	snag	Incense cedar	81	6/14/18	6/14/18	1	1	
		maternal rest	live tree	Incense cedar	89	6/18/18	6/18/18	1	1	

		maternal rest	snag	White fir	84	6/28/18	6/28/18	1	1
F07T	2017	natal	snag	White fir	86	3/27/17	4/22/17	27	1
		maternal	live tree	Red fir	152	4/25/17	6/2/17	39	3
F07T	2018	natal	snag	White fir	86	3/29/18	4/24/18	27	1
F08T	2018	natal	live tree	Red fir	89	4/10/18	4/20/18	11	1
		maternal	live tree	White fir	90	4/23/18	5/9/18	17	0

Table 3.5. Den initiation dates and number of suspected kits for each adult female fisher monitored in the southern Cascades of Oregon from 2016-2017. Suspected initiation dates indicate dates when fishers were first located by triangulation or homing at the natal den site. *Indicates that some kits survived to weaning but were known to have died after weaning and prior to independence.

Fisher ID	Year	Suspected Initiation Date	Max No. Kits Suspected	No. Kits to Weaning
F01T	2016	22-Mar	2	2
	2017	25-Mar	-	0
	2018	28-Mar	3	3*
F02T	2016	Unknown	2	2*
	2017	22-Mar	3	3*
F03T	2016	31-Mar	2	2
	2017	25-Mar	2	1
F06T	2018	19-Mar	1	1
F07T	2017	25-Mar	3	3
	2018	29-Mar	2	-
F08T	2018	Unknown	1	-
Mean		25-Mar	2.111	1.556

Table 3.6. Distances (in meters) that two female fishers traveled away from their respective dens during the 2018 denning season on the Klamath Plateau. n represents the number of days monitored past suspected parturition.

Fisher ID	n (days)	Mean Distance (m) \pm sd	Range (m)
F01T	57	2331 \pm 1631	4 – 6775
F07T	21	1793 \pm 1166	18 – 4354

Table 3.7. Minimum distances (in meters) that two female fishers traveled during 24-hour periods during and prior to the 2018 denning season. n represents the number of days monitored past suspected parturition or the number of days monitored outside of the denning season.

Fisher ID	Season	n (days)	Mean Minimum Distance Traveled (m) \pm sd	Range (m)
F01T	Denning 2018	57	6597 \pm 4789	45 – 20,325
F07T	Denning 2018	21	5311 \pm 2610	1257 – 10,854
F01T	Winter 2017	34	7294 \pm 3069	829 – 13,803
F07T	Fall 2017	34	6129 \pm 2806	866 – 12,429

a) Live trees



b) Snags



c) Logs



d) Slash piles



Figure 3.1. Photo panel of structure types used by fishers as rest and den sites in the southern Cascades of Oregon. Photo C is an adult female fisher carrying a presumed juvenile northern goshawk (*Accipiter gentalis*) to her kits.

e) Stumps



f) Subnivean space



Figure 3.1 cont. Photo panel of structure types used by fishers as rest and den sites in the southern Cascades of Oregon.

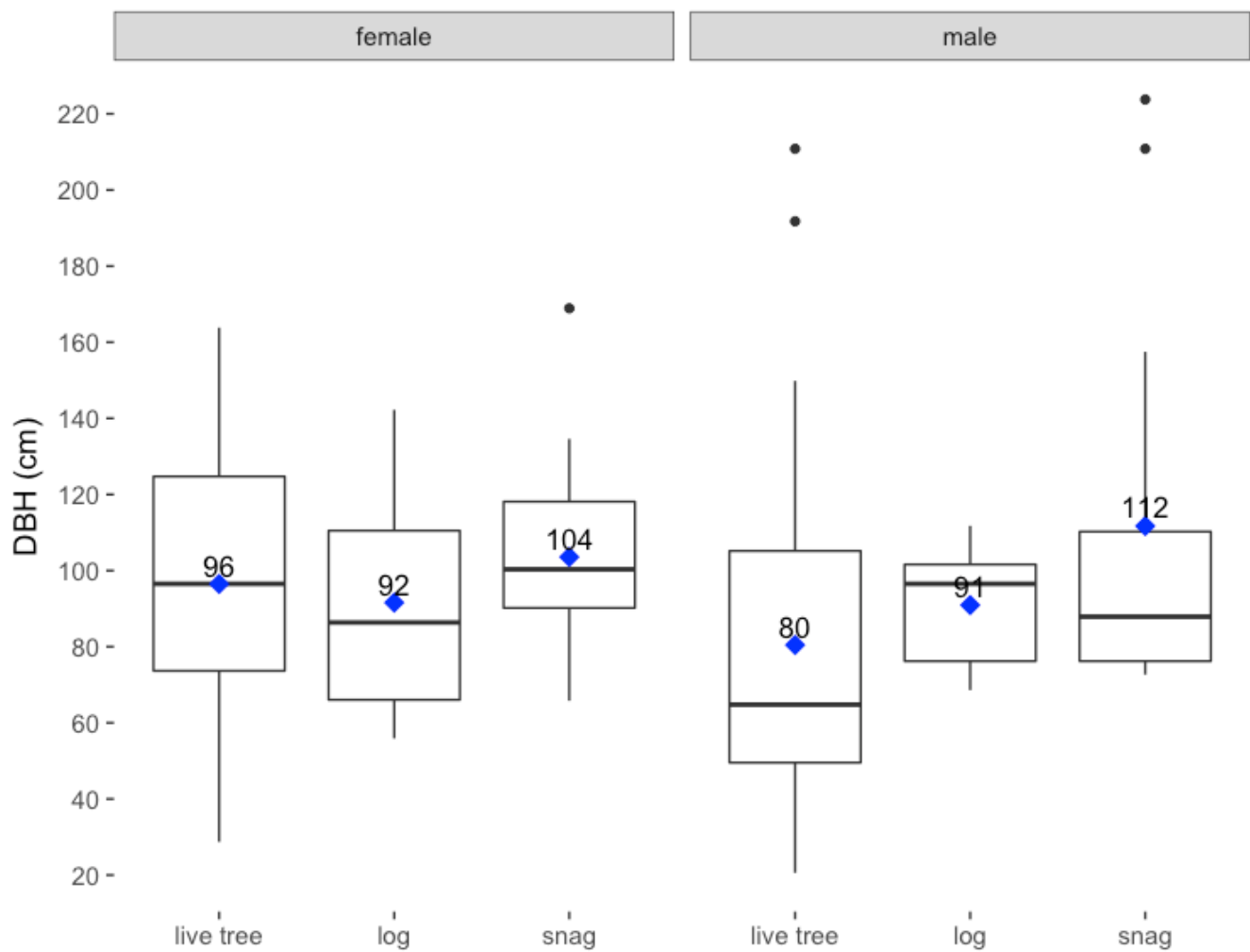


Figure 3.2. Diameter at breast of height of fisher rest and den structures in the southern Cascades of Oregon. Thick black lines represent median values, blue diamonds with labels represent mean values, boxes bound the 25 and 75% quartiles of the data, and black dots represent extreme values in the dataset.

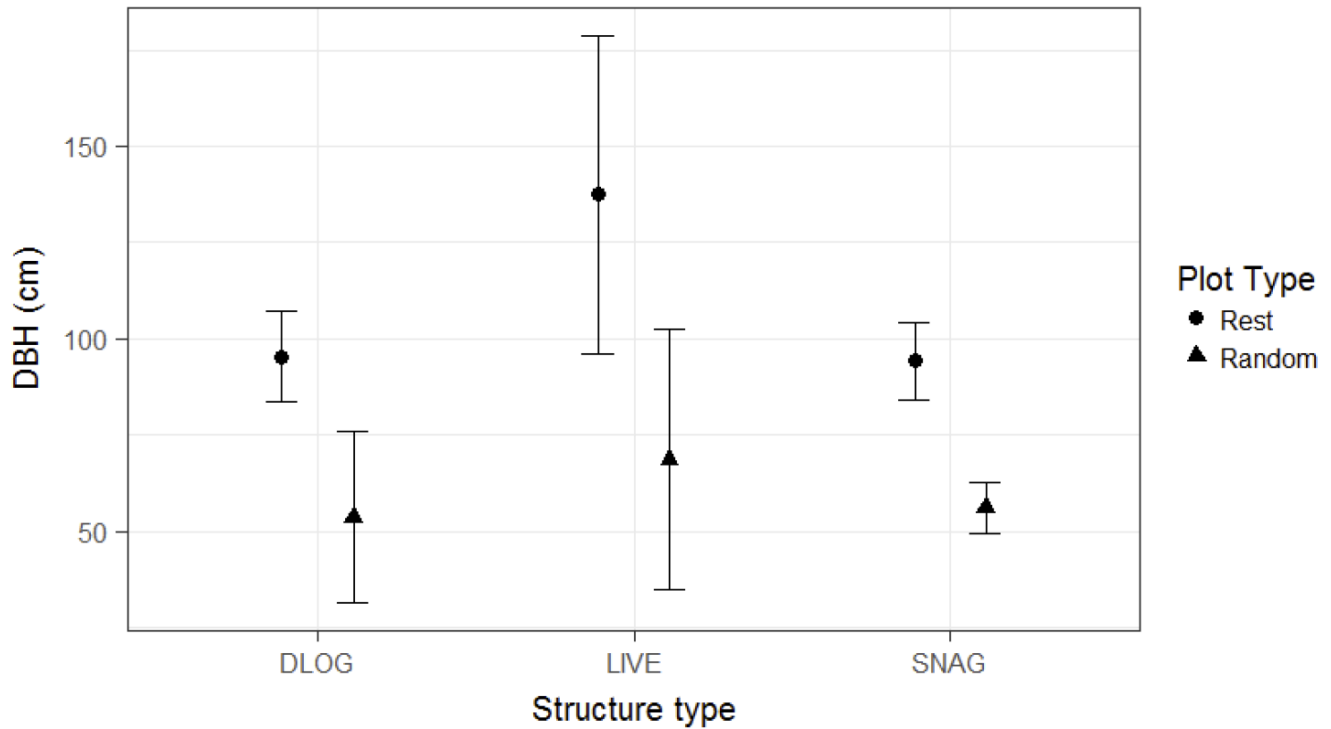


Figure 3.2b. Diameter at breast of height of a stratified random selection by individual of fisher rest and den structures (n= 70) and paired random structures within their home range in the southern Cascades of Oregon. Points represent the mean value with 95% confidence intervals with symbols demonstrating rest (circles) and random (triangles) for downed logs (DLOG), live trees, and snags. These data are preliminary results from vegetation data collected at a subset (~50%) of known fisher rest and den locations paired with random locations within that fisher's home range.

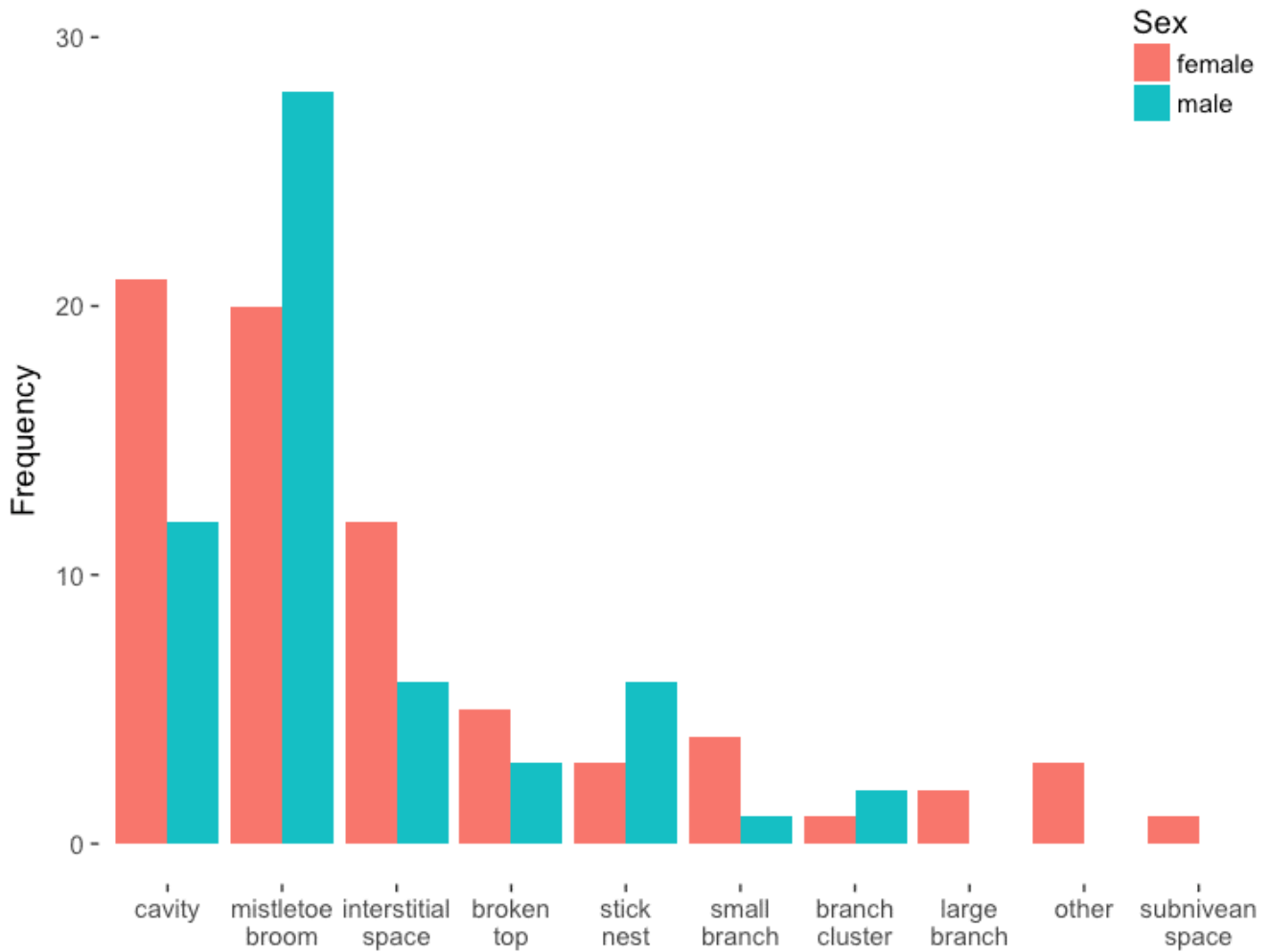


Figure 3.3. Frequency of fisher rest site microsites used by females (red) and males (blue) in the southern Cascades of Oregon. These data do not include den or maternal rest site microsites, which were restricted to cavities at dens but also included interstitial space for maternal rest sites.

a) Cavities



b) Mistletoe brooms



c) Broken tops



d) Stick nests



Figure 3.4. Photo panel of microsites fishers used at rest/den structures in the southern Cascades of Oregon.

e) Branch clusters



f) Large branches



h) Small branches



i) Other (i.e., hollow in trunk, cut top)



Figure 3.4 cont. Photo panel of microsites fishers used at rest/den structures in the southern Cascades of Oregon.

a) Live trees. This Douglas fir tree was used as a natal den by F03T in 2016.



b) Snags. This white fir snag was used as a natal den by F01T in 2017.



Figure 3.5. Examples of natal den (a and b), maternal den (c, d, and e) and maternal rest (f and g) structure types in the southern Cascades of Oregon.

c) Live trees. This red fir tree was used as a first maternal den by F07T in 2017.



d) Snags. This incense cedar snag was used as a first maternal den by F02T in 2016.



Figure 3.5 cont. Examples of natal den (a and b), maternal den (c, d, and e) and maternal rest (f and g) structure types in the southern Cascades of Oregon.

e) Logs. This Douglas fir log was used as a maternal den by F02T in 2017.



f) Slash piles. This slash pile was used as a maternal rest site by F01T in 2016.



Figure 3.5 cont. Examples of natal den (a and b), maternal den (c, d, and e) and maternal rest (f and g) structure types in the southern Cascades of Oregon.

g) Logs. This white fir log was used as a maternal rest site by F02T in 2017.



Figure 3.5 cont. Examples of natal den (a and b), maternal den (c, d, and e) and maternal rest (f and g) structure types in the southern Cascades of Oregon.

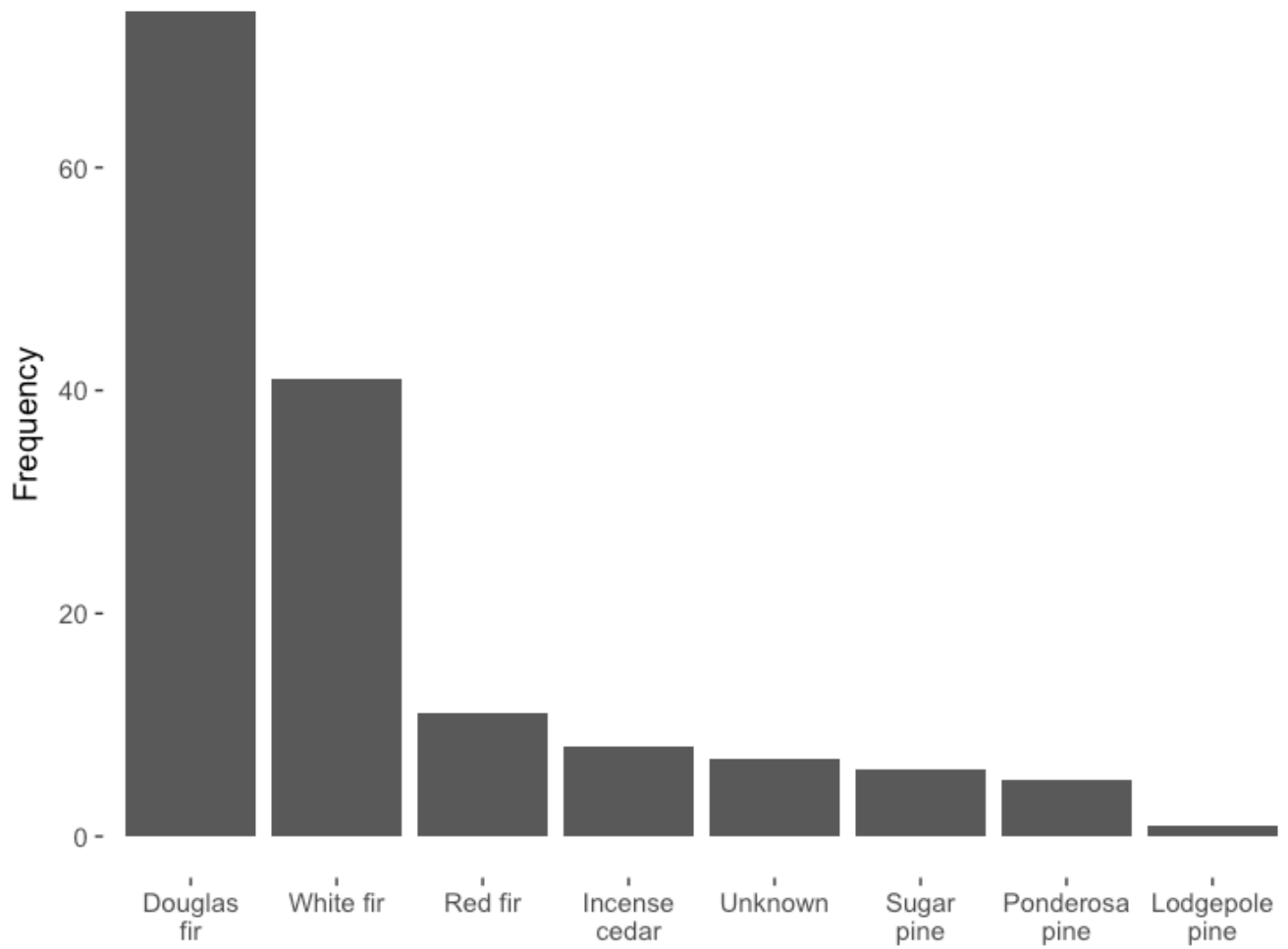


Figure 3.6. Frequency of tree species used as fisher rest and den structures in the southern Cascades of Oregon.

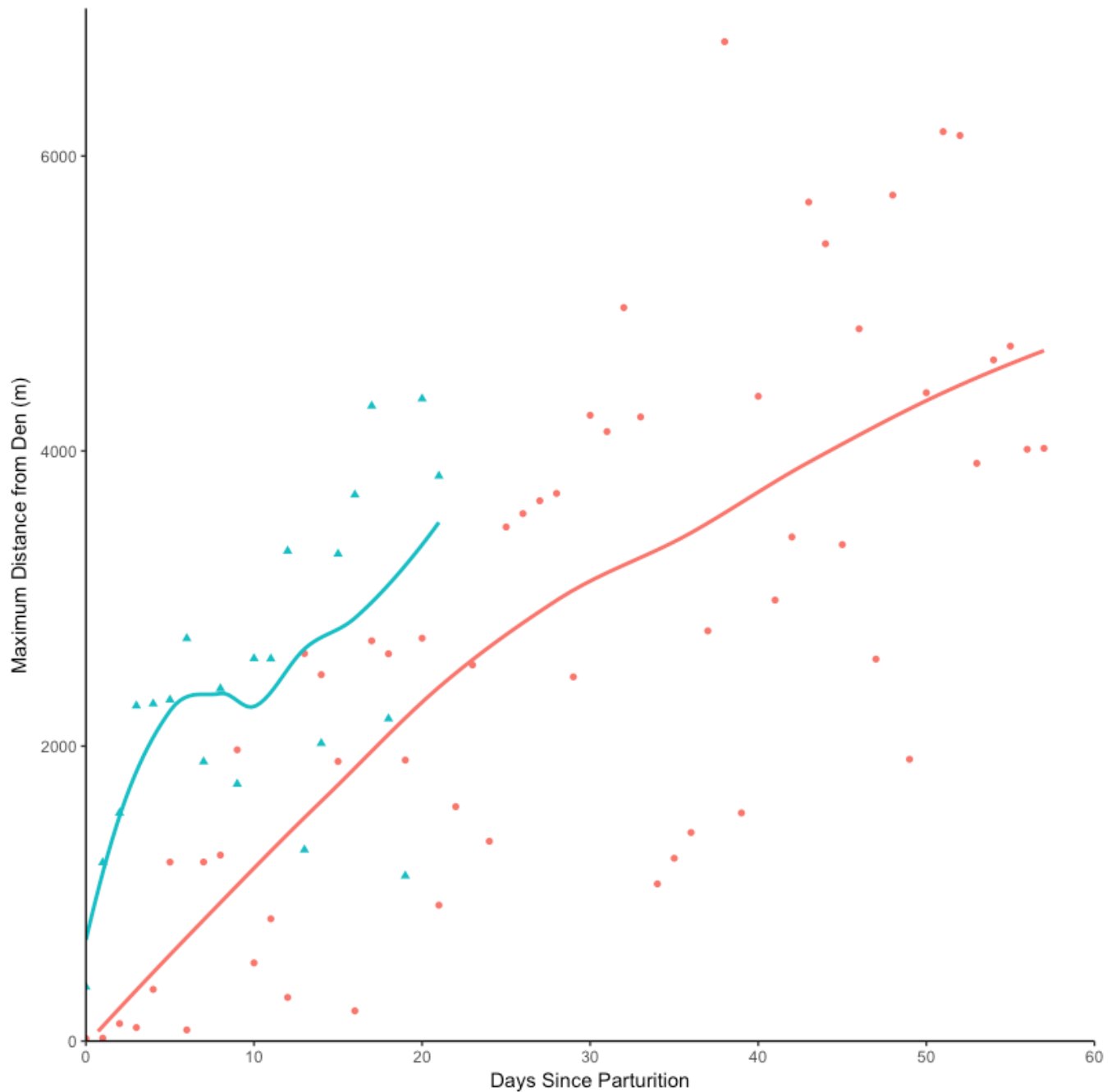


Figure 3.7. Maximum linear distances that two female fishers traveled away from their dens as a function of days since suspected parturition. Both females traveled over 1 km away from their dens before kits had reached 1 week of age, and the maximum distance a female was found away from her den (6.7 km) occurred before kits were 6 weeks old. Lines represent LOESS (locally weighted scatterplot smoother) regressions, whereas points represent actual distance values in meters. The blue line with triangle points represents data from fisher F07T, while the red line with circle points represents data from F01T.

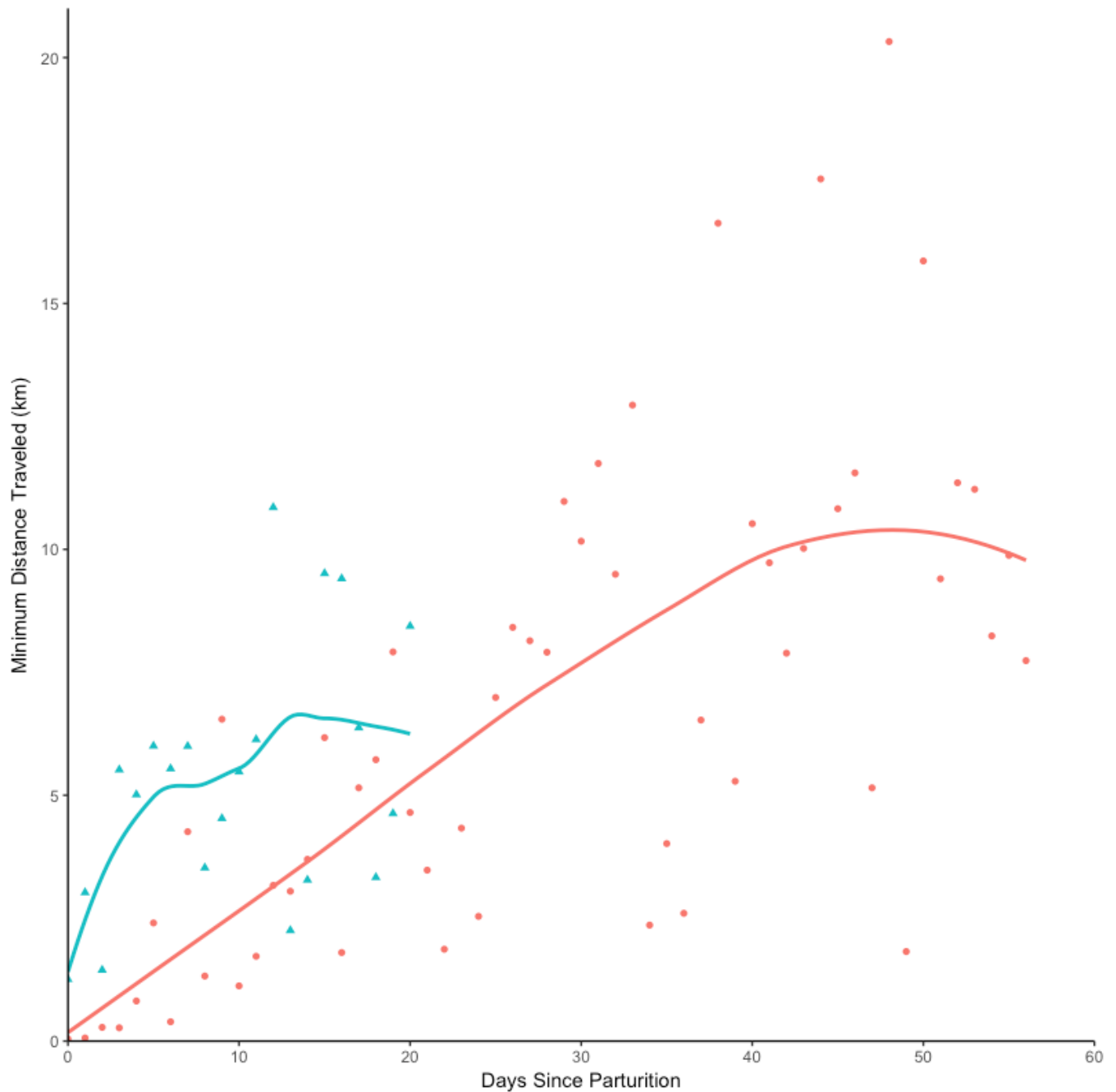


Figure 3.8. Minimum distances traveled by two female fishers as function of days since suspected parturition. Females were already traveling an average of over 5 km per day by the time kits were 3 weeks old. One female traveled over 20 km in a day before her kits were weaned. Lines represent LOESS (locally weighted scatterplot smoother) regressions, whereas points represent actual distance values in kilometers. The blue line with triangle points represents data from fisher F07T, while the red line with circle points represents data from F01T.

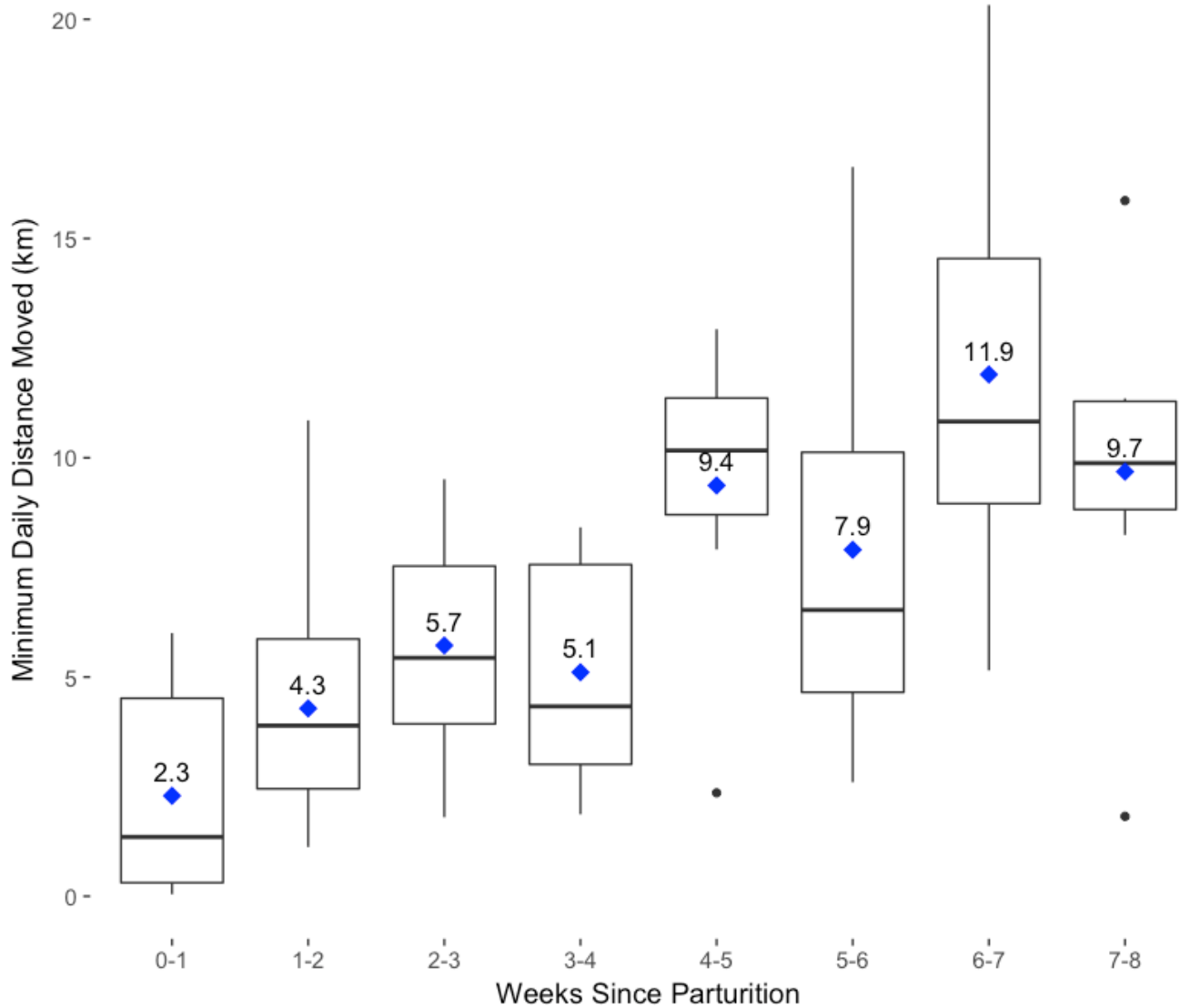


Figure 3.9. Weekly averages and distributions of minimum daily distances moved by female fishers during the 2018 denning season. Thick black lines represent median values, blue diamonds with labels represent mean values, boxes bound the 25 and 75% quartiles of the data, and black dots represent extreme values in the dataset.

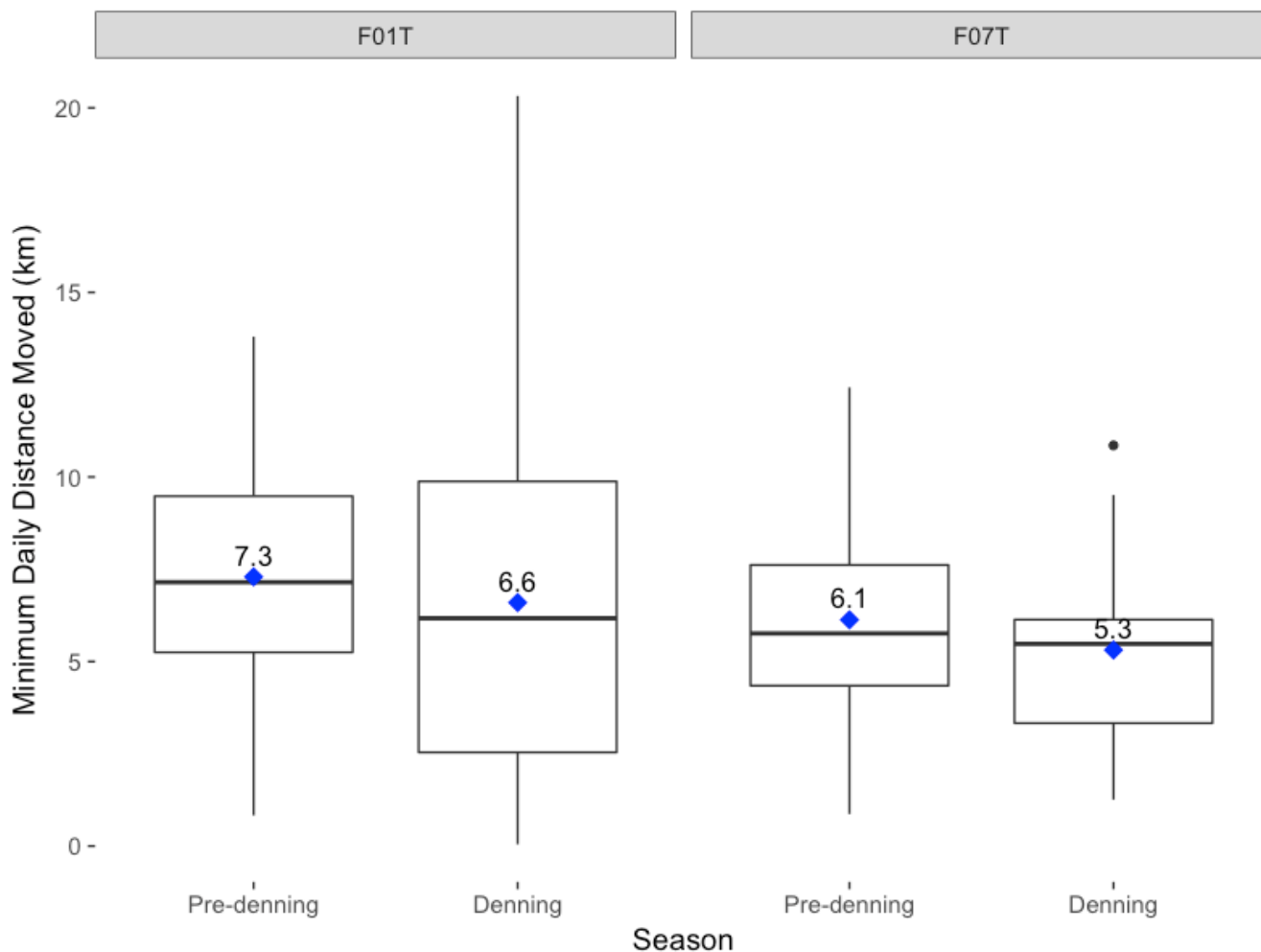


Figure 3.10. Distribution and average minimum daily distances moved for two female fishers with GPS collar deployments the prior to (pre-denning) and during the denning seasons. Thick black lines represent median values, blue diamonds with labels represent mean values, boxes bound the 25 and 75% quartiles of the data, and black dots represent extreme values in the dataset. Denning season data for F07T was limited to 21 days of monitoring, due to a slipped collar, while F01T was monitored for 57 days during the denning season.

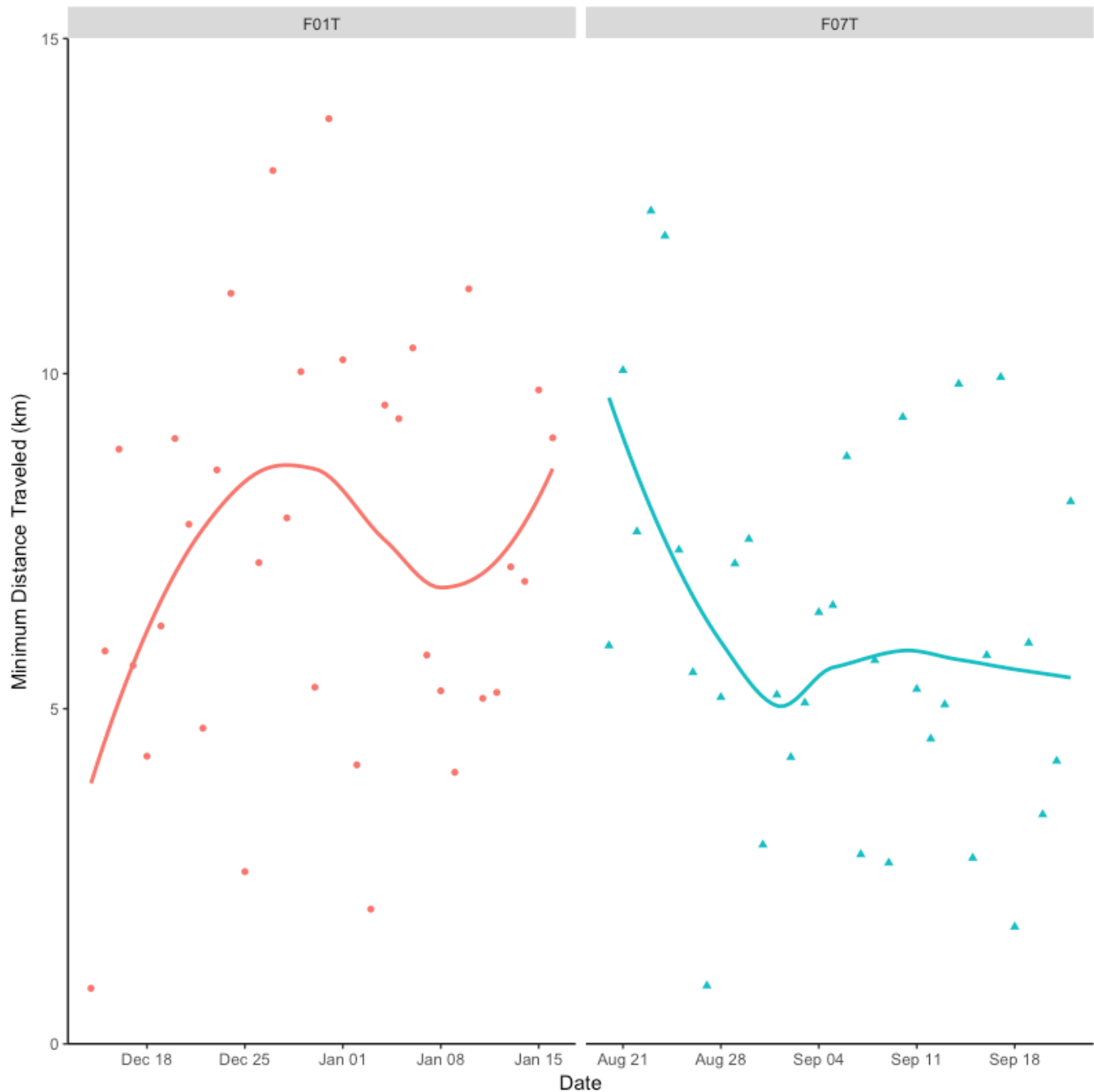


Figure 3.11. Minimum 24-hour distances traveled by two female fishers prior to the 2018 denning season. Minimum daily distances traveled prior to denning averaged 5.67 km (± 3.3 SD). Lines represent LOESS (locally weighted scatterplot smoother) regressions, whereas points represent actual distance values in kilometers.

Additional research products: using GPS data to identify rest zones: progress and update

Introduction

Species that nest or den in cavities (e.g., chambers in trees, snags, under the snow), or use similar features daily, are examples for which site fidelity may be essential to individual fitness. Cavities and surrogates (e.g., subterranean burrows, rock crevices, dense mistletoe brooms, bird and squirrel nests) may provide benefits such as local thermal refugia, reducing temperature extremes and noxious compounds (Thompson and Purcell 2016), reduced predation (Matthews et al., in review), or increased thermal insulation (Taylor and Buskirk 1994, Maziarz and Wesołowski 2013). Nests and dens may be used annually for several years, with animals either dispersing or moving in short proximity (e.g., Shields 1984). As such, structures with elements (“microsites”) used for denning, resting, and nesting are focal for species conservation and often sought for preservation (Gibbons and Lindenmayer 1997). Nonetheless, the locations of these structures may be exceedingly cryptic, with identification requiring radio telemetry or trained field observers following adults demonstrating breeding behavior (Martin et al. 2004).

Recent technology may assist in accurately quantifying rest and den structure use. Satellite telemetry has proven more accurate than previous methods to identify nests for turtles (Tucker 2010). Similar methods assigning GPS point clusters have been used to identify prey remains for large carnivores (Cristescu et al. 2014, Blecha and Alldredge 2015, Cassaigne et al. 2016). Nonetheless, using satellite telemetry as a tool to identify rest or den structures has not been completed.

We evaluated whether GPS technology could be used as a conservation tool to identify critical structural elements for a rare and elusive mammalian carnivore, the fisher (*Pekania pennanti*). We predicted clusters of GPS locations could be used to minimally identify areas of increased importance, and that if fishers reused resting and denning structures, such clusters could accurately identify important structural elements. Second, we validated our technique and ascribed uncertainty using both VHF telemetry and remote cameras. Here, our goal was to understand whether GPS location cluster techniques could reveal locations and use of critical habitat elements used for fisher resting and denning. We describe predicted fisher resting ecology observed during our study, quantifying the number of predicted locations used monthly, duration of use, and spatial arrangement. We quantify the degree of fidelity within our study populations and test whether site fidelity was a function of structure type (e.g., log, snag), size (diameter), site-level features, or a combination therein.

Materials and methods

We deployed W500 Wildlink GPS collars (Advanced Telemetry Systems, Isanti, Minnesota, USA; 60-100g) on adult fishers opportunistically (October 2015-June 2018), but only analyzed a subset of our data for this exercise (October 2015 – June 2017) because a new analysis with a hidden markov model will likely eclipse these methods. While on free-roaming fishers, the GPS was programmed to estimate locations every 15 minutes or 30 minutes between attempted location attempts. We set the collars to estimate the percent activity from accelerometer-derived movement within each 15-minute period.

We combined data from both the GPS and movement summaries from the accelerometer to inform when we presumed a fisher was resting. We assumed a point cluster was a presumed resting event when 3 criteria occurred: (1) consecutive locations were <30 minutes apart, (2) the distance between consecutive locations was <60m which was double expected accuracy, and (3) activity was less than 10% of the prior 15 minute bout (e.g., moving less than 1.5 minutes total). We considered a resting event to have occurred only if these criteria were met for >1.5 hours. Then, we spatially

defined the area where we presumed the fisher was resting, suspecting there was a measurable zone. We presumed “restzones” encompassed the rest structure and used criteria where there was at least 1 cluster by at least 1 individual. The accumulation of cluster locations were joined and buffered by 10m. Each restzone was assigned a unique identification number (Figure 4.1).

We tested whether our criteria for identifying restzones from GPS location data were accurate using two methods. First, we conducted radio telemetry during our study and had technicians identify resting and denning structures using VHF telemetry. From these data, we were able to identify the precise resting structure, structure type (e.g., log, snag, live tree), size (diameter at breast height), and microsite (e.g., cavity, mistletoe broom). Second, we identified restzones with high estimated reuse (based on the presence of multiple GPS location clusters over time at the rest zone) and placed remotely triggered cameras facing suspected rest structures. We monitored both a subset of rest structures and within restzones with remote cameras. Each structure or restzone was monitored with remote cameras for a period of 3 months to address potential seasonal variability in use of different rest structure types, but also to provide enough time for revisitation. We presumed that because a marten patrols the perimeter of its home range in an average of 4.6 days (Moriarty et al. 2017) and fishers appear to have similar movements within 22 days (Moriarty, unpublished data), that several opportunities for restzone or rest structure re-use would arise within a 90 day period. In addition, we attempted to address other potential sources of inter-individual and spatial variability by monitoring rest structures used by both male and female fishers and by monitoring rest structures spatially-distributed across the landscape.

We deployed cameras at structures within a restzone with the intent of maximizing detectability, i.e., maximizing the likelihood that we would capture a fisher on camera if it reused a given structure. Most large structures within the restzone were monitored with 2 cameras, but we used up to 9 cameras dispersed on structures within the amorphous area within the restzone to provide adequate coverage. We used Bushnell Aggressor Trophy cameras (Bushnell, Overland Park, MO), set ~4-5 m away from potentially used structures. The field of view of each camera typically included the ground and the access point for each structure; for example, for a live tree rest structure, approximately half of the field of view would include the bole of the tree, and the other half would include the ground at the base of the bole of the tree. The purpose of positioning the cameras in this orientation was two-fold: (1) to differentiate between fishers that were using the structure (e.g., entering and exiting) and fishers that were merely traveling within the vicinity of the structure (e.g., scent-marking at the structure and subsequently leaving), and (2) to detect other species of animals that may be traveling within the vicinity of fisher rest structures (e.g., fisher predators such as mountain lions or bobcats).

We processed and tagged photos using Picasa digital image processing software. We assigned all photographs of fishers with a confidence code (CC) to develop an index of structure reuse. Our confidence codes were based on proximity and orientation of a fisher to a rest structure (Figure 4.2a-d) in a given photograph and included: CC1 – fisher entering or leaving structure (Figure 4.2a); CC2 – fisher within a body length and in-line (i.e., moving towards or away) with a structure (Figure 4.2b); CC3 – fisher within a body length and not in-line (i.e., not moving towards or away) with a structure (Figure 4.2c); and CC4 – fisher within a photographic frame, at any distance greater than a body length away (Figure 4.2d).

From this, we calculated several metrics related to the use of each restzone: the number of presumed total resting events (clusters), the number of resting individuals, and the duration the fisher

was presumed resting. Further, we evaluated whether restzones were spatially clustered or dispersed, and the average distances between restzones used infrequently (e.g., 1-2 recorded clusters) and those used often (e.g., >5 recorded clusters).

When we had identified a structure and microsite using VHF telemetry, we also summarized the size of the structure and type of microsite as a function of the number of clusters (or presumed re-use events).

Ethics statement

All necessary permits were obtained for the described study, which complied with all relevant regulations. We captured and processed fishers using methods approved by the U.S. Forest Service Research and Development's Institute for Animal Care and Use Committee (Permit: 2015-003) and Oregon Department of Fish and Wildlife with a Scientific Take Permit (Permits: 118-15, 034-16). GPS deployments on fishers were performed under anesthesia, and all efforts were made to minimize suffering and discomfort. We followed recommendations by the American Society of Mammalogists (Sikes et al. 2011) and used capture techniques that minimized spread of potential diseases (Gabriel et al. 2012a).

Results

We captured and radio-tracked 12 fishers (5 females and 7 males) between October 2015 and June 2017. From these, we were able to place GPS collars on 9 individuals (4 females, 5 males) on 16 occasions accumulating 43,227 locations that we considered accurate (3-D, >4 satellites, <500m between consecutive locations). Overall, we had 69% fix success with 27,784 locations appear to be from resting data and 26,234 locations within clearly defined rest zones with no missing values. This suggests fishers were resting approximately 61% of the observed period while data were being collected, but the number of days monitored varied by fisher (see Table 4.1).

We identified 1549 clusters which we presumed to represent resting events. Spatially, we identified 566 rest zones with no missing data. We observed 50 occasions with known VHF rest or den structures that overlapped restzones (30% of VHF locations). In addition, of the first 12 restzones for which we deployed remote cameras, 100% had fishers either returning to the area (CC3) or using a structure (CC2, CC1). Of the 19 clusters that we have monitored to date, 95% have had fisher detections. As such, we assumed our algorithm as able to discern resting events from foraging or consuming prey while immobile.

Using only GPS data, we observed 45.5% reuse as defined by a spatially aggregated cluster on more than 1 occasion ($n = 258$ zones) and 12.5% were used >3 occasions. Only 4 rest zones were used >16 occasions. Of the restzones, 8% were used by more than one GPS collared fisher ($n = 45$). Fishers used an average of one restzone per day (0.6-1.5 structures, Table 4.1). On average, we recorded fishers within a restzone for 6.72 hours.

Restzones were highly geographically clustered with an average distance of 295 ± 289 m ($\bar{x} \pm SD$) between restzones (nearest neighbor ratio = 0.603). When we classified distances between restzones used >3 occasions or by >1 individual ($n=120$) then the average distance between zones was 613 ± 777 m.

In restzones that had a resting event identified using VHF telemetry, we identified 38 structures where diameter at breast height was applicable and collected (e.g., not a slash pile). Reuse did not

appear contingent on structure size (Figure 4.3), but cavities were reused more frequently than other microsites (Figure 4.4)

We suspect this is a minimum estimate of both restzones used and reused. When plotting the number of restzones used over time, the accumulation curves did not asymptote (Figure 4.4), suggesting fishers may use different locations seasonally or in general.

Discussion

We used time stamped GPS location data and simple algorithms to identify both periods when we presumed fishers were resting or were in the vicinity of the presumed resting structure. This capacity provides a new opportunity to describe fisher resting habitat and to spatially identify critical habitat elements. Nonetheless, we did not likely document all of the rest structures or restzones used by our collared individuals, nor were we able to define potential biases caused by GPS error. For instance, the GPS would be more likely to accumulate locations in an open space like a mistletoe broom than within a cavity. These uncertainties can be addressed by using multiple methods, like remote cameras and VHF telemetry by observers. As such, until the bias can be quantified, we feel this is a complementary method that provides a wealth of new information and can address numerous researchable questions.

Quantifying the relative importance of each structure, or restzone, is one of the most critical questions for future research to address. This challenge has two facets: remotely identifying structures, ideally without radio collared fishers, and understanding the importance of each structure. Our endeavor provides the most comprehensive, effective, and accurate technique to identify resting structures, or the vicinity of structures, without constant efforts by field crews. Further, we were able to verify fishers reusing restzones and structures by remote camera. Our estimates of reuse were a far underestimate because of the short temporal period in which we were able to collect data with current GPS collar battery life limitations. Nonetheless, there has been little success defining the characteristics of a rest structure due to the diversity of sizes and features (Figure x.2) or the vegetation patch around the vicinity of resting structures (Green 2017). Therefore, we believe telemetry is still the best opportunity to collect such data.

Once rest structures are identified, we contend this dataset highlights a new challenge. Each fisher may use hundreds of rest structures, saturating the landscape. From a manager's perspective this provides several challenges. First, it is currently impossible to differentiate a rest structure from a den structure by using structure size or other notable features or attributes that do not involve telemetry (Green 2017, Green et al. 2018). It is far more likely that the size, configuration, and thermal capacity of the cavity and chamber within the structure is being selected as opposed to the size of the structure itself (Aubry et al. 2018b, Matthews et al. In review). Therefore, if regulations exist to protect den structures, either extensive telemetry needs to occur with a census of females during multiple denning seasons or all rest structures need to be considered as potential den structures. Second, our methods of data collection for rest and den structures are neither random nor comprehensive, requiring a critical evaluation of how to identify structures that clearly benefit individual fisher's fitness in contrast to any location used opportunistically after feeding. Our current research trajectory is to quantify whether reuse rates can provide an accurate index of relative importance, but this clearly requires multiple methods and approaches. Daily VHF telemetry with field observers fails to identify structures that are reused with any accuracy – when VHF telemetry suggested 31% reuse, remote cameras verified 98% (Moriarty et al. 2017). Here, we identified 11% structure reuse with VHF

telemetry (Objective 2), 49% with GPS cluster methods, and nearly 100% with remote camera monitoring (albeit camera data and processing are incomplete). Missing resting structures due to field techniques (e.g., locating rest structures daily versus weekly) has extensive opportunities for misidentifying habitat elements (Carvalho et al. 2015). Thus, designing an experimental study within a demographic or multiple demographic telemetry-based fisher studies to address the need to define “importance” would greatly assist in our understanding of fisher ecology and long-term requirements for population stability.

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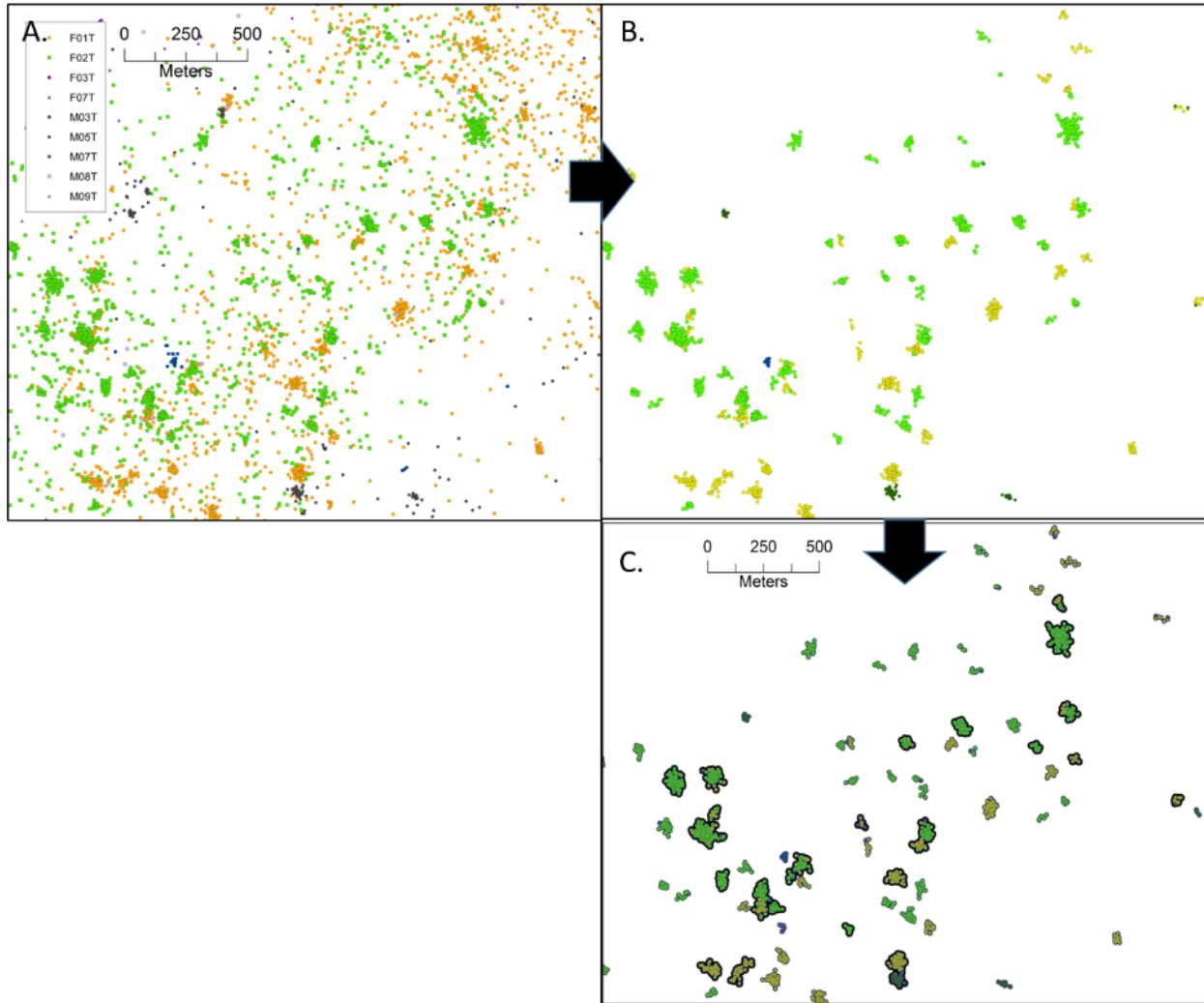


Figure 4.1. An example of the method used to create restzones, or areas where we presumed fishers were resting. First, we gathered time-stamped GPS location data that we presumed was accurate (A). Then, we identified areas where we presumed fishers were not moving by limiting the values to locations with consecutive locations <30 minutes apart with <60m traveled, and <15% activity (B). Areas with >5 uses or >1 individual were designated as higher use and outlined in black (C). Colors represent unique individuals.

a



b



c



d



Figure 4.1. Examples of confidence code levels used in phototagging of restzone and rest structure reuse. A: CC1 – fisher entering or leaving structure. B: CC2 – fisher within a body length and in-line (i.e., moving towards or away) with a structure. C: CC3 – fisher within a body length and not in-line (i.e., not moving towards or away) with a structure. D: CC4 – fisher within a photographic frame, at any distance greater than a body length away from a structure.

Table 4.1.

Fisher	Days Monitored	Restzones	Ave. Restzones/ Day
F01T	113.6	110	0.97
F02T	66.0	72	1.09
F03T	100.3	77	0.77
F07T	23.0	20	0.87
M03T	184.8	150	0.81
M05T	24.9	38	1.53
M07T	34.9	34	0.97
M08T	151.6	97	0.64
M09T	16.1	12	0.75
Range	16.1-184.8	12-150	0.6-1.5

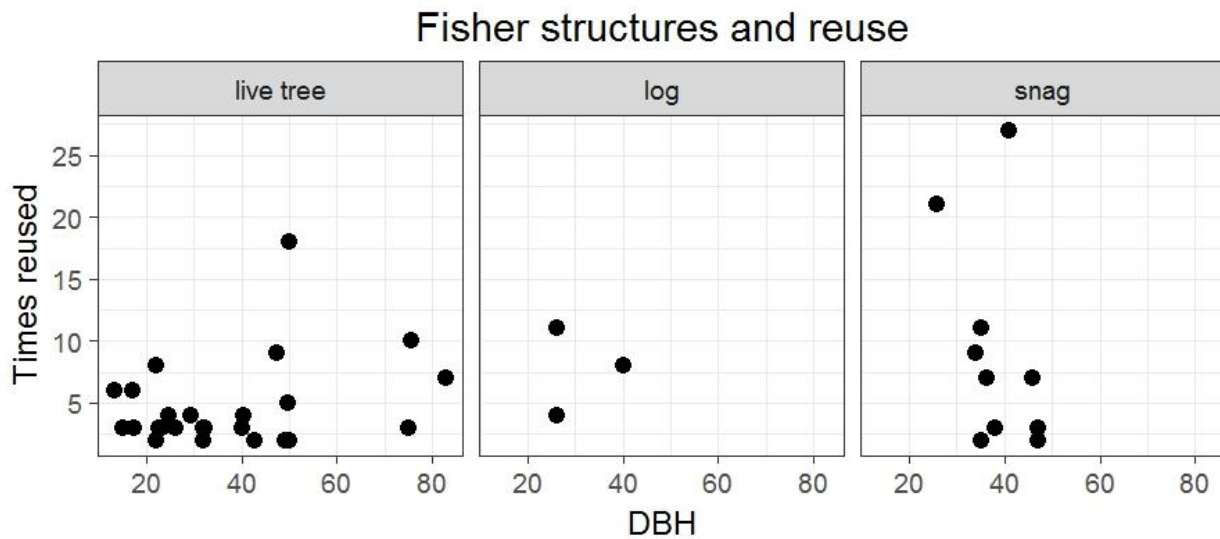


Figure 4.3. We identified 38 locations where we both created a restzone and there was a VHF identified structure (tree, log, or snag). We depict size of that confirmed structure (x-axis) with number of times presumed reused, or the number of clusters identified within a rest zone (y-axis).

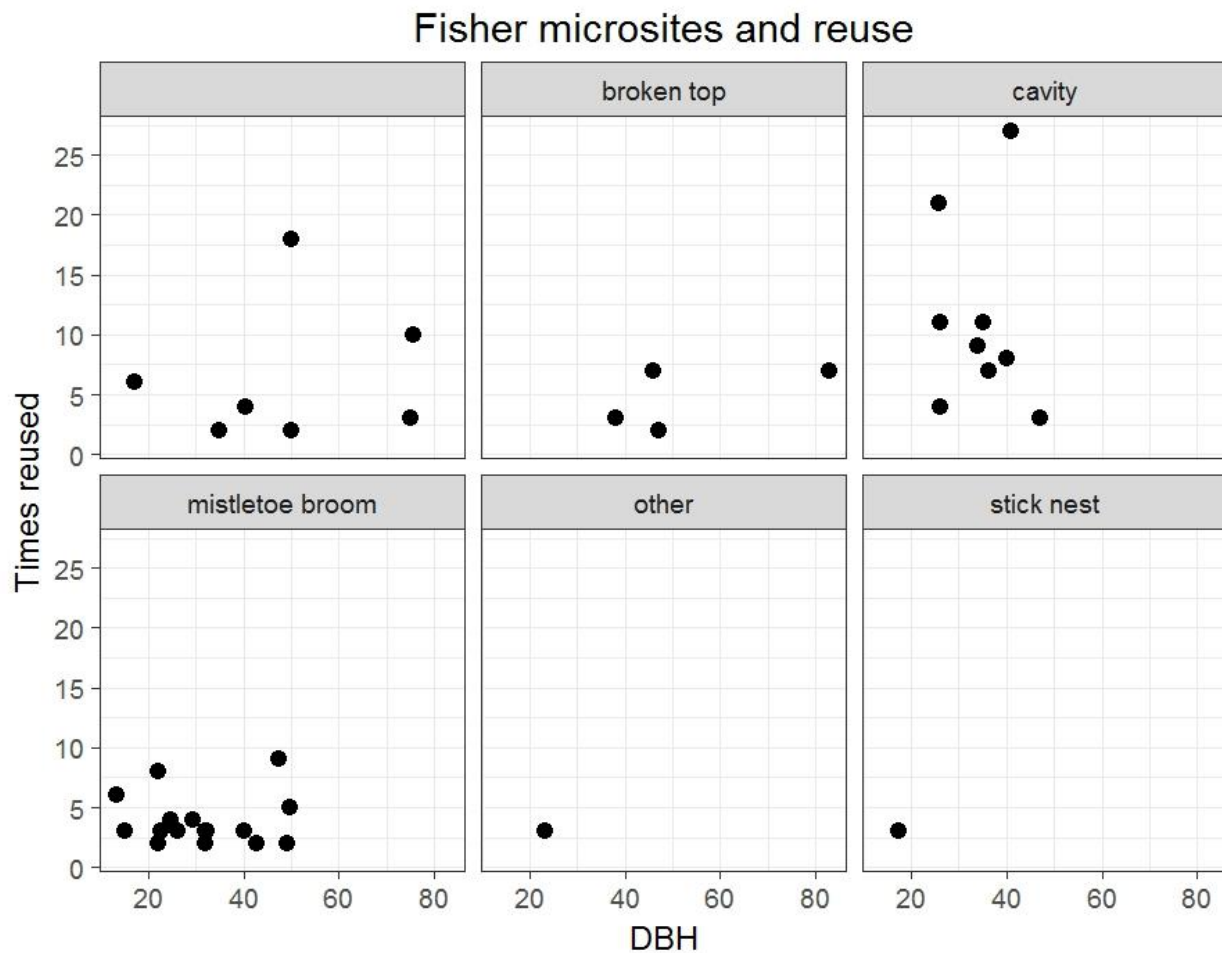


Figure 4.4 We identified 38 locations where we both created a restzone and there was a VHF identified structure with a confirmed microsite (i.e., a fisher was seen or the signal was strongly consistent with a location). We depict size of that confirmed structure (x-axis) with number of times presumed reused, or the number of clusters identified within a rest zone (y-axis) for each microsite type (unknown, broken top, cavity, mistletoe broom, other (e.g., slash pile entrance), or stick nest).

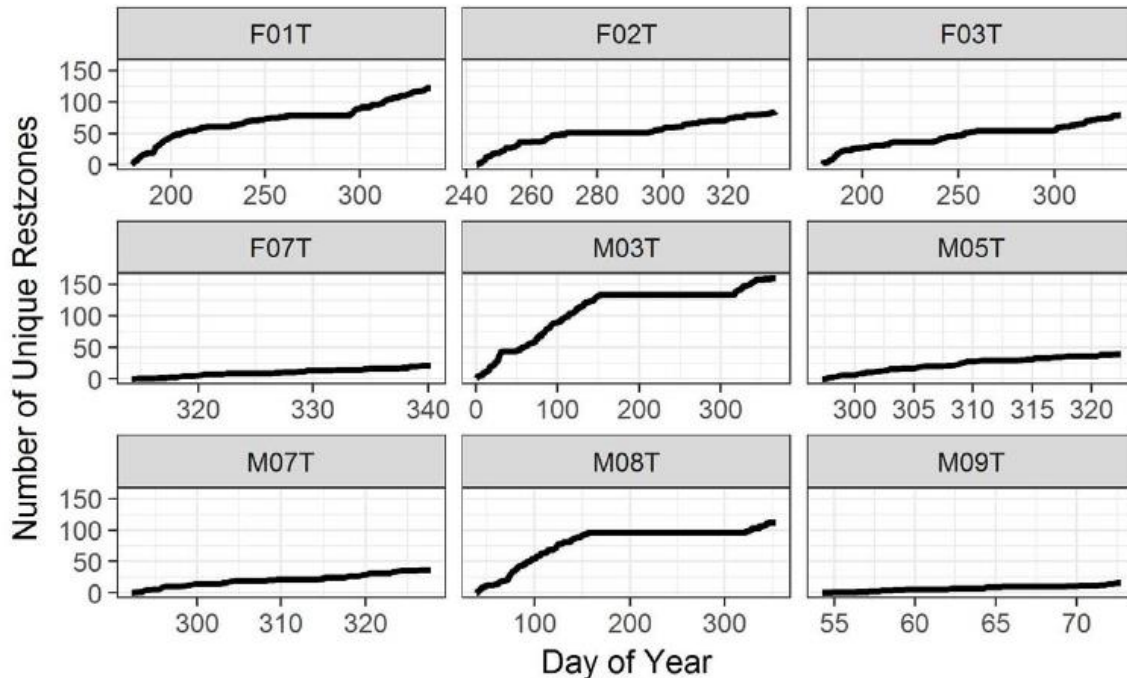


Figure 4.5. We identified 566 restzones for 12 individual fishers. Number of unique restzones did not asymptote with the number of days each individual was monitored. Flat portions of the lines represent periods with no GPS data.

Appendix 1: Detailed field methods

A1.1: Capture protocol

A1.2: Telemetry protocol

Equipment Needed: R1000 receiver, Yagi antenna, Coax cables, Tree tags, Aluminum nails, Hammer, Data sheet, Clipboard, Flagging, Binoculars, Camera, Sharpie

Three bearings greater than 20 degrees apart in less than twenty minutes is the goal for each triangulation. Obtain bearings by systematically narrowing down the precise signal direction. First do a 360 degrees sweep with the antenna to determine general signal direction. This should give you a direction to start narrowing the signal down from, check 180 degrees a couple times to ensure the strongest signal is being narrowed. After determining a general direction turn down the gain until the strongest direction is ~4 bars on the receiver. Next find the “edge” of the signal on each side, this should yield a 60-90 degree signal arc. The “edge” can be determined visually by finding the directional barrier between one bar and no bars on either side of the strongest signal. If the signal is not strong enough to show bars on the receiver there should be an auditory drop off at the edge. Mark the edges to yield a signal arc by kicking out or marking a line at the edges of the signal. Barring other signal complications like topography, the bisection of the signal arc should be the bearing used.

There can be significant topography that amplifies or diminishes the signal strength. Vertical relief like cliffs and ravines make the signal difficult to narrow, bounce occurs when there are two strong spikes in the signal, usually within 60 degrees. Move around while narrowing down the signal, sometimes a couple meters yields a difference in the bearing. Usually the spot with the strongest signal should be used to take a bearing. Sometimes moving several hundred meters is necessary to get an accurate bearing.

Repeat the process to obtain three bearings. This often takes four- six different bearings to get three that make sense. Typically discount the first bearing or the first several until I have a better idea of the terrain and location of the animal. Then check access, roads and trails, and land topography on maps to maximize efficiency and accuracy - go to those points and get bearings. This process involves experience of the study area and ability to identify confounding topography. Try to get as close to the animal as possible on the road system and drive to spots to take bearings. Usually there’s enough time to get one bearing from hiking, typically this will be the last needed.

If the animal is moving three bearings in less than ten minutes is best. Otherwise there’s significant error associated with the triangulation. The initial rules still apply so if it’s necessary to take the full 20 minutes to locate a moving animal then do so. The whole process should be sped up to get bearings quickly, try to use a partner if available and take bearings simultaneously. If there’s an opportunity to come back to that animal later in the day when it might have settled down then do so.

A1.3: Rest and den site monitoring protocol

Our goal is to collect rest and den structure data opportunistically after fishers have been located by a successful triangulation. Triangulated locations of fishers and other project priorities need to be achieved before initiating a “walk-in” to collect rest site data. Successful triangulations are crucial to collect before moving in to locate the resting structure. We need to be able to compare the

locations based on triangulation with more specific and confident rest point locations to evaluate bearing error and triangulation accuracy. Furthermore, location data could be lost by attempting to find a rest site and disturbing the animal before a structure is located. The emphasis is on systematically locating the animal before collecting secondary data like rest structure use.

When attempting to find a rest structure the researcher needs to prioritize stealth and a careful narrowing in search for the animal. A direct approach walking in the direction of the strongest signal (full bars, gain lowered) should be taken until a coax signal is achieved (coax and receiver only) indicating proximity (~100-200m, depending on collar location and orientation). Caution should always be taken when approaching an animal but is of special emphasis with coax proximity. Continue the direct approach reducing the gain on the receiver to narrow down the signal location. Once a researcher is within 50m of the animal an indirect approach should be taken. Continue listening to the signal but angle 30 degrees tangentially around the location of the strongest signal. This should initiate a circular walking pattern around the rest structure that reduces disturbance and increases potential to locate the animal. At this point hypotheses on potential rest structures in the area should be formed and systematically eliminated to locate the precise structure.

We've found fishers resting in downed logs, broken top snags, cavities, large tree limbs, and dirt burrows as well as human structures. Circle the area once identifying potential resting structures. Evaluate these structures by directing the antenna at each structure, eliminating ones in weak signal directions. To narrow down between two structures it might be necessary to approach closely and point the antenna at each, narrowing to the strongest. The micro-site may be well off the forest floor such that when close the vertical axis is as important to narrow down as the horizontal axis.

Subnivean structures are typically more insulated from approach noise making winter rest structures below snow easier to find. Summer is more difficult. Some structures insulate well and seem to be more secure, like snag cavities, making fishers less likely to flee an approaching researcher. Large branches and broken top snags demand a more careful approach and can still lead an animal to flee before a structure is located. It's impossible to know what structure the animal is in before walking in. Try to spot the fisher before it spots you, if you see it fleeing from a structure at least data can be collected even if you've disturbed the animal.

The data sheet is organized in order of collection. On the back is a space for sketching distinguishing features of the rest area for future relocation. Try to take helpful notes to accompany the sketch.

If the fisher is securely in a cavity or not in the area, place a tree tag in the structure used. Otherwise tag a distinct tree and include this information and orientation to the structure (bearing and distance) in the relocation notes. Engrave fisher ID, date, observer ID and structure info on the side opposite the tag number, hammer in with this side out. Label flagging with the same info as the tree tag and hang in a visible area close to the tag tree or rest structure.

Appendix 2: Fisher captures and demographic information

A.2.1. Capture summary

We captured and anesthetized 16 individual fishers (8 female and 8 male) on a total of 44 occasions between October 2015 and March 2018 (Table A.2.1a). Fisher weight and neck circumference were sexually dimorphic (Figures A.2.1c & A.2.1b). Males weighed on average 4.74 kg (± 0.95) with an average neck circumference of 22.88 (± 2.89) cm; whereas females averaged 2.59 (± 0.28) kg and 17.78 (± 1.46) cm. Females did not vary widely in weight or neck circumference between age class. Male weight and neck size did not vary highly between subadults and adults, but juvenile males were on average smaller than adult and subadult males. Adult male weight and neck circumferences were the most variable of all groups.

Table A.2.1a. Summary of fisher weights and neck circumferences as a function of sex and age class.

Age Class	n captures	Female (n=8)		n captures	Male (n=8)	
		Mean weight \pm sd (kg)	Mean neck circ. \pm sd (cm)		Mean weight \pm sd (kg)	Mean neck circ. \pm sd (cm)
adult	19	2.61 \pm 0.32	17.53 \pm 1.00	11	4.89 \pm 1.01	23.32 \pm 3.37
subadult	4	2.65 \pm 0.21	19.38 \pm 2.74	4	4.84 \pm 0.77	22.78 \pm 1.97
juvenile	4	2.48 \pm 0.13	17.28 \pm 0.63	2	3.70 \pm 0.14	20.90 \pm 1.27
All	27	2.59 \pm 0.28	17.78 \pm 1.46	17	4.74 \pm 0.95	22.88 \pm 2.89

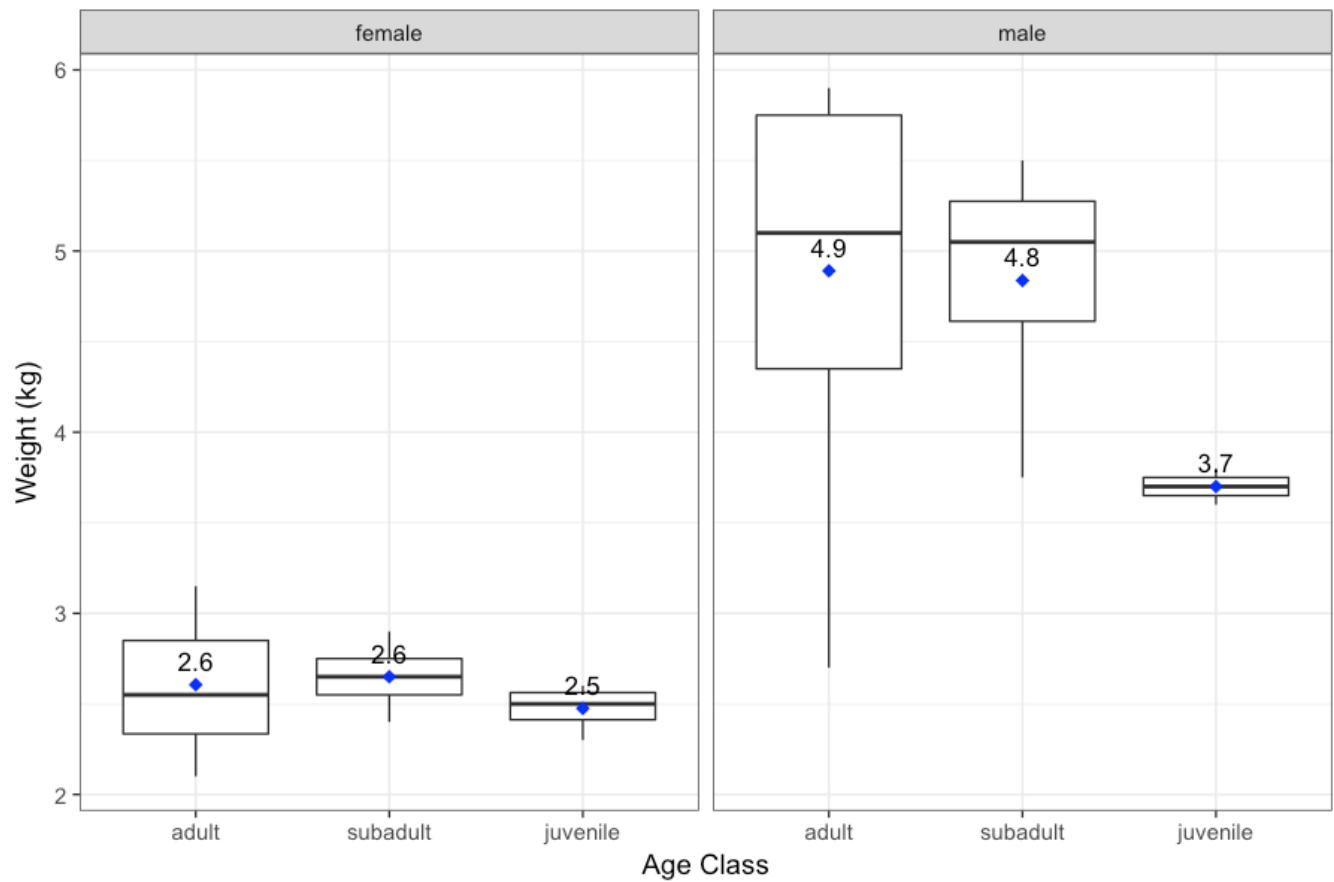


Figure A.2.1a. Fisher weights as a function of age class and sex. Thick black lines represent median values, blue diamonds with labels represent mean values and boxes bound the 25 and 75% quartiles of the data.

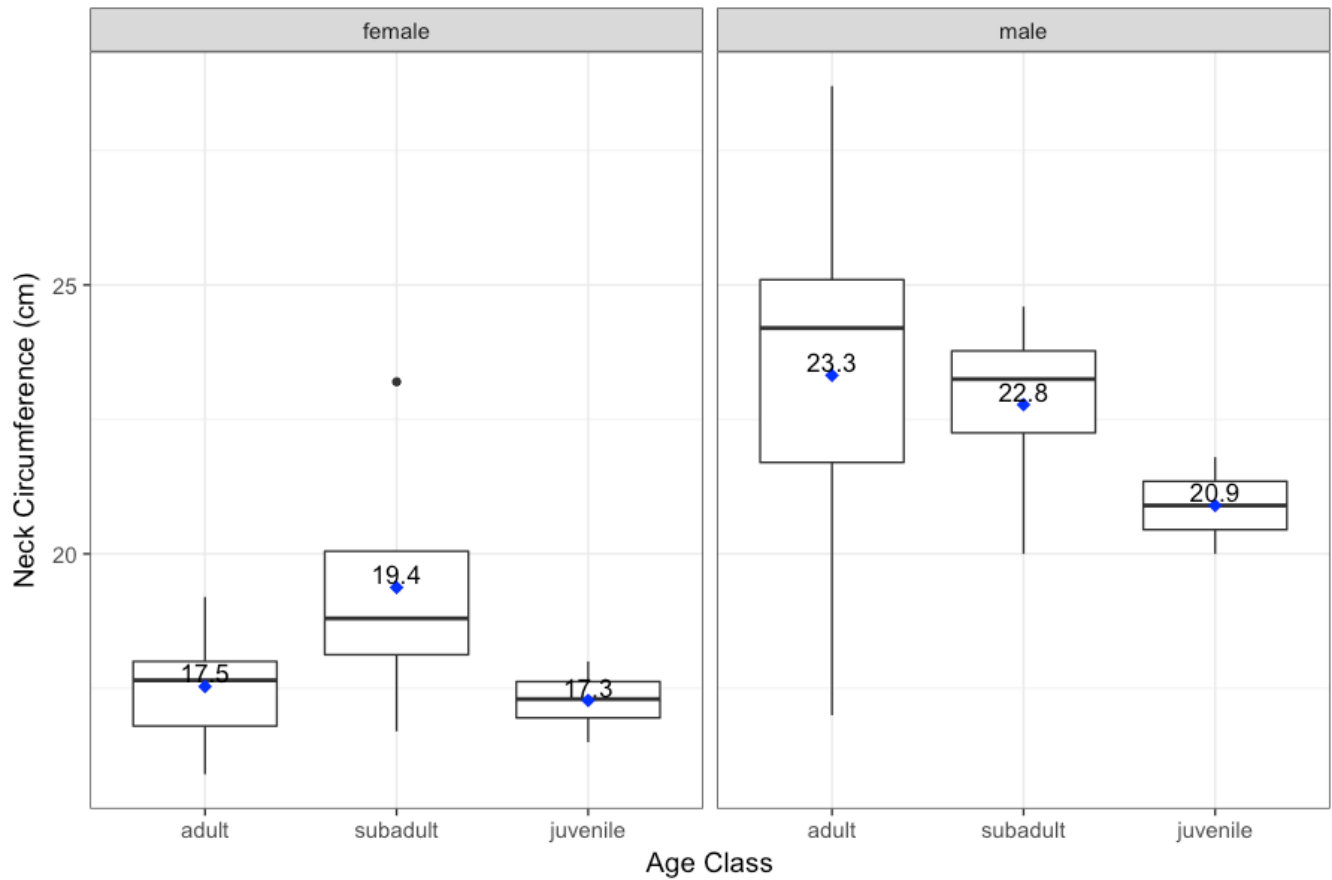


Figure A.2.1b. Fisher neck circumference measurements as a function of age class and sex. Thick black lines represent median values, blue diamonds with labels represent mean values, boxes bound the 25 and 75% quartiles of the data, and black dots represent extreme values in the dataset.

A.2.2. Location summary

Subadult and adult fishers were fit with VHF or GPS radio-transmitters (n=6 females, 7 males). From October 2015 through August 2018, radio-collared individuals were located using 3 methods: GPS technology, radio-triangulation, or homing techniques (rest sites/areas, dens, and visuals).

Table A.2.2.a Summary of location types and monitoring dates for telemetered fishers on the Klamath Plateau.

Fisher	Sex	Age Class	3D-Fix GPS Locations	VHF Triangulations	Rest Sites/Areas, Dens, & Visuals	Minimum Date	Maximum Date
F01T	female	adult	10,130	40	34	10/22/15	5/21/18
F02T	female	subadult & adult	5707	39	32	10/23/15	6/6/17
F03T	female	adult	9113	34	34	10/26/15	12/3/17
F06T	female	subadult & adult	0	0	9	2/9/18	8/24/18
F07T	female	adult	2436	8	15	11/9/16	4/20/18
F08T	female	subadult & adult	0	36	22	2/13/17	6/15/18
M01T	male	adult	0	18	12	11/10/15	1/3/17
M03T	male	subadult & adult	13,608	0	7	11/10/16	5/31/17
M04T	male	adult	0	10	6	3/2/16	3/20/17
M05T	male	adult	1660	0	3	10/23/16	11/17/16
M07T	male	subadult	2065	1	1	10/18/16	11/22/16
M08T	male	adult	14,229	1	34	11/13/16	7/30/18
M09T	male	adult	4642	1	12	2/11/17	6/25/18
Total			63,580	188	220	10/22/15	8/24/18

Appendix 3: Space use

A.3.1.

We explored several home range models and parameterizations to evaluate the most appropriate fit to our data (Table A.3.1). We found the model and parameterization using all GPS locations, the adehabitat R package, and href smoothing parameter aligned with our expectations of individual fisher space use based on our field experience. Individual fisher home ranges are presented in figure A.3.1.

Table A.3.1. Home range models were evaluated for each individual fisher using all GPS data and datasets excluding collections of locations identified as rest clusters. Models were developed using R packages adehabitat, ks, and ctmm with href and plugin smoothing parameters.

Fisher GPS data	R package	Smoothing parameter
All locations	adehabitat	href
	ks	href and plugin
	ctmm	href
Cluster locations removed	adehabitat	href
	ks	href and plugin
	ctmm	href

Figure A.3.1. Home range models developed for fishers in the southern Cascades of Oregon using GPS collar data modeled using R packages adehabitat (Calenge 2006) and an href smoothing parameter.

Figure A.3.1a. Home range model developed for fisher F01T during life of monitoring in the southern Cascades of Oregon using GPS collar data modeled using R package adehabitat (Calenge 2006) and an href smoothing parameter.

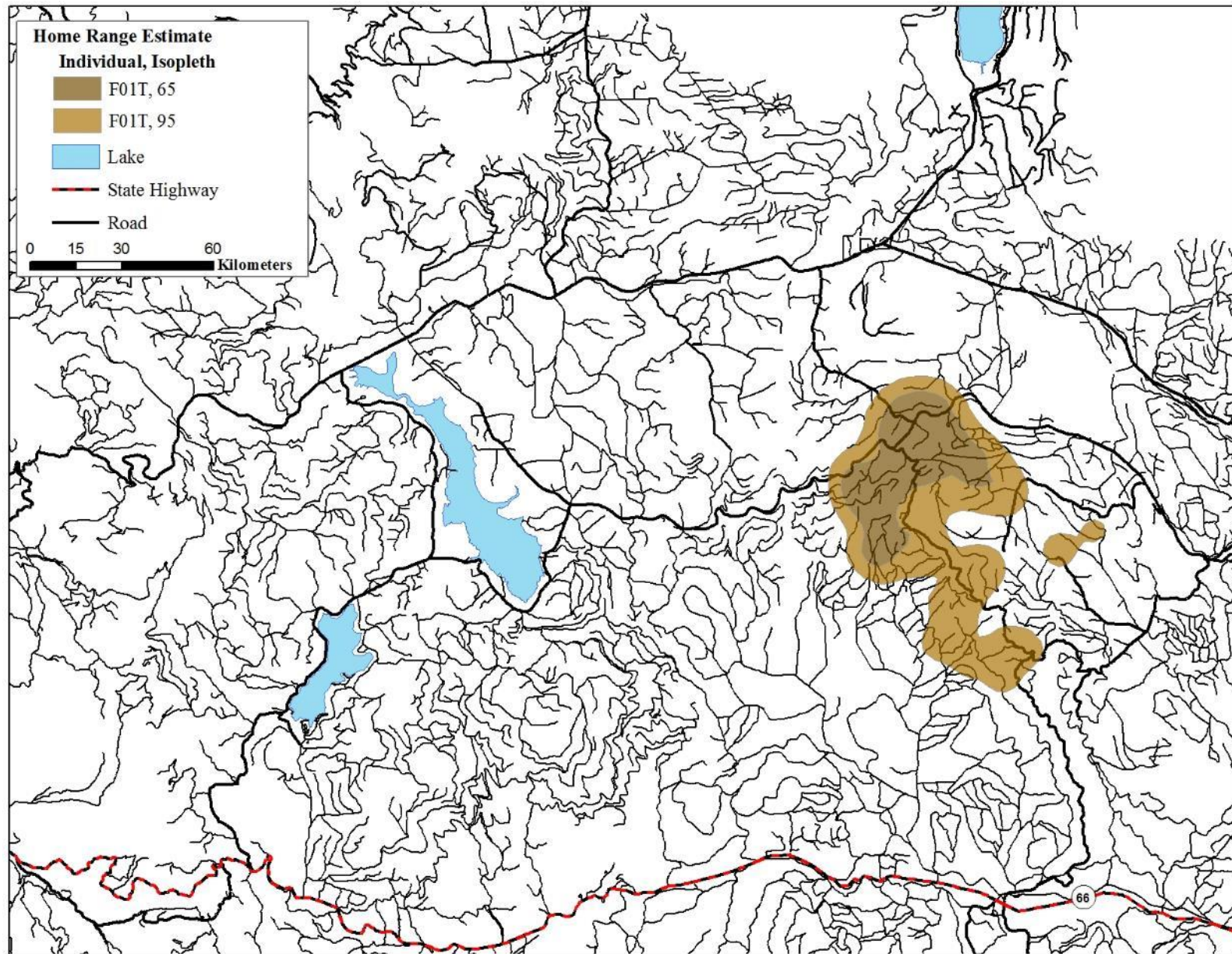


Figure A.3.1b. Home range model developed for fisher F02T during life of monitoring in the southern Cascades of Oregon using GPS collar data modeled using R package adehabitat (Calenge 2006) and an href smoothing parameter.

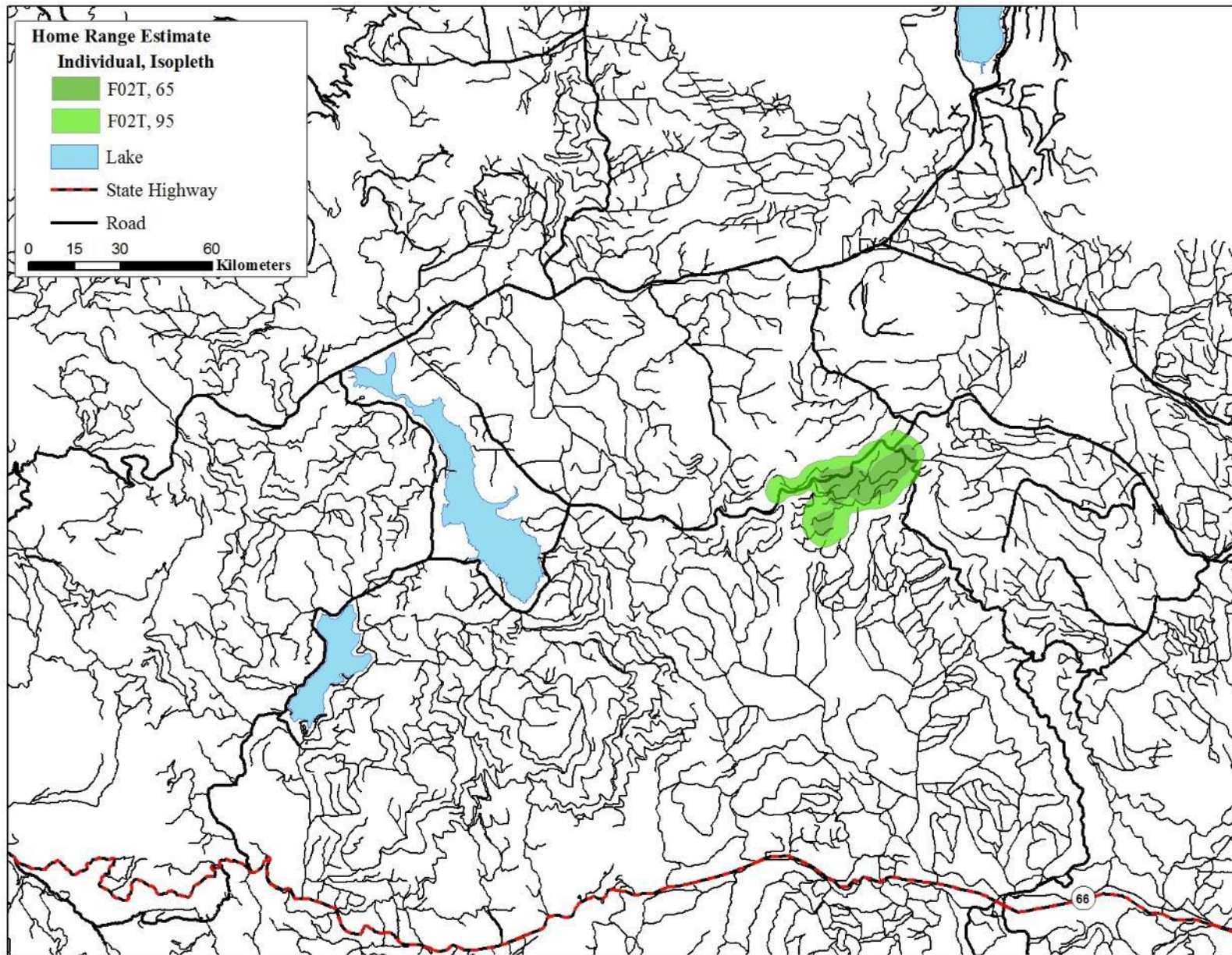


Figure A.3.1c. Home range model developed for fisher F03T during life of monitoring in the southern Cascades of Oregon using GPS collar data modeled using R package adehabitat (Calenge 2006) and an href smoothing parameter.

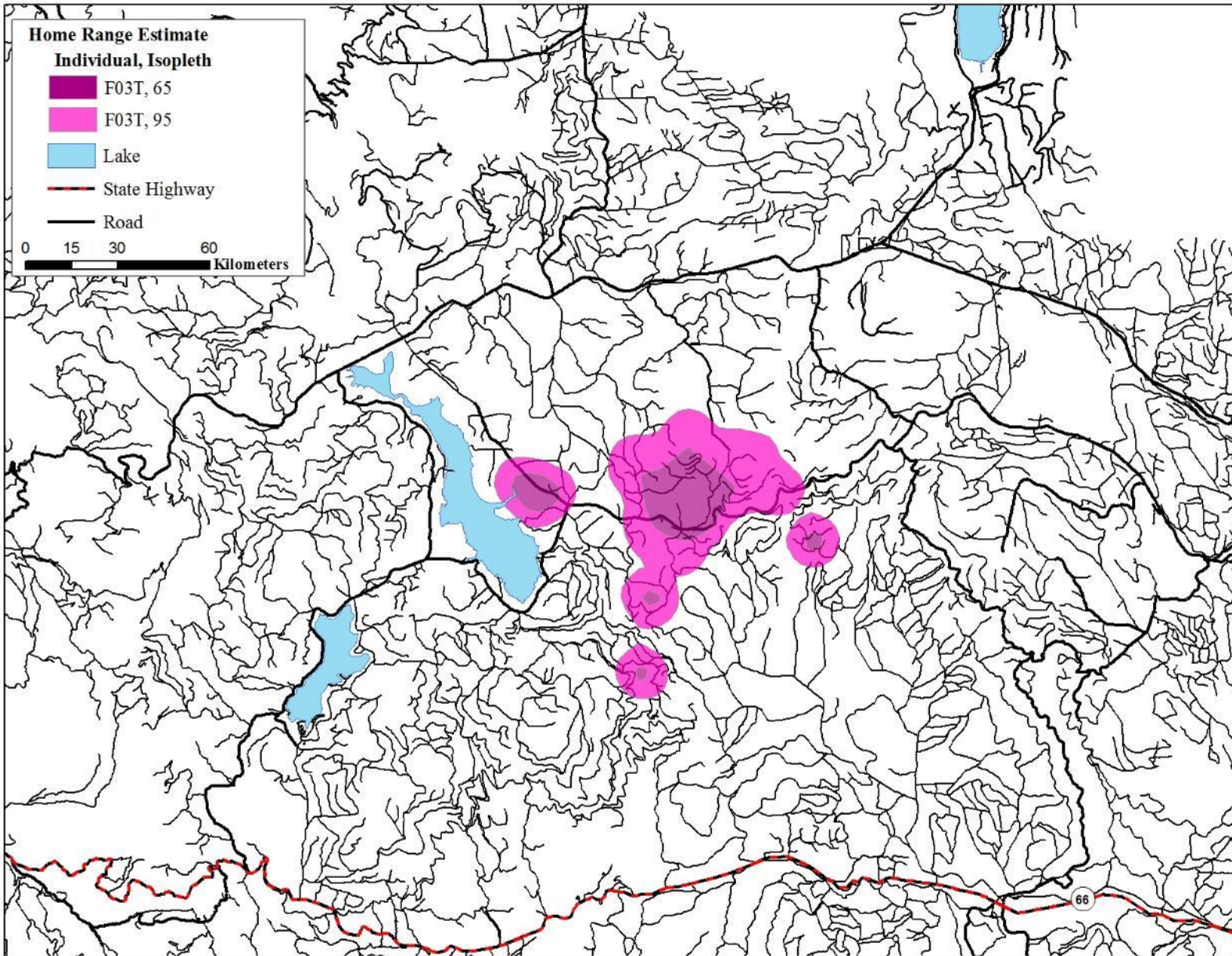


Figure A.3.1d. Home range model developed for fisher F07T during life of monitoring in the southern Cascades of Oregon using GPS collar data modeled using R package adehabitat (Calenge 2006) and an href smoothing parameter.

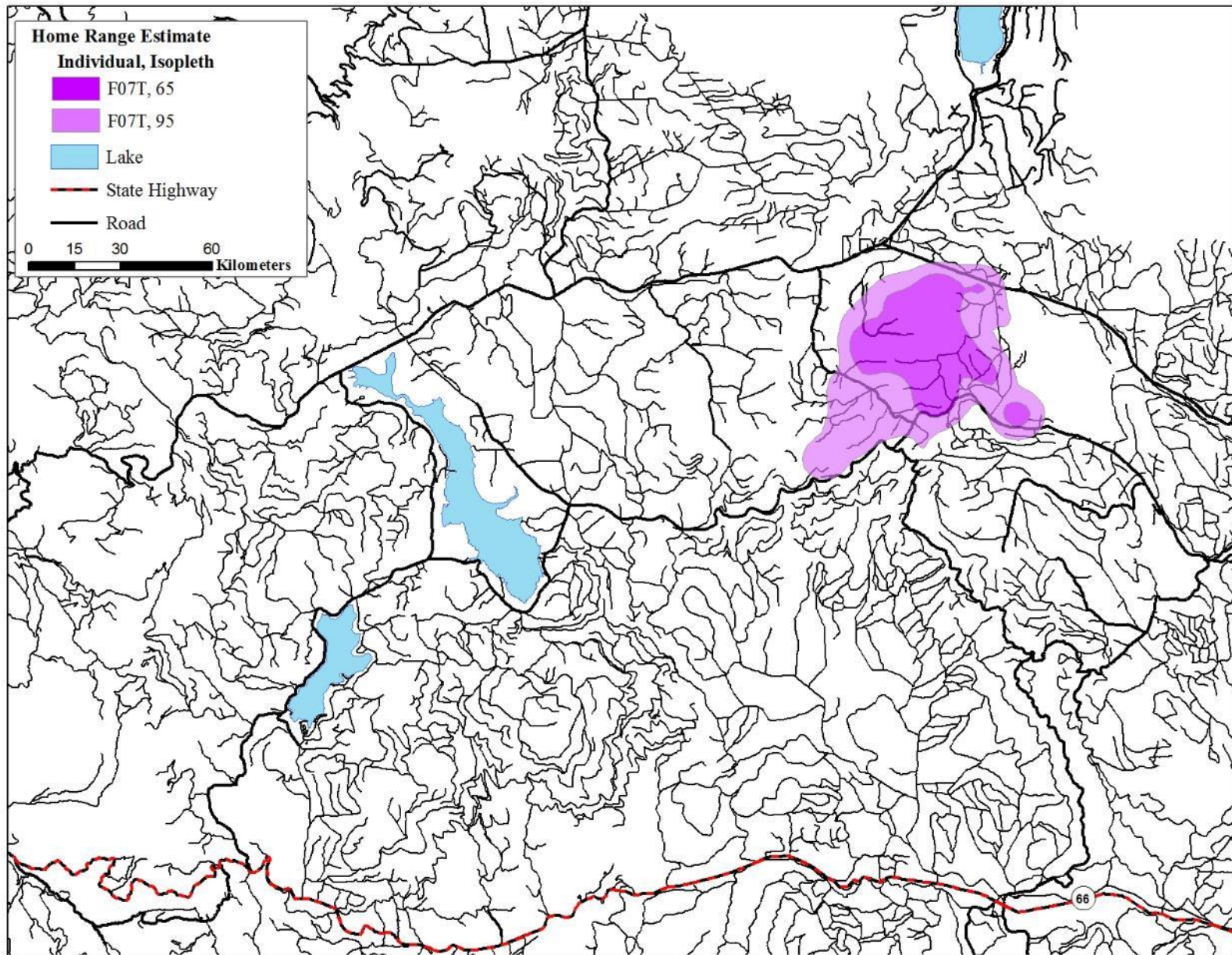


Figure A.3.1e. Home range model developed for fisher M03T during non-breeding season, life of monitoring in the southern Cascades of Oregon using GPS collar data modeled using R package adehabitat (Calenge 2006) and an href smoothing parameter.

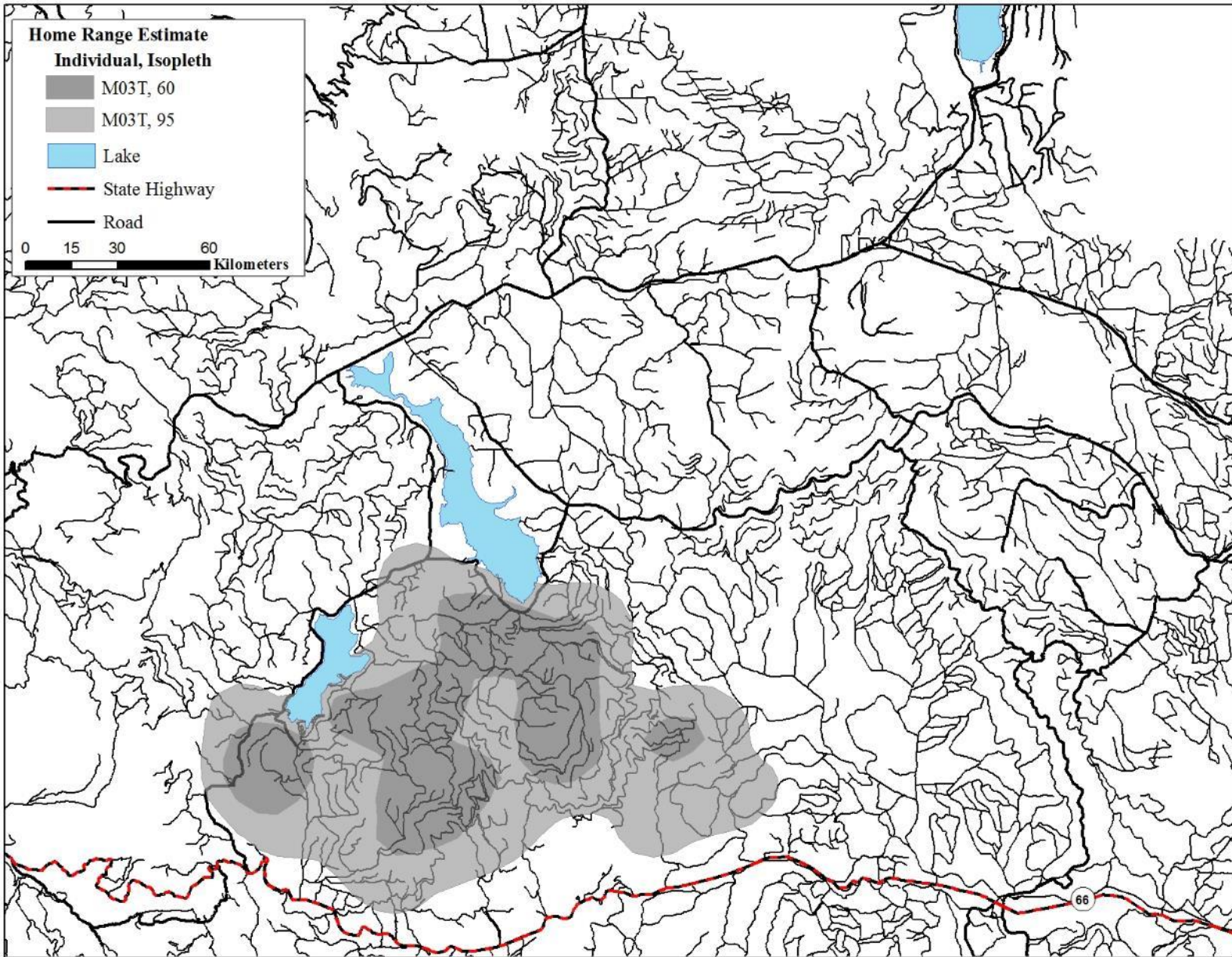


Figure A.3.1f. Home range model developed for fisher M03T during breeding season, life of monitoring in the southern Cascades of Oregon using GPS collar data modeled using R package adehabitat (Calenge 2006) and an href smoothing parameter.



Figure A.3.1g. Home range model developed for fisher M05T during non-breeding season, life of monitoring in the southern Cascades of Oregon using GPS collar data modeled using R package adehabitat (Calenge 2006) and an href smoothing parameter.

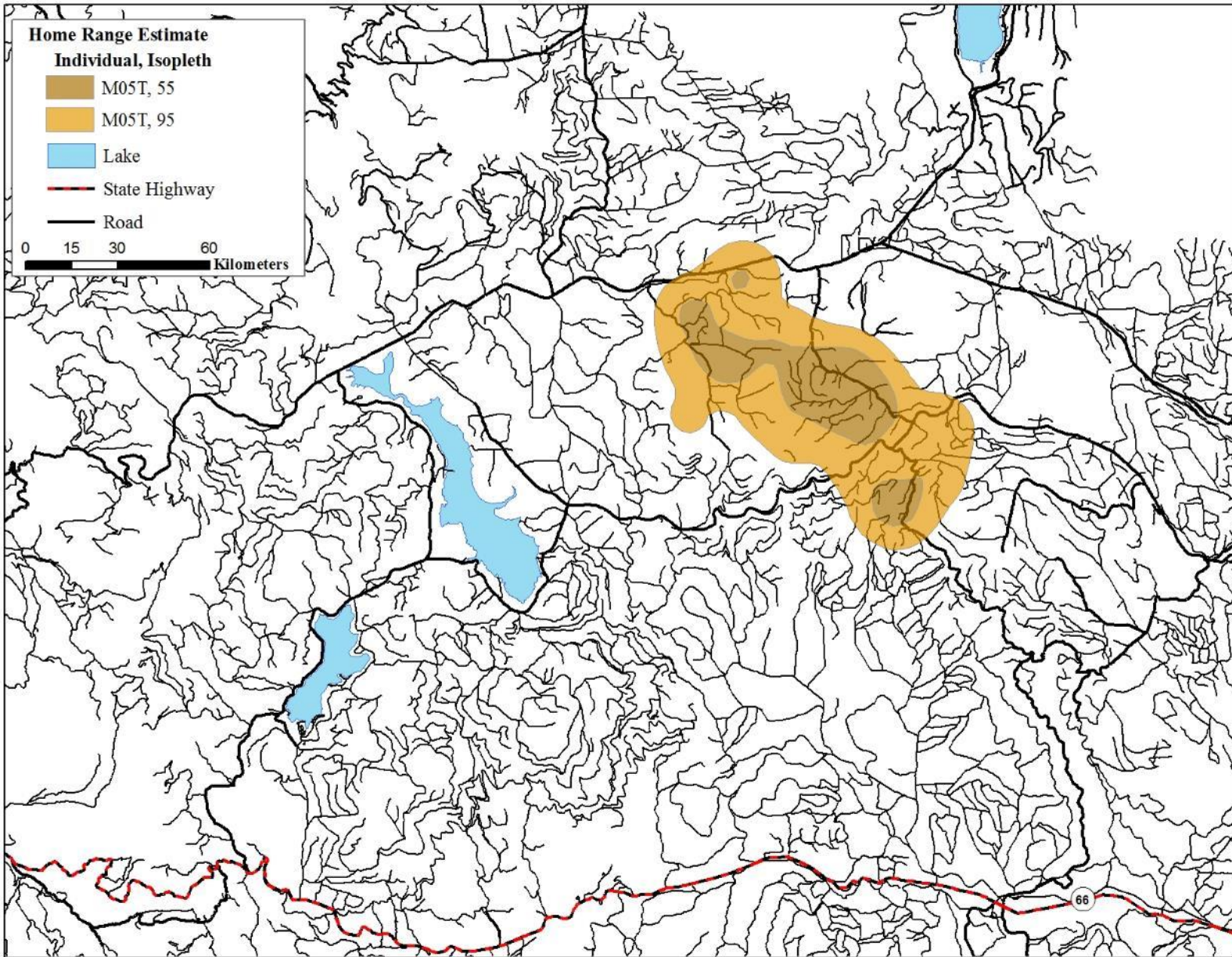


Figure A.3.1h. Home range model developed for fisher M07T during non-breeding season, life of monitoring in the southern Cascades of Oregon using GPS collar data modeled using R package adehabitat (Calenge 2006) and an href smoothing parameter.

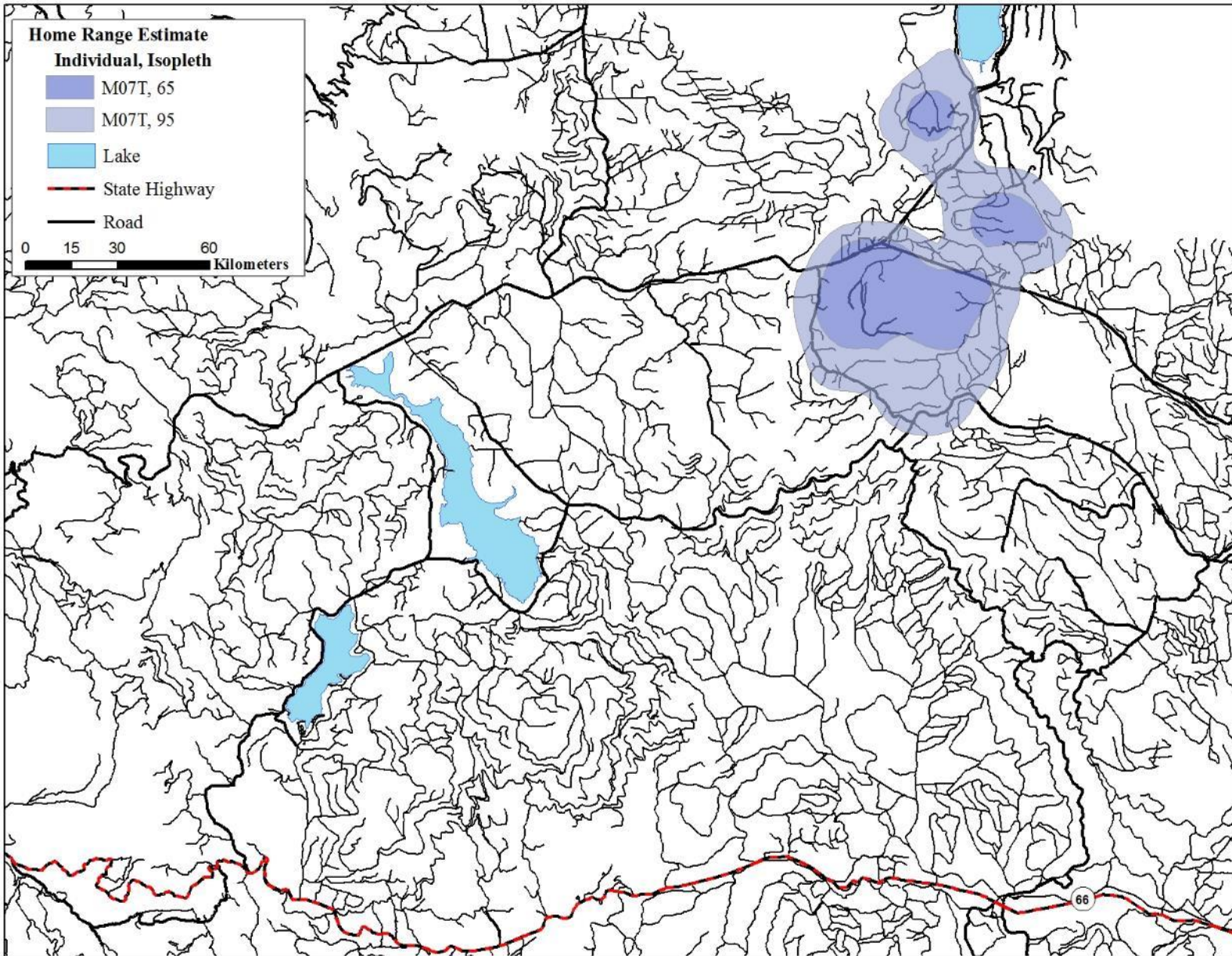


Figure A.3.1i. Home range model developed for fisher M08T during non-breeding season, life of monitoring in the southern Cascades of Oregon using GPS collar data modeled using R package adehabitat (Calenge 2006) and an href smoothing parameter.

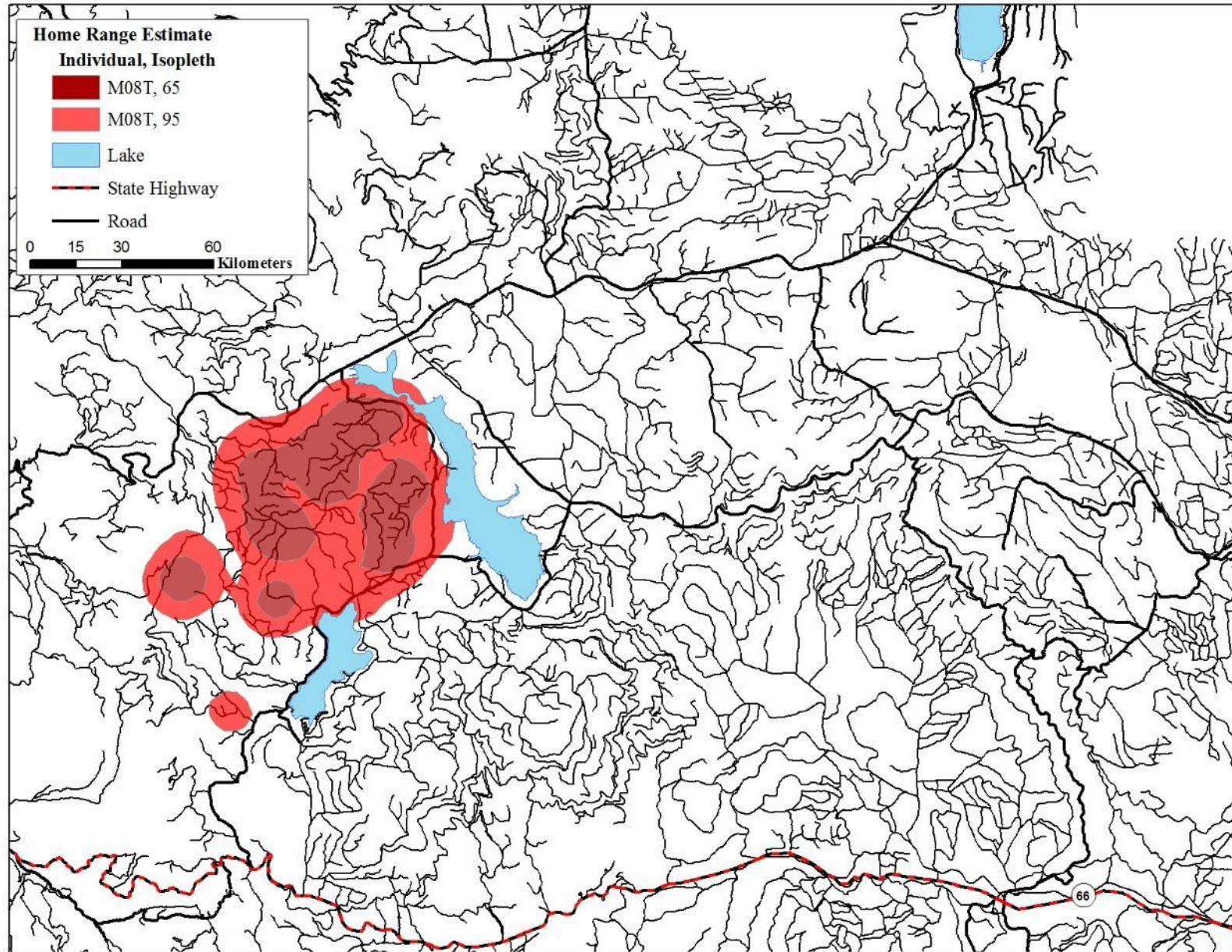


Figure A.3.1j. Home range model developed for fisher M08T during breeding season, life of monitoring in the southern Cascades of Oregon using GPS collar data modeled using R package adehabitat (Calenge 2006) and an href smoothing parameter.

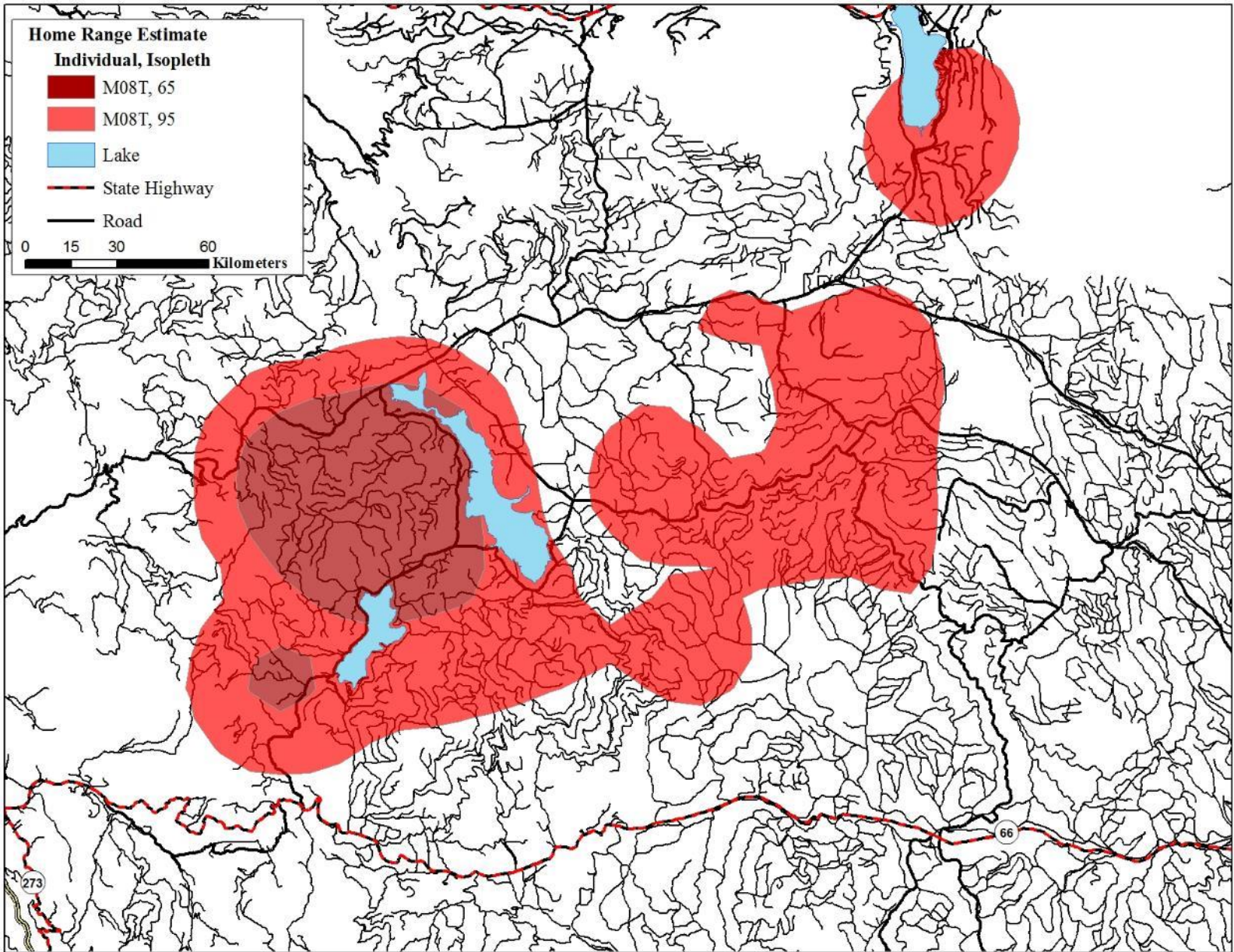
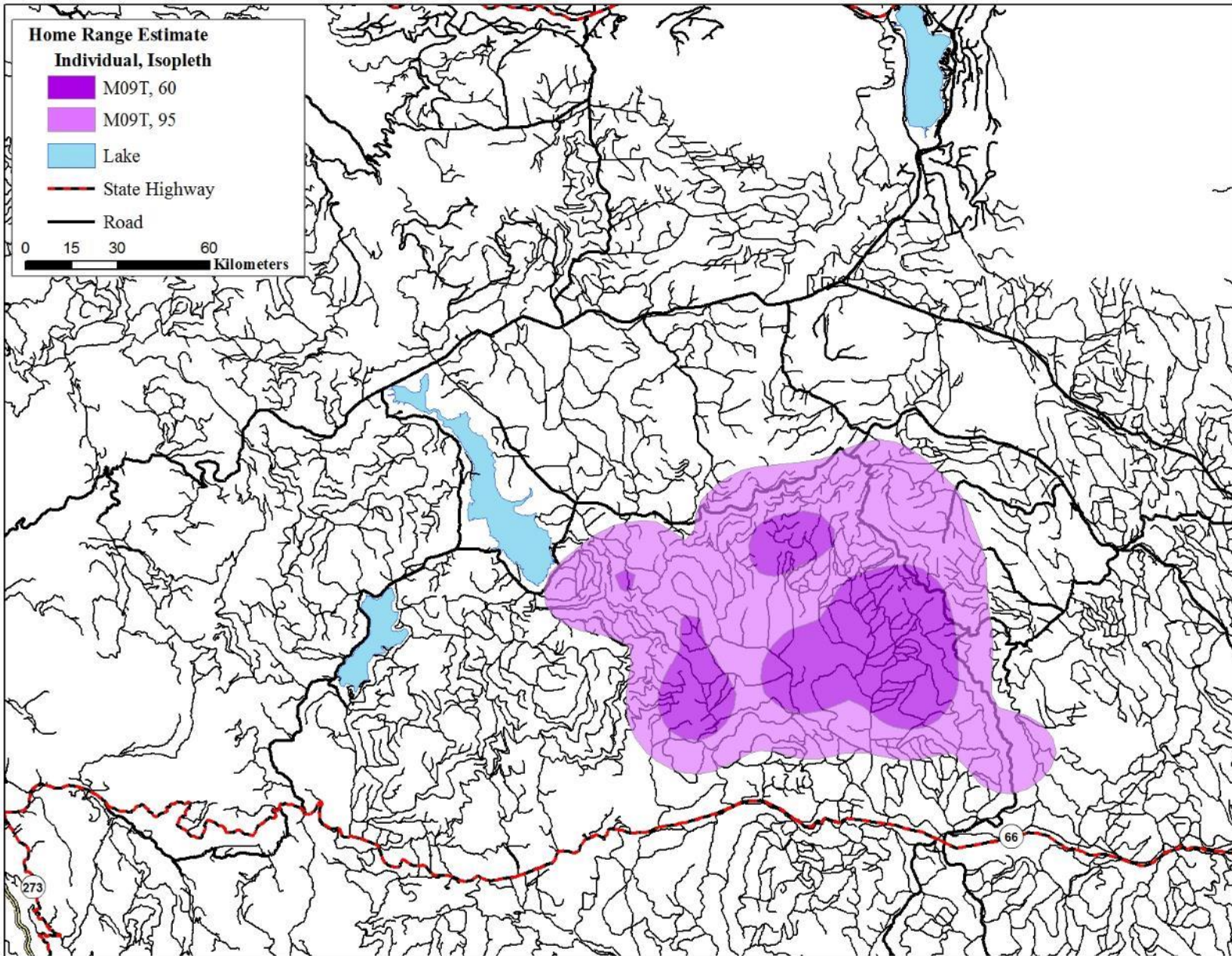


Figure A.3.1k. Home range model developed for fisher M09T during breeding season, life of monitoring in the southern Cascades of Oregon using GPS collar data modeled using R package adehabitat (Calenge 2006) and an href smoothing parameter.



Appendix 4: GPS Collar Testing

A.4.1. GPS Testing Methods

Brief Methods

We radio collared adult fishers with very high frequency (VHF) transmitters (Advanced Telemetry Systems, Isanti, Minnesota, USA; M1820, 27-31g) and GPS collars with VHF transmitters. All necessary permits were acquired (Oregon Scientific Take Permit, Institute for Animal Use and Care Permit) and we followed guidelines for the ethical treatment for wild animals (Sikes and the Animal Care and Use Committee of the American Society of Mammalogists 2016). Radio frequencies were approved by the Oregon Department of Fish and Wildlife and did not conflict with neighboring projects. We retrofitted the collar attachments with soft leather portion as an eventual break-away device, using a tested protocol (R. Green, Kings River Fisher Study, unpublished) and placed three pieces of reflective banding on the VHF antenna for individual identification with remote cameras.

We obtained an estimated location using triangulation at least once a week (Appendix A1.1) and located inactive fishers to their resting or denning location (Appendix A1.2). We collected telemetry data combining triangulations and aerial telemetry for our analysis with the criteria that expected precision of each location was within 200 m of the actual location. Mostly, we used VHF telemetry to locate rest and den structures when fishers were inactive.

We deployed W500 Wildlink GPS collars (Advanced Telemetry Systems, Isanti, Minnesota, USA; 60-100g), Lotek Iridium (Lotek/Sirtrack Limited, Havenlock North, New Zealand; 130g), and Lotek LiteTrack RF-40 (Lotek/Sirtrack Limited, Havenlock North, New Zealand; 50g) on adult fishers opportunistically in accordance with necessary permits (Objective 1 methods, Capture and handling). Each W500 collar had both a very high frequency (VHF) unit with an external antenna powered by the same battery as the GPS. Conversely the Lotek collars had a separate battery for the GPS and VHF, allowing relocations to occur even when the GPS battery had expired. All GPS collars had a remote downloading feature to obtain data from a fisher without recapturing the individual. While on free-roaming fishers, the GPS was programmed to estimate locations every 15 minutes with occasional settings at a 30-minute interval between attempted location attempts.

We deployed GPS collars on adult fishers opportunistically, aiming to increase the number of individual fishers within a season. The majority of locations were collected with ATS W500 GPS collars. We tested Sirtrack LiteTrack Iridium 130 (Sirtrack Limited, Havenlock North, New Zealand; 130g) collars with field trials and on 2 male fishers and during field trials. On fishers, one Iridium collar featured swift fix technology while the other was equipped with standard GPS technology, and both were programmed to estimate locations at 30-minute intervals. Finally, we deployed LiteTrack RF-40 (Sirtrack Limited, Havenlock North, New Zealand; 40g) on 2 female fishers during the 2018 denning season to evaluate denning female movements. LiteTrack RF-40 collars were GPS-enabled with swift fix technology and were programmed to estimate locations at 30-minute intervals.

We tested GPS units within the study area to determine GPS accuracy and fix rates (this section). In addition, we tested collars for functionality before deploying them on fishers. We presumed the GPS was operational if it was able to collect >1 location with >4 satellites accurate within 30m both during an office pre-trial and at the capture location. All GPS collars were operational from the company and ready for field deployment.

GPS Background – Tradeoffs with small collars and “Standard” versus “Swift” GPS

Global positioning system (GPS) telemetry provides opportunities to collect detailed information from free ranging animals with a high degree of precision and accuracy (Frair et al. 2010). Miniaturization of GPS receivers and electronics has enabled researchers to use lightweight GPS collars (80-125g) to study mammals greater than 2.5 kg (Blackie 2010, Recio et al. 2011, Brown et al. 2012, Adams et al. 2013, Kölzsch et al. 2016, Roberts et al. 2016, McMahon et al. 2017). Smaller “miniature” GPS collars (42-60g) for mammals have been available since 2009, but have seldom been tested or reported in peer-reviewed scientific literature (but see Cypher et al. 2011, Thompson et al. 2012, Moriarty and Epps 2015, McMahon et al. 2017, Linnell et al. 2018). However, this technology is not without disadvantages. GPS failures and technical malfunctions can severely reduce performance, limiting sample size and data quality (Hebblewhite and Haydon 2010). Use of lightweight GPS collars has been cautioned because limited battery life may increase malfunctions and reduce their functionality as a data collection tool (Blackie 2010, Cypher et al. 2011). This limitation is compounded by GPS error which affects all GPS units regardless of size, and includes both location error and failed location attempts resulting in missing data (Frair et al. 2010). GPS error can systematically bias resource selection studies (Frair et al. 2004, Visscher 2006), home range estimation (Horne et al. 2007), and evaluation of movement patterns (Hurford 2009). As such, minimizing bias due to GPS error and maximizing battery life are upmost importance for research with free ranging animals, especially for miniature collars.

Although performance of any GPS device is affected by a range of environmental conditions and locations of available satellites (Grewal et al. 2007), during wildlife research, GPS error is most often attributed to satellite signal obstruction due to vegetation, topography, or animal behavior (Frair et al. 2010). Failed location attempts are most often associated with dense canopy cover (Frair et al. 2010, Recio et al. 2011), and a combination of factors (e.g., canopy cover, topography, satellite availability) can explain increased location error (Recio et al. 2011). Furthermore, GPS error may be compounded by multiple obstructions (Augustine et al. 2011). For instance, the bottom of a ravine may have both topographical and vegetation obstruction. Such interactions may differ between study areas and collar brands, potentially explaining the wide range in percent fix success (successful GPS locations divided by the total attempts) and location error reported in studies in mountainous terrain (Lewis et al. 2007, Sager-Fradkin et al. 2007). GPS error also may be influenced by animal behavior through individual habitat preferences or when an animal rests or dens in areas obstructed from satellites (e.g., burrows, cavities, buildings) (D'Eon and Delparte 2005).

A largely unrecognized factor that may influence GPS error is the fix schedule, or user-parameterized duration between fix attempts. Fix schedule has been assumed to have little (Cain et al. 2005) or no influence on GPS error, but Moriarty and Epps (2015) clearly demonstrate through experimental trials that some negative effects of vegetation can be mitigated with short duration between locations. GPS error may be reduced, and battery life increased, if the time between fix attempts is short enough to allow the GPS receiver to retain two types of satellite information: almanac and ephemeris data. Almanac data include coarse orbital parameters of satellites and are valid for several weeks (2008, Tomkiewicz et al. 2010). Ephemeris data are precise satellite locations and are valid for one to four hours depending on the GPS receiver (1996, Grewal et al. 2007, Tomkiewicz et al. 2010). Retaining satellite information reduces the time and power necessary to obtain a fix (Singh 2006), and as such may allow the GPS time to average its position and decrease location error. For instance, Augustine et al. (2011) simulated the influence of time on fix success when the GPS receiver was 60% obstructed by vegetation; they predicted ~90% fix success at a 15

minute fix interval but only ~50% fix success at a 2 hour fix interval, presumably because of the declining relevance of the ephemeris data over that longer time interval. Although these simulations were not intended to be extrapolated to different GPS receivers and study areas, they suggest that fix success is proximally affected by fix interval and ultimately by satellite information, particularly ephemeris data.

GPS with Swift fix capability differ from a standard GPS in that receiver obtains a quick (i.e., fraction of a second) snapshot of the radio signals produced by overhead GPS satellites. These signals are processed onboard the tag and compressed into a snapshot containing just the satellite ID numbers, their respective pseudo-ranges, and a timestamp. These snapshots must be post processed by a computer that has downloaded satellite ephemeris locations in the approximate area to generate a location. Thus, the post processing tool requires time, information about the GPS satellites' positions in the sky (ephemeris data), as well as a rough estimate of satellite location to estimate a location. An estimated location derived from a given snapshot can change slightly if re-processed with new information about the tag's clock error, or a different seed location for satellites is used. These particular Swift fixes differs from rapid or fastloc fixes that use a fraction of second to collect a snapshot of radio spectrum for further postprocessing into pseudoranges and subsequently for position calculations. Lotek's similar methodology is called *fast fixes* where the GPS collects signals from satellites for a little longer to the point of getting actual pseudoranges but without any attempt to download ephemeris and/or almanac data, which is done later during postprocessing. Swift fixes will take a few seconds to collect proper signals. Their position error should be less than fastloc or rapid fixes and will be close to standard fixes error. Nonetheless, because no almanac or ephemeris data are stored, we might predict lower less fix success than a standard GPS in dense canopy cover (Moriarty and Epps 2015, Augustine et al. 2011).

Standard GPS tests

We tested GPS units within the study area, programming the collars at the same schedule most frequently used on fishers (every 15-minutes). We both conducted stationary and mobile trials where we determined fix success, or the number of successfully collected locations divided by the total number of attempts, and accuracy, or the distance between the estimated location and a GPS tracklog (Garmin 60CSx) location.

Lotek/Sirtrack collars (LiteTrack RF-40 and LiteTrack Iridium 130) were equipped with both standard GPS technology and swift fix GPS technology. Swift fix technology allows the collars to take quicker fixes, extending the battery life of the collar without increasing the collar weight. Nonetheless, there may be a trade-off between the Swift fix technology and location accuracy. We report accuracy and fix rates between the standard and swift GPS technology for Iridium collars.

Field movement trials – stratified by vegetation type

Lotek/Sirtrack LiteTrack collars were also tested within the study area to determine the accuracy and fix success rate of the GPS technology under optimal (low canopy) and suboptimal conditions (dense canopy). Canopy cover data derived from the GNN mapping was classified as low (<25%), moderate (25-60%), or dense (>60%). We assessed accuracy by calculating the distance between collar locations and a simultaneous GPS tracklog location using a Garmin GPS 60CSx (Garmin International Inc., Olathe, Kansas, USA). Fix rate was determined by dividing the number of successful locations by the total number of attempted locations.

We conducted a series of six trials each to determine the accuracy and fix rates in landscape patches either with primarily low or dense canopy cover. A technician hiked with collars held apart by several feet, scheduled to take 9 fixes each at 15-minute intervals, in either a low canopy patch or a dense canopy patch. Collars were cleared between trials so that there was no satellite memory, collars were activated within the respective canopy patch, and testing was conducted only on days with no/low cloud cover.

Additionally, for the LiteTrack Iridium collars, we tested Iridium transmission rates in low and dense canopy cover types for both the standard GPS and swift fix GPS technology. Collars were set to either transmit 1 fix or 3 fixes per message, allowing for each collar to attempt an Iridium transmission 3 to 9 times during each trial.

Finally, both Sirtrack brand GPS collars and ATS Wildlife collars were deployed on actual fishers in the field. We compared fix rates and Iridium transmission rates found during human testing trials to those of collars deployed on fishers.

A.4.2. GPS Testing Results

Mean GPS error differed between stationary and mobile trials of ATS Wildlink 500 collars, with fixes having higher mean errors while the collars were mobile (Table A.4.2a). Overall average error for Wildlink collars was 39 meters, and fix rates were 100% during these trials.

During Sirtrack GPS testing trials, all 3 Sirtrack collars performed best in low canopy cover stands compared with dense canopy stands in terms of GPS fix rates (Table A.4.2b). Fix rates were 100% for both Iridium collars and 86% for the LiteTrack RF-40 model collar in low canopy stands. Both Iridium models clearly outperformed the LiteTrack RF-40 model in dense canopy stands, where the fix rate was only 31% for the RF-40 model.

Both Iridium model collars had low mean errors in low canopy stands, and higher mean errors in dense canopy stands (Table A.4.2c). The standard GPS Iridium collar had a lower error in low canopy stands than the swift Iridium collar did (7m and 35m, respectively). Although the standard GPS Iridium collar had a slightly higher error in dense canopy than the swift Iridium collar (147m and 137m, respectively), there was significantly less variability in the accuracy of the standard Iridium collar than the swift Iridium collar despite a lower sample size. The swift LiteTrack RF-40 model collar had a significantly high mean error in lower canopy stands (243m) and a slightly higher mean error in dense canopy stands (149m) than the Iridium models. Variability in error for the LiteTrack RF-40 collar was similar in dense canopy stands to that of the standard GPS Iridium collar; however errors were highly variable in low canopy stands. Overall, Iridium transmission rates were high (100%) in low canopy stands for both the standard GPS and swift fix models. In dense canopy stands, the standard and swift fix models performed similarly, with transmission rates of 27% and 24% respectively. Transmission rates were higher for both collars when programmed to transmit every fix rather than every 3 fixes (Table A.4.2d).

We deployed four Sirtrack GPS collars on fishers to test their efficacy and to compare actual fix rates with fix rates obtained while testing collars during human trials (Table A.4.2.e, Table A.4.2.f). One LiteTrack Iridium collar with standard GPS technology was deployed on male M08T in October 2017, and one LiteTrack Iridium collar with swift fix GPS technology was deployed on male M03T from October- 2017. We also deployed two LiteTrack RF-40 collars on female fishers from March-May 2018. Actual successful fix rates for collars worn by fishers were lower for all collar types than fix rates for the same collar models estimated during human trials in dense canopy forest stands. This may be due to

the use of cavity microsites by fishers, where GPS fix attempts are less likely to be successful due to an obstructive physical barrier between the collar and the satellite's reach.

Similar to during human trials, Iridium GPS collars deployed on fishers (mean fix rate of 75% \pm 14) outperformed the LiteTrack RF-40 models (mean fix rate 22% \pm 11). Iridium transmission rates were lower when deployed on fishers (14%) than when conducting human collar trials (100% in low canopy and 23% in dense canopy). This may be due in part to the less frequent Iridium transmission schedule of the collars deployed on fishers. However, an increased Iridium transmission rate would likely have reduced the battery life, making the collars less practical when deployed on animals.

Table A.4.2a. ATS Wildlife 500 GPS collars were tested for accuracy and fix rates during both stationary and mobile trials. Locations obtained by the GPS collars were compared with locations from a handheld GPS unit to calculate mean GPS error (\bar{x}) from total attempted fixes (n).

Test Type	\bar{x} error (m)	Min	Max	SD	n
Stationary	21	1	18	18	375
Mobile	159	1	255	255	56
Overall	39	1	104	104	431

Table A.4.2b. Sirtrack GPS collars were tested during a series of 6 trails in both low canopy (<25%) and dense canopy (>60%) stands for overall GPS fix rates. Fix rates do not account for the accuracy of each point, only whether or not the collar communicated with enough satellites to obtain a fix. Fix rate denotes the percentage of successful fixes out of the total number of fixes attempted (n).

Collar Type	Low Canopy		Dense Canopy	
	Fix Rate (%)	n	Fix Rate (%)	n
Standard GPS Iridium	100	45	82.2	45
Swift Iridium	100	45	90.7	54
Swift LiteTrack RF-40	86.1	36	31.3	32

Table A.4.2c. Sirtrack GPS collars were tested during a series of 6 trails in both low canopy (<25%) and dense canopy (>60%) stands for accuracy. Locations obtained by the GPS collars were compared with locations from a GPS tracklog to calculate mean GPS error (\bar{x}) from successful fixes (n).

Collar Type	Low Canopy					Dense Canopy				
	\bar{x} error (m)	Min	Max	sd	n	\bar{x} error (m)	Min	Max	sd	n
Standard GPS Iridium	7	1	19	5	45	147	2	1785	352	37
Swift Iridium	35	1	86	26	45	137	2	3117	466	49
Swift LiteTrack RF-40	243	3	5390	960	31	149	16	1203	371	10

Table A.4.2.d. Sirtrack LiteTrack Iridium 130 collars were tested during a series of 6 trails in both low canopy (<25%) and dense canopy (>60%) stands to determine successful Iridium transmission rates. During 3 trials, collars were programmed to attempt an Iridium transmission every 3 fixes. During the remaining 3 trials, collars were programmed to attempt an Iridium transmission every fix. Success rate is defined as the percentage of fixes successfully transmitted over the Iridium service out of the total number of fixes attempted (n).

Collar & Trans. Rate	Low Canopy		Dense Canopy	
	Success rate (%)	n	Success rate (%)	n
Standard- every fix	100	27	44.4	27
Standard- every 3 fixes	100	18	0	18
Swift- every fix	100	27	25.9	27
Swift- every 3 fixes	100	18	22.2	27

Table A.4.2e. Summary of Sirtrack brand GPS collar deployments on 4 fishers. Iridium collars were tested on males during the fall of 2017, while LiteTrack RF-40 model swift fix collars were tested on females during the 2018 denning season. Fix rates represent the total number of successful GPS fixes divided by the number of GPS fixes attempted (n). Transmission rate represents the percentage of attempted GPS fixes that were successfully transmitted through the Iridium service out of the total number of attempted fixes (n).

Collar Type	Fisher	Dates	Battery life	Fixes attempted (n)	Successful fix rate	Transmission schedule	Transmission rate (%)
LiteTrack Iridium Standard	M08T	10/11/2017 - 10/28/2017	17 days	782	65%	18 fixes per message	18%
LiteTrack Iridium Swift	M03T	10/16/2017 - 12/02/2017	47 days	2274 ^a	85% ^a	12 fixes per message	10%
LiteTrack RF-40	F01T	03/07/2018 - 05/21/2018	74 days	3565	30%	NA	NA
LiteTrack RF-40	F07T	03/07/2018 - 04/19/2018	61 days	2064 ^b	14% ^b	NA	NA

a- The collar deployed on fisher M03T was not retrieved from the field, thus number of fixes attempted was estimated based on deployment date/time and the final message received through the Iridium service. Similarly, the percentage of successful fixes was calculated by dividing the number of successful fixes transmitted through the Iridium service divided by the total number of fixes transmitted through the Iridium service, and is likely an overestimate since successful Iridium transmissions are more likely to occur following a successful GPS fix.

b- Fisher F07T slipped her collar on 4/19/2018 in a tree cavity. Although fix attempts continued through 5/7/2018, fix rate was calculated using data collected prior to her slipping the collar.

Table A.4.2.f. Comparison of successful GPS fix rates for 4 collar types during human testing trials and during actual deployments on fishers. Fix rate was defined as the number of successful GPS locations over the total number of GPS location attempts.

Collar Type	Mean Human Trial Overall Fix Rate \pm sd (%)	Mean Fisher Deployment Fix Rate \pm sd (%)
ATS Wildlife 500	100 \pm 0	73.0 \pm 10.3
Iridium Standard	91.1 \pm 28.6	85 \pm N/A
Iridium Swift	95.0 \pm 22.0	65 \pm N/A
LiteTrack RF-40 Swift	60.3 \pm 49.3	22.0 \pm 11.3

A.4.2. Discussion

Researchers using GPS technology on wildlife should test collars to confirm that the scale of mean GPS error is suitable for the scale of the analyses being conducted. GPS locations were less accurate in dense canopy stands than in low canopy stands, and were also less accurate while mobile than while stationary. Careful consideration should be given when fine-scale habitat analyses are being conducted, particularly in areas with small patch sizes where GPS error may greatly influence results.

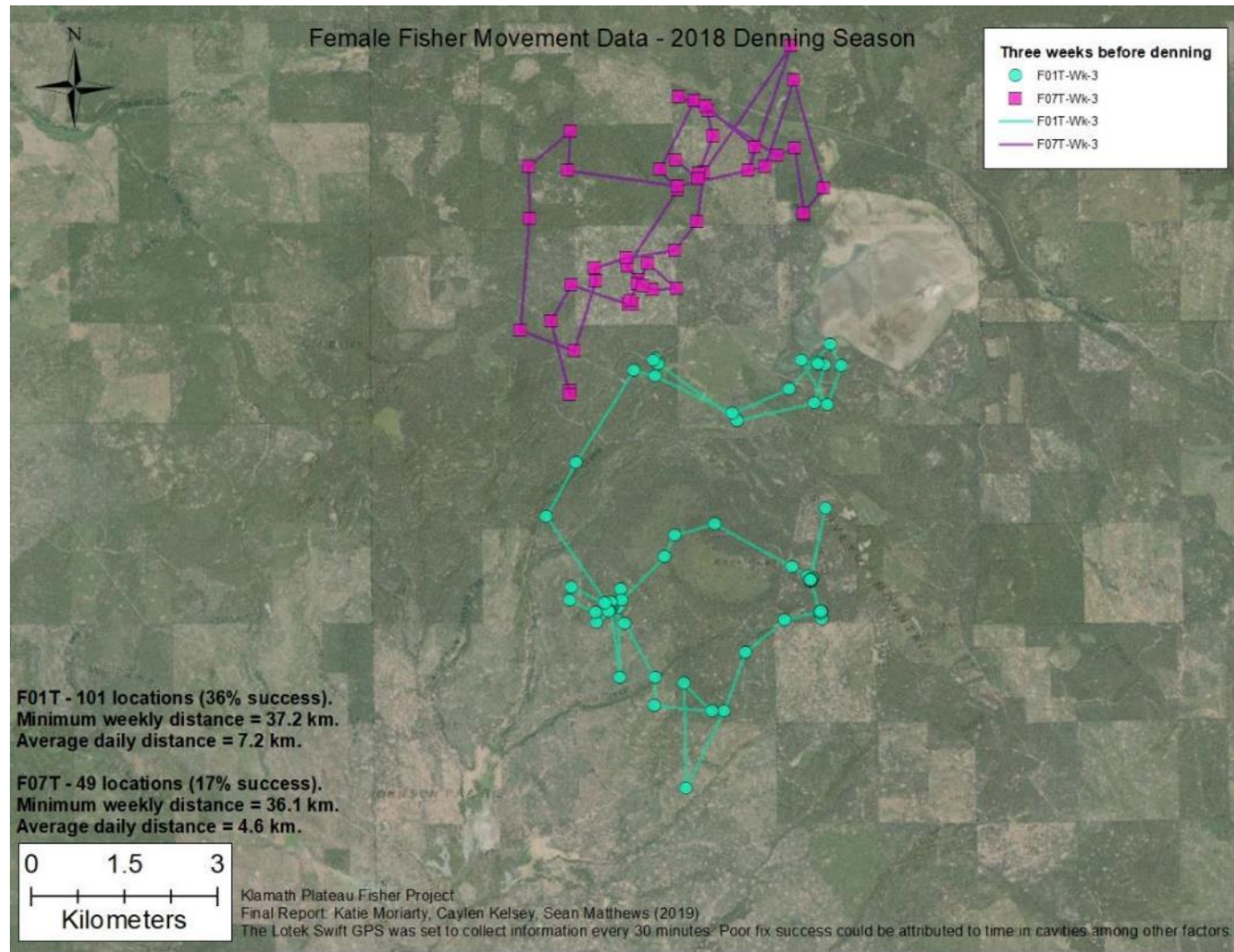
Battery life is still a limiting factor for the efficacy of using GPS technology on small to medium-sized animals. Mean battery life for ATS Wildlink 500 female-sized collars (single AA battery) was 35 days (\pm 7, sd) when programmed to attempt fixes at 15-minute intervals and 34 days programmed at 30-minute intervals. While the Sirtrack swift fix LiteTrack RF-40 model offered a longer mean battery life (68 days \pm 9) at a 30-minute fix interval, there was a trade-off in the mean percentage of successful fixes. However, the LiteTrack RF-40 model had a lower average successful fix rate of 22% when compared to the similar ATS Wildlink 500 female-sized model at 73%. This may have also been influenced by the time of the year when females were spending more time in dens. Nonetheless, we suspect that the lack of acquiring ephemeris data can severely reduce fix success in dense cover. As such, although the swift fix technology may offer longer battery longevity than standard GPS technology, a longer battery life does not necessary equate to a higher number of successful GPS fixes in total. To mitigate for this, a much higher fix rate may be needed. GPS technology should be selected so that the balance between battery life and number of successful locations aligns appropriately with the research objectives.

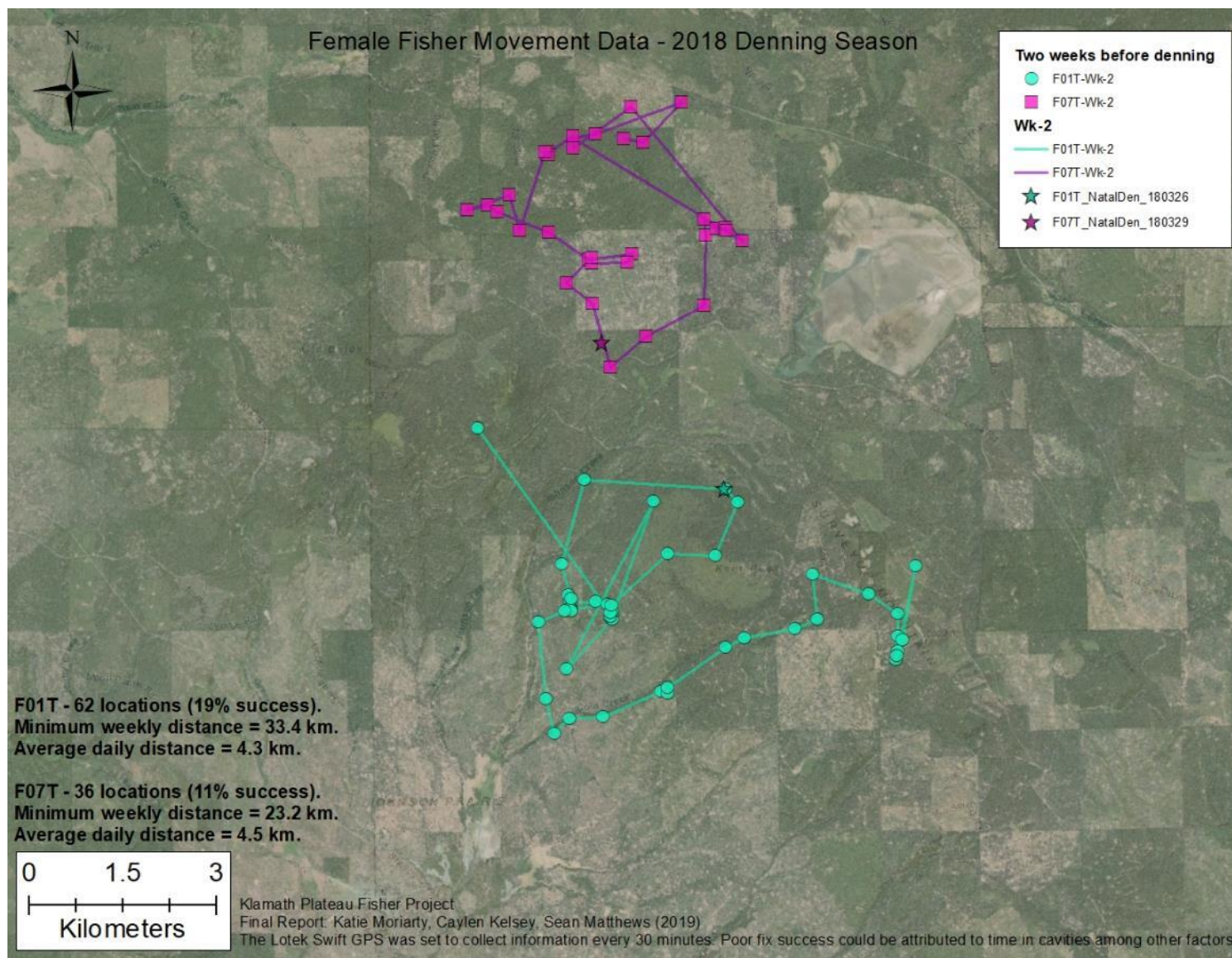
Although Iridium technology offers the opportunity to collect data without needing to retrieve the collar or collect remote downloads, it's efficacy appears to be limited for wildlife in habitats associated with dense canopy cover, for small to medium-sized wildlife with a reduced capacity to wear heavy collars, or for obligate cavity users that may be inhibited by bulky collars. While we found that successful fixes rates of Iridium collars were comparable to those of other GPS technology for medium-sized animals, overall Iridium transmission rates were low, thus negating the remote data transmission advantage that Iridium collars have over store-on-board or remote-downloadable GPS collars.

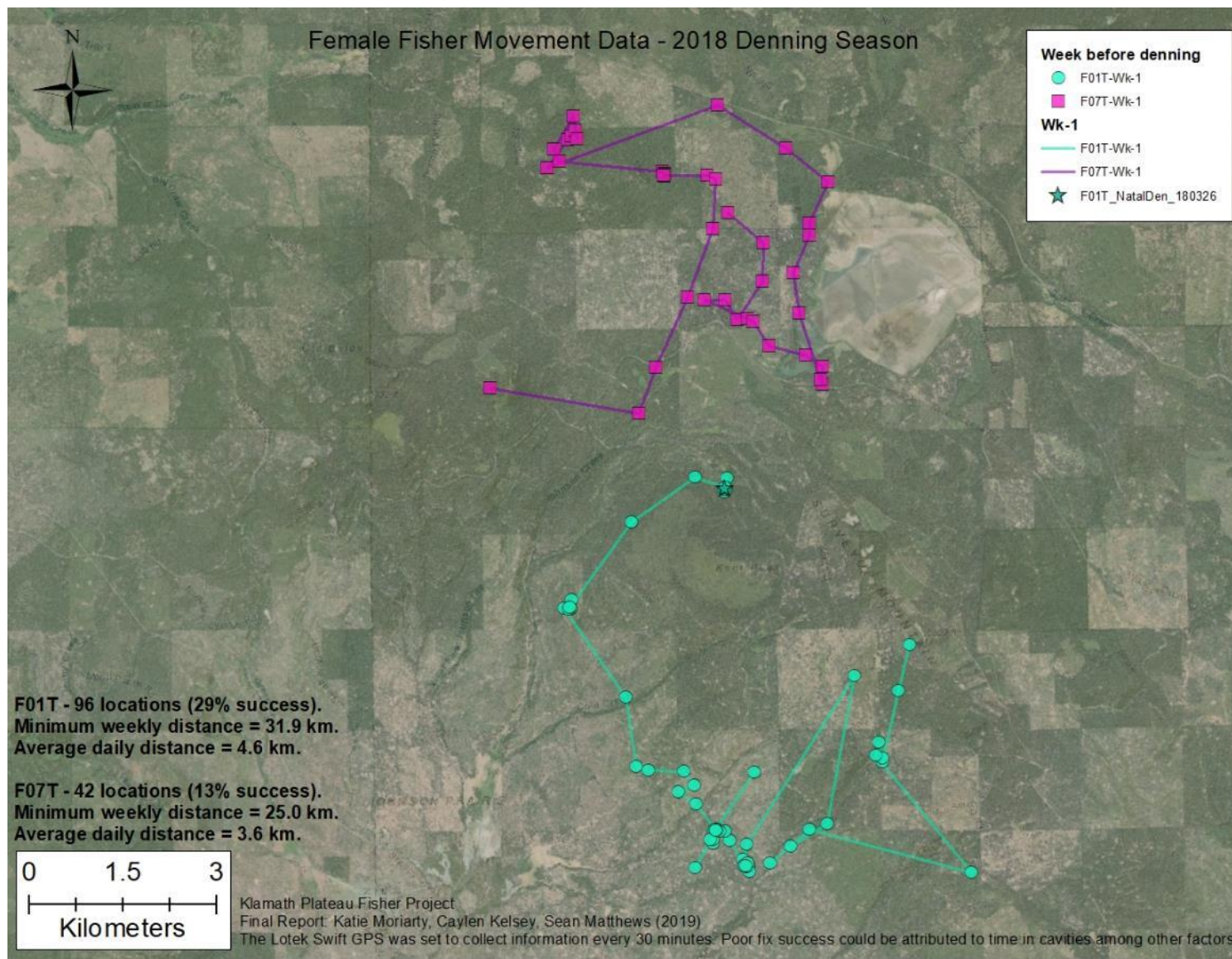
For this particular model, despite a relatively low weight of 130 grams, less than 2.7% of the mean weight of an adult male fisher and 5% of the mean weight of an adult female fisher in our study

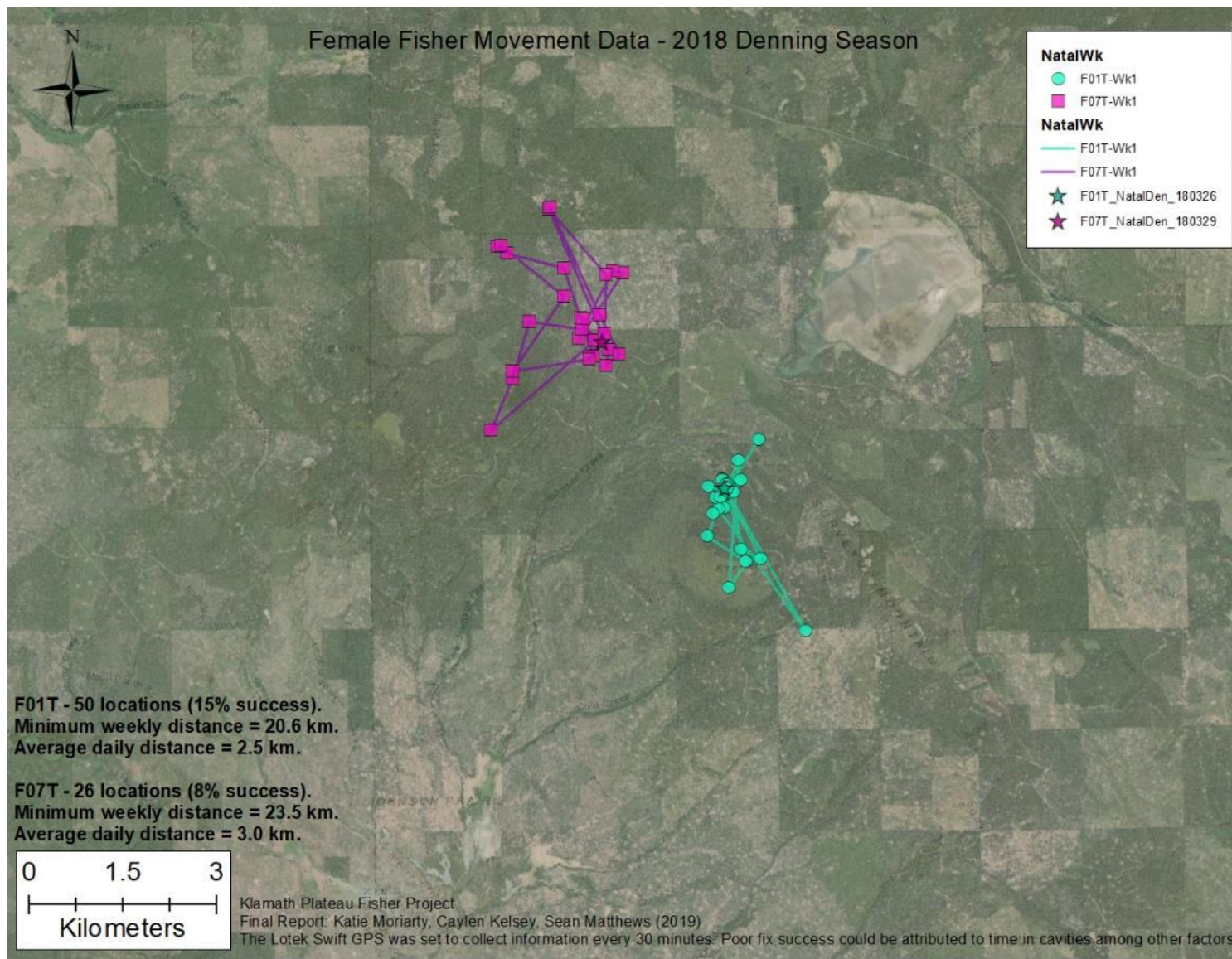
area, the collar's design was bulky. Fishers were likely inhibited from using some cavity microsites that they might have otherwise used without the collar present, especially for females where 29% of rest structures were located in cavity microsites and who require cavities for denning. We do not feel Iridium collars, at their current size and shape, are an appropriate tool for female fishers due to the potential impact on reproductive success. If Iridium collars are used on a dense canopy-associated species, frequent Iridium transmission attempts (every fix or every 3 fixes) would assist in maximizing the data that can be obtained without collar retrieval. This program would also greatly reduce battery life, and may not benefit a study in comparison to the amount of data that could be collected by observer downloads.

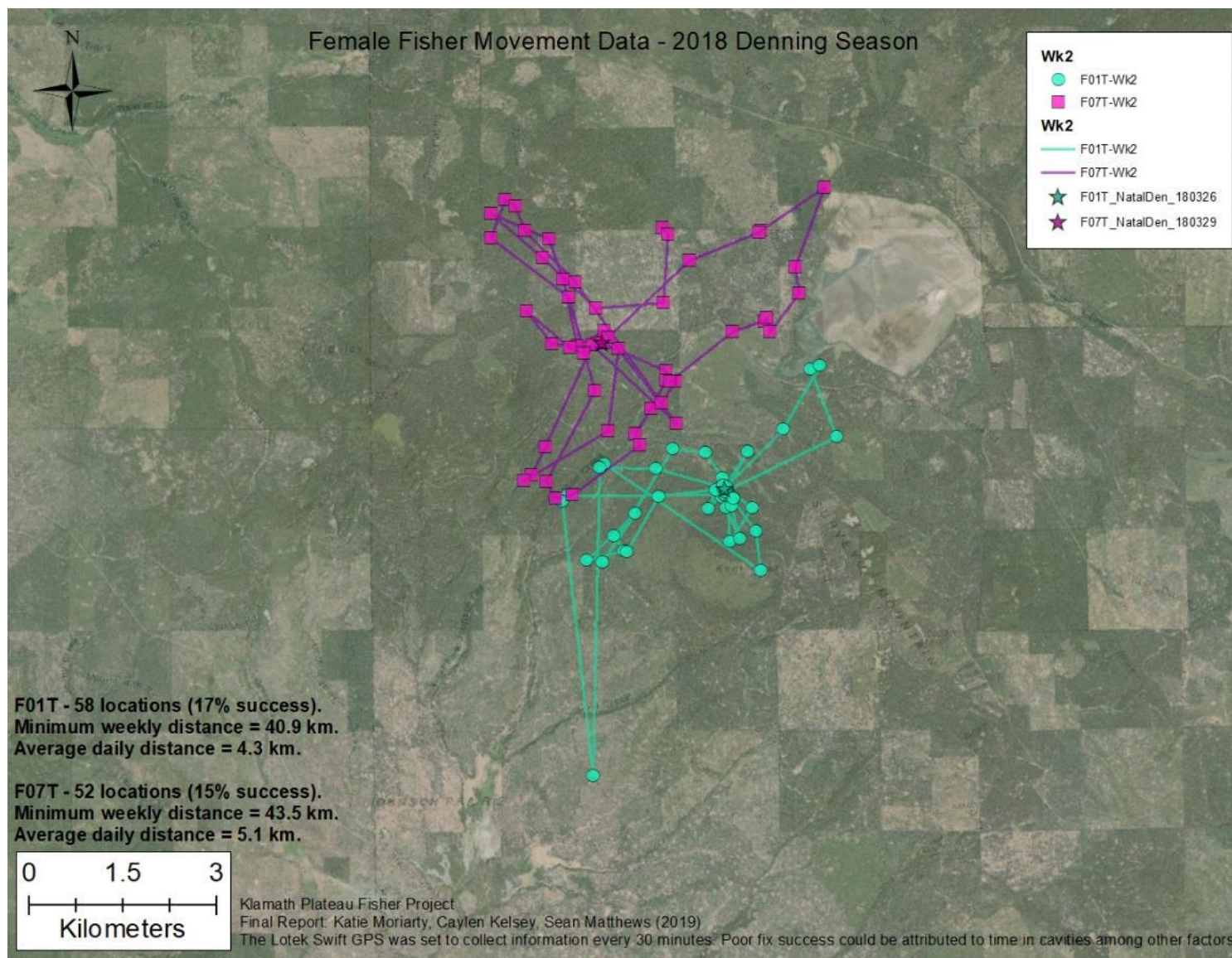
Appendix 5: Female Movements During Denning Season, Weekly Figures

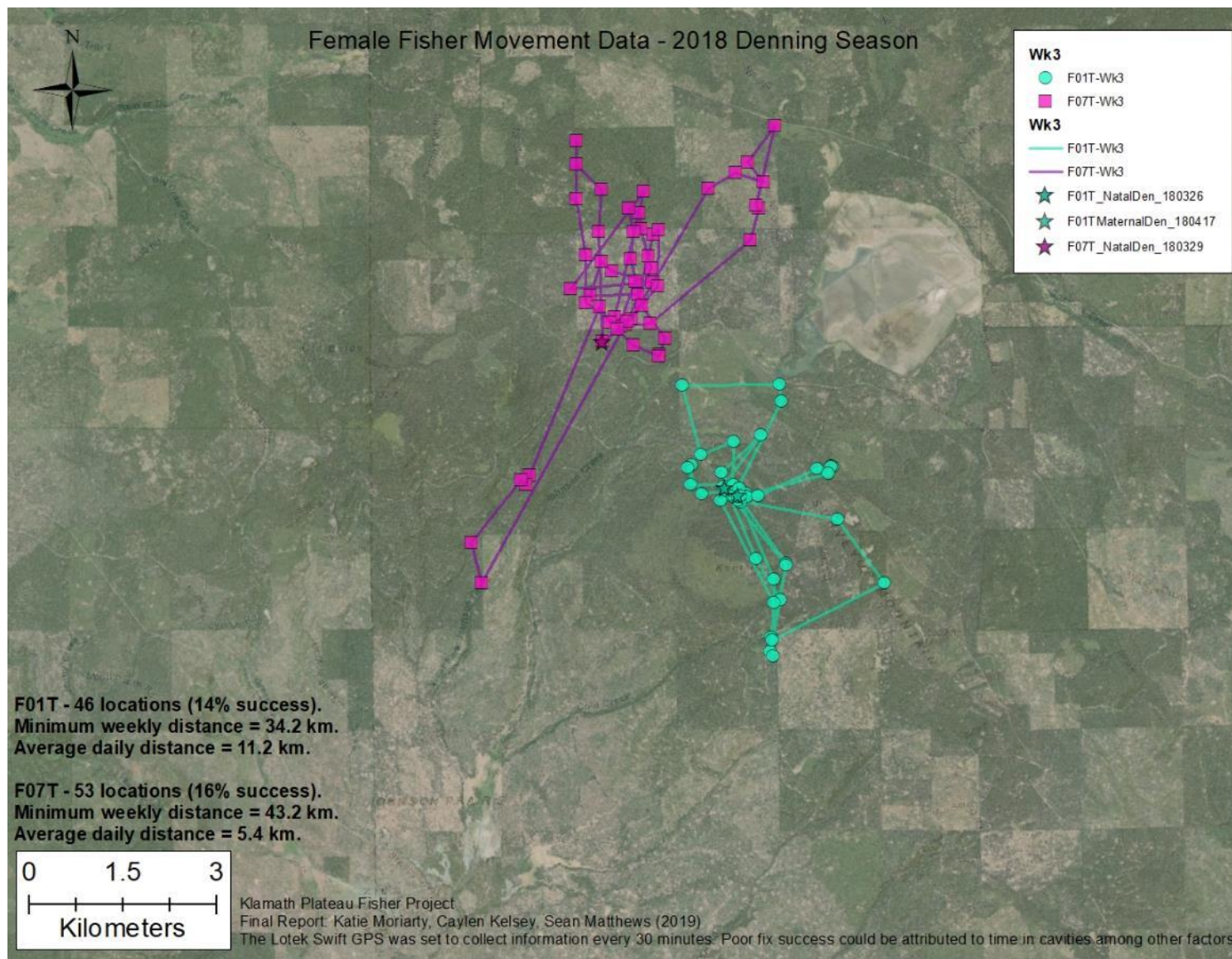


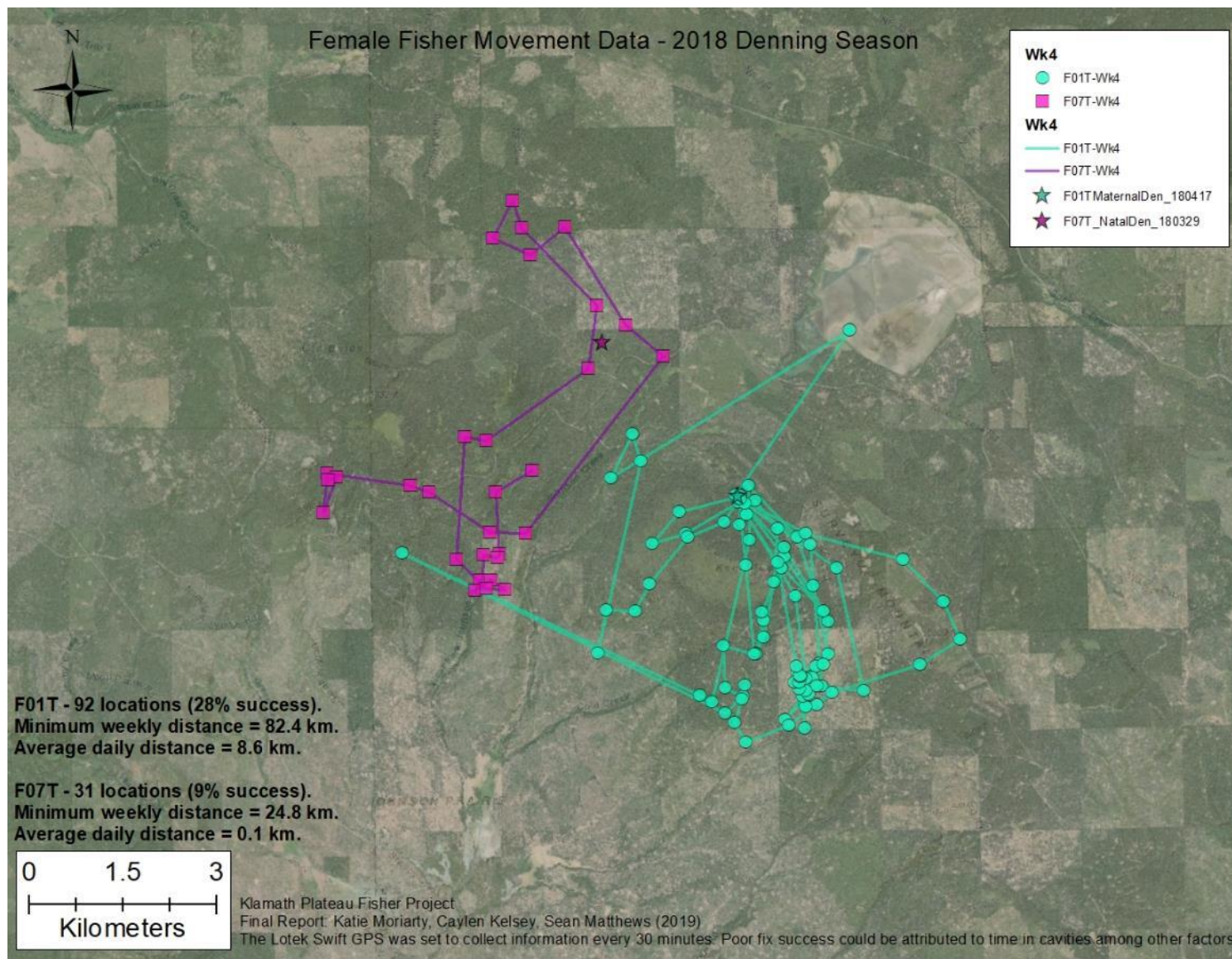


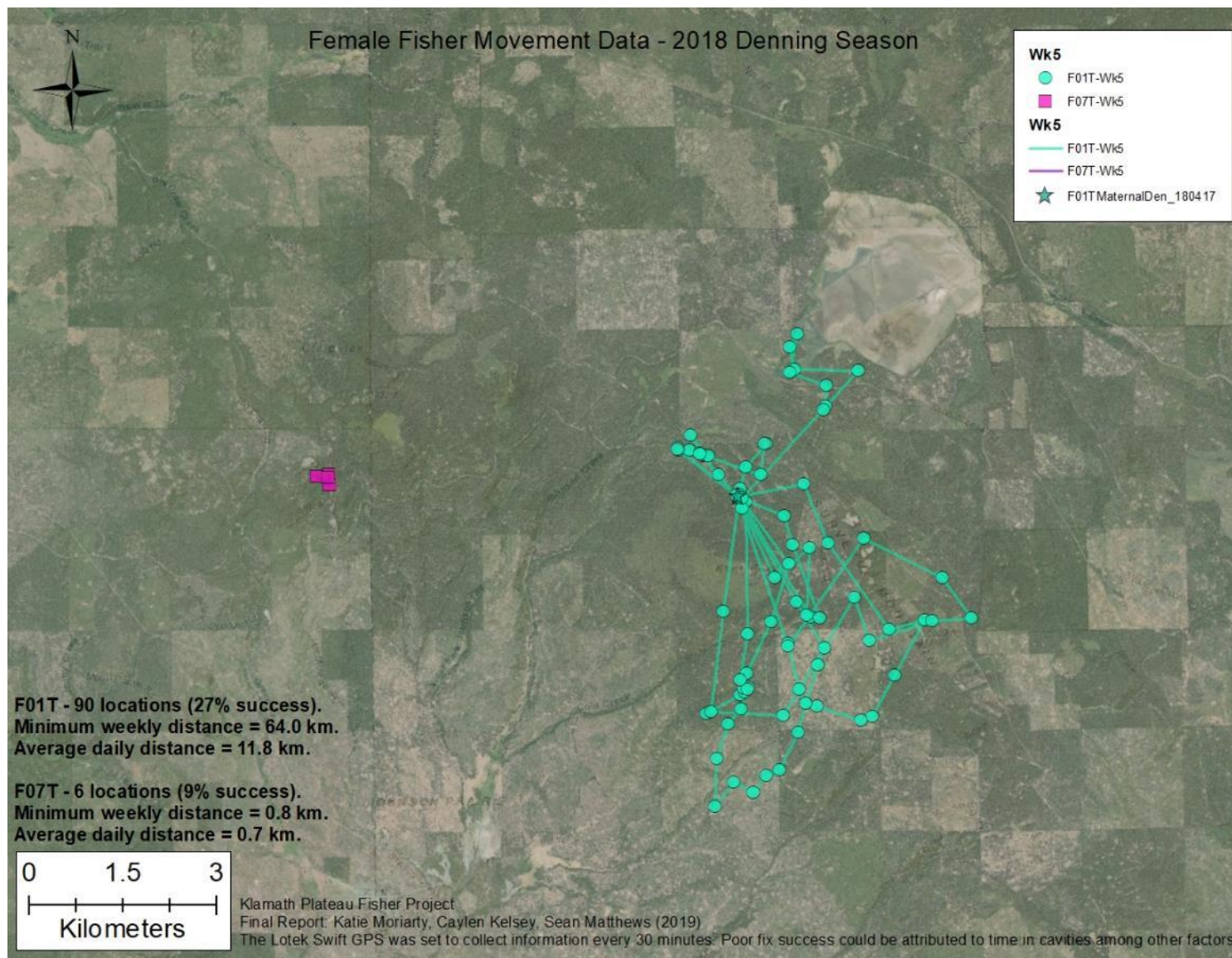


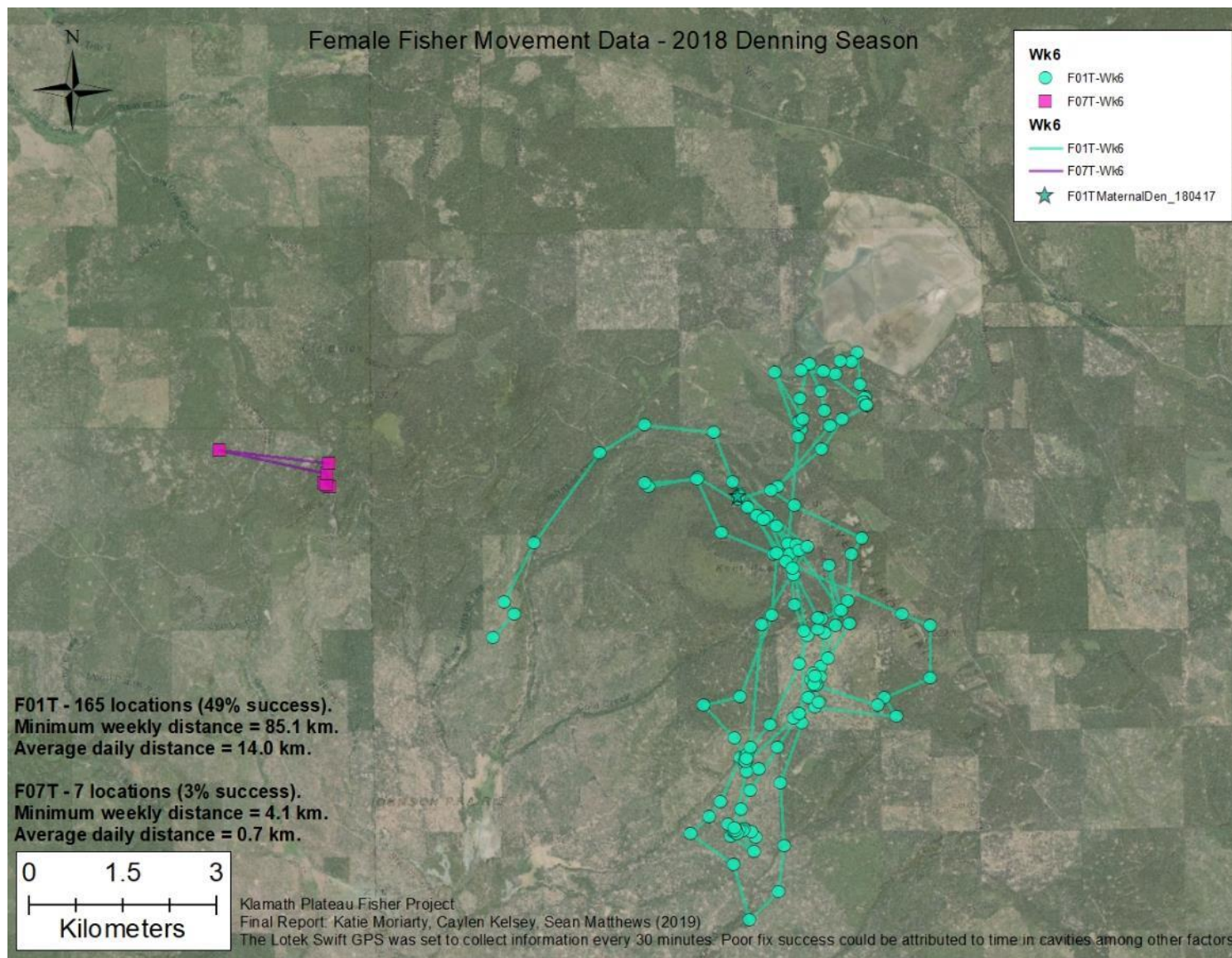


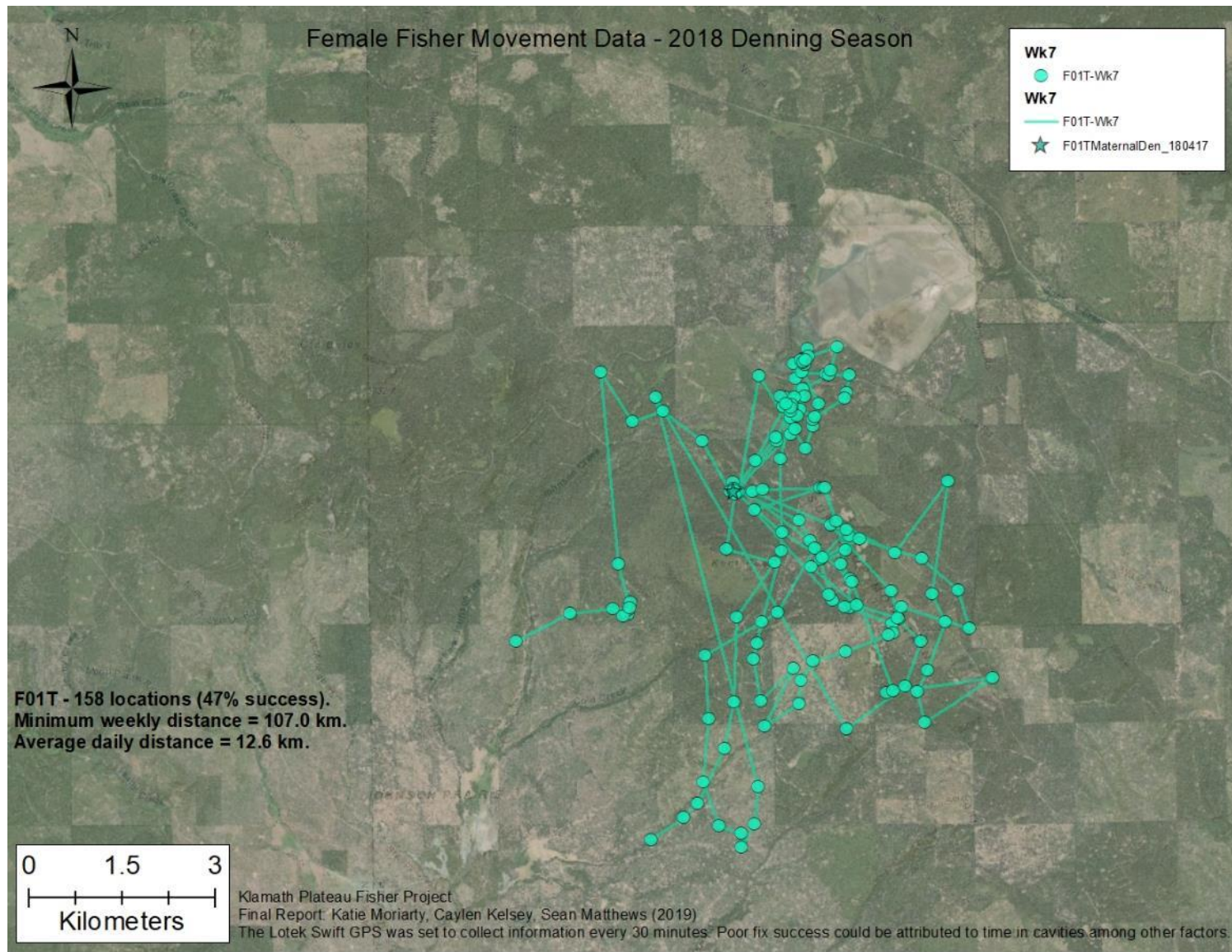


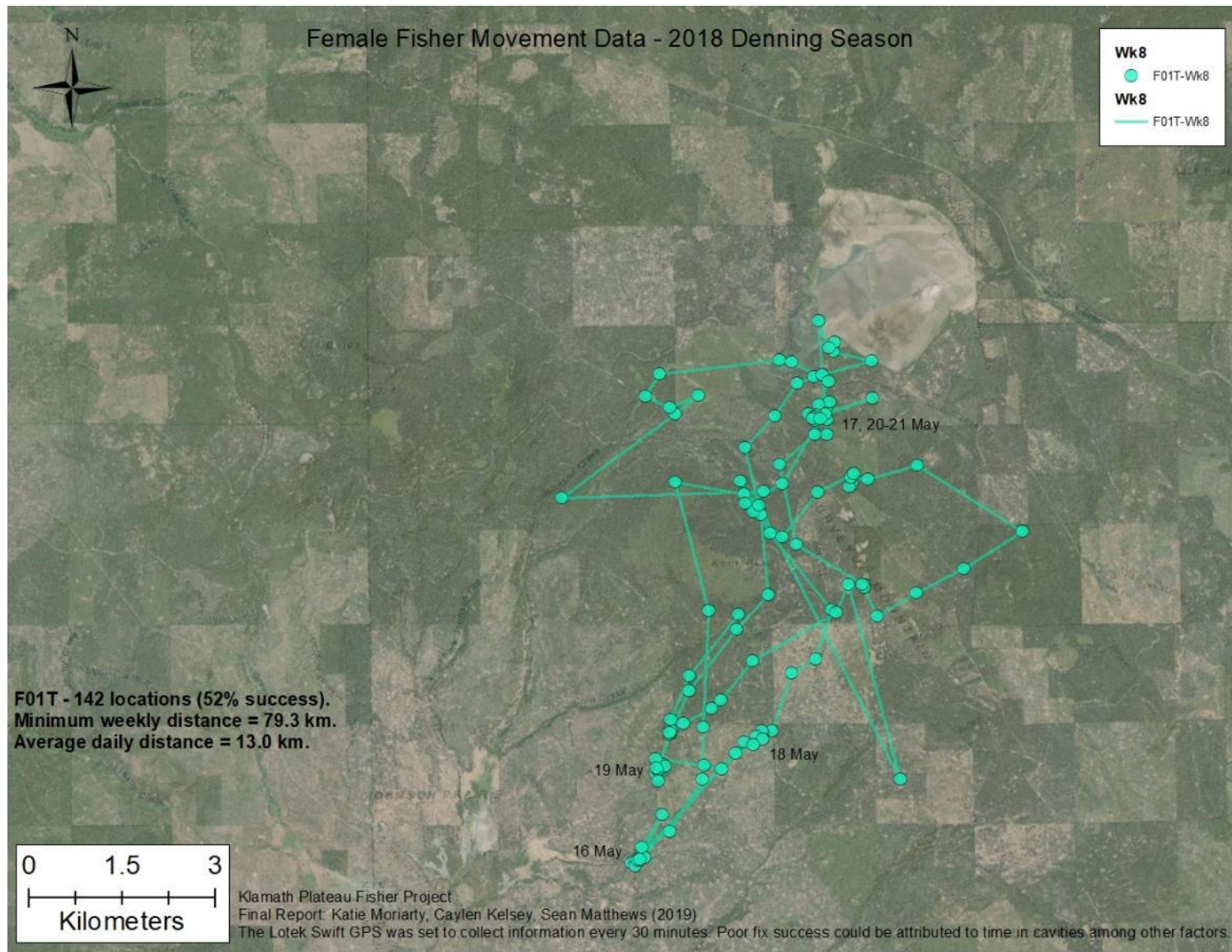












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