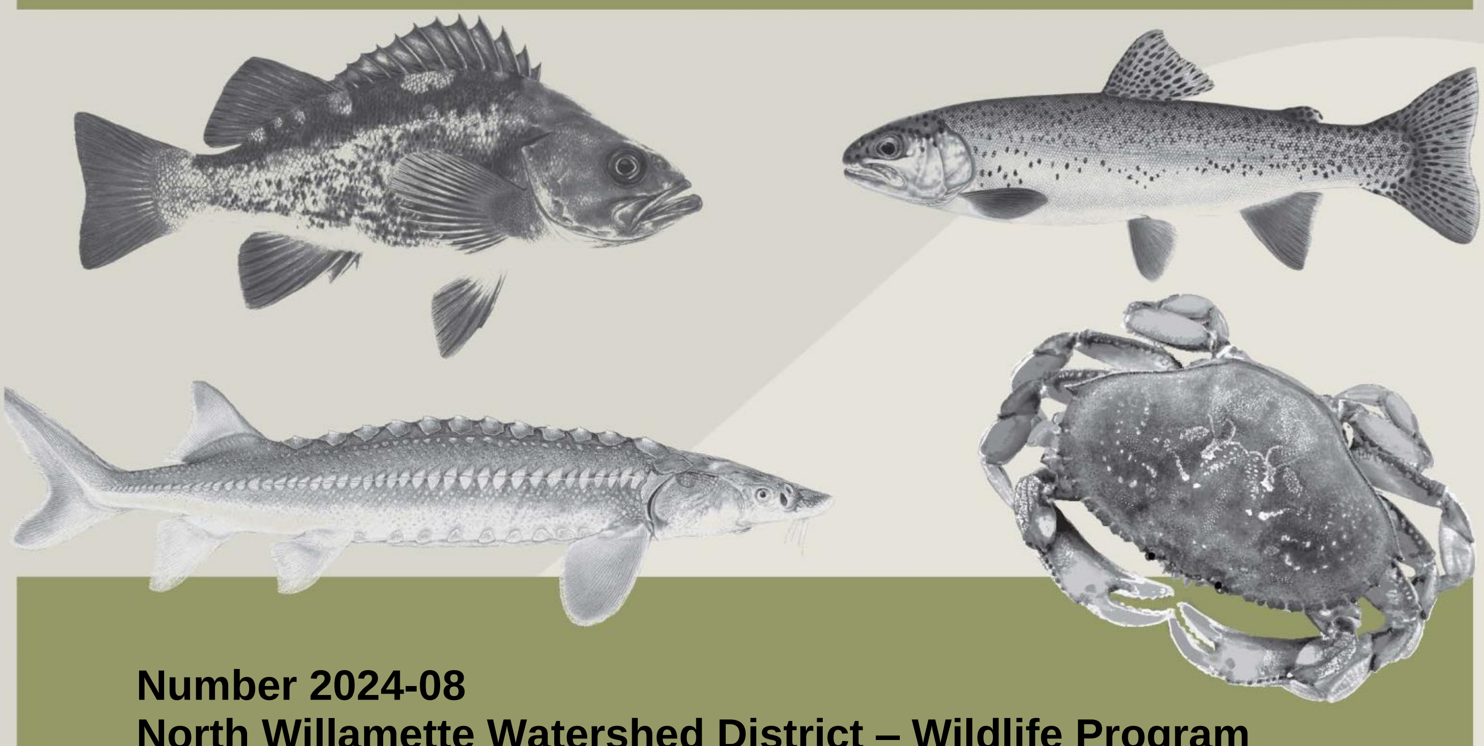
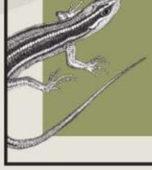
Science Bulletin

Oregon Department of Fish and Wildlife



Number 2024-08
North Willamette Watershed District – Wildlife Program

Elk Movement Ecology in the Southern Mount Hood Region, 2015-2023.



This report should be cited as:

Keiter, D. A., B. R. Cate, L. E. Sanders, and T. B. Ott. 2024. Elk Movement Ecology in the Southern Mount Hood Region, 2015-2023. Science Bulletin 2024-08. Oregon Department of Fish and Wildlife, Salem.

Elk Movement Ecology in the Southern Mount Hood Region, 2015-2023.

Prepared by

Dave A. Keiter
Ben R. Cate
Lindsey E. Sanders
Tessa B. Ott

Oregon Department of Fish and Wildlife
North Willamette Watershed District – Wildlife Program
17330 SE Evelyn St.
Clackamas, OR 97222

October 2024

CONTENTS

ABSTRACT

Increasing human populations in Oregon have led to greater demand for outdoor recreational opportunities near Mount Hood. Simultaneously, research has demonstrated negative effects of outdoor recreation on wildlife, including elk (*Cervus canadensis*). To better understand the potential impacts of landscape development and expanded recreational opportunities during summer months on wildlife, we GPS-collared 15 female elk near Government Camp, Oregon from 2015-2023. Specifically, we evaluated 1) known causes of elk mortality, 2) overlap between elk summer core areas and proposed recreation development sites (ski areas) near Mount Hood, 3) migration routes used by elk, and 4) frequency with which elk crossed major highways in their summer range. We found that vehicle collisions (n = 3) were the most frequent known cause of death for collared elk during this study. Elk core use areas in summer heavily overlapped ski areas near Government Camp (19.6% to 95.4% overlap). Elk showed high range fidelity and tended to use consistent migration corridors across years. Elk crossed highways frequently in the summer with a median rate of 3.7 crossings/elk/30 days. Overall, observed space use patterns suggest this elk population could be susceptible to increased development and summer recreation activities that co-occur with elk habitat use near Government Camp. Limiting development in elk summer range and taking measures to address vehicle-caused mortality could help facilitate continued elk presence in this region.

INTRODUCTION

Increasing human populations in Oregon have led to a concomitant demand for additional outdoor recreation opportunities. This is particularly true near Mount Hood in the Cascade Mountains, largely due to its proximity to Portland: Oregon's most populous city. While winter sports (skiing, snowboarding, etc.) have historically been popular forms of recreation on and around Mount Hood, recently concessionaires and other businesses have expanded or proposed expansion of summer recreational offerings within legally permitted ski areas in this region (e.g., SE Group 2022). Proposed summer recreation opportunities include development of mountain biking trails, alpine slides, and a "mountain coaster". The natural areas surrounding Mount Hood provide habitat for a variety of native wildlife species; as such, improved understanding of the potential impacts of development and increased summertime recreation is needed to guide regulatory decision-making and permitting of proposed projects on federally-managed, or public, lands.

Elk (*Cervus canadensis*) are an economically and culturally important ungulate species in Western Oregon that benefit from the early successional habitat associated with downhill ski areas. Elk in the Cascade Mountains consist of intermixed Roosevelt (*C. canadensis roosevelti*) and Rocky Mountain elk (*C. canadensis nelson*) due to frequent past translocations (Stussy et al. 1994). Expansion of summer recreation opportunities in ski areas could result in the loss of high-quality forage habitat for elk during a critical life history period. Female elk in this region give birth on their summer range and spend the summer and fall with juvenile elk foraging. The nutrient-dense forage provided by early successional habitat on summer range is important to allow female and juvenile elk to accrue body fat leading into winter (Cook et al. 2004). Early seral habitats provide highly nutritious forage for elk (Cook et al. 2016) but the proportion of early seral habitat present on federal lands has decreased greatly over the last few decades due to changes to timber cutting (Thomas et al. 2006) and fire suppression practices. There is strong evidence to suggest that public lands in Western Oregon and Washington may be nutritionally insufficient for lactating elk during summer and fall (Cook et al. 2016). As such, the open areas and early successional habitat associated with ski areas may currently provide some of the highest quality summer range habitat in the Mount Hood National Forest for elk.

In addition to the direct impacts of habitat loss, disturbance caused by outdoor recreation can also affect elk populations. Naylor et al. (2009) and Wisdom et al. (2018) demonstrated that different types of outdoor recreation (ATV riding, mountain biking, hiking, and horseback riding) caused elk to avoid trails, increase the amount of time spent moving, and decrease the amount of time spent foraging. While elk responded most strongly to ATV riding, they avoided trails used for all forms of recreation evaluated. Interestingly, the negative response by elk was stronger in response to mountain biking than hiking or horseback riding (Wisdom et al. 2018). Furthermore, research on elk calving grounds suggests that disturbance to female elk during the calving season (simulated through back-country hiking) resulted in depressed reproductive rates (Phillips and Alldredge 2000, Shively et al. 2005). Other research has demonstrated longer-term shifts away from areas of human use and decreased habitat use by elk in response to human recreation (Procko et al. 2024).

Currently, there are data gaps surrounding the elk population near Government Camp, on the south side of Mount Hood. This area experiences heavy snowfall in winter causing this elk population to migrate to lower elevations. However, little is known about where their winter range is located, the routes these elk travel when migrating, or when migration occurs. This information could help land managers to assess the potential impacts of new recreational activities on elk populations in the Mount Hood region. Understanding the migration ecology of a population is critical, as disruption of migratory routes has been linked to rapid declines in ungulate populations (Bolger et al. 2008). Basic information on observed causes of death for adult female elk in this population may also help managers evaluate the status of this population and determine means to address population declines. A large-scale study of known fate survival of elk in the Western Cascade Mountains of Oregon found that poaching was the most common cause of death for adult female elk (44% of mortalities; Stussy et al. 1994). Since that research, the Oregon Department of Fish and Wildlife (ODFW) and Oregon State Police have conducted extensive anti-poaching campaigns in Oregon.

In this study, we aimed to improve our understanding of the ecology of elk in the Southern Mount Hood region and to assess potential impacts of proposed summertime recreational development. Specifically, our objectives were to evaluate: 1) known causes of elk mortality, 2) overlap between elk core use areas in summer and proposed recreation development sites (ski areas) near Mount Hood, 3) migration routes used by elk, and 4) frequency with which elk crossed major highways in their summer range. Improved knowledge of causes of mortality, migratory behavior, and overlap with recreation will allow ODFW to better manage this elk population and provide improved guidance to land management agencies (e.g., U.S. Forest Service) regarding proposed development projects in the region.

METHODS

Field methods

We deployed 3 baited walk-in corral traps in the vicinity of Government Camp, OR in the Santiam Wildlife Management Unit (WMU) to capture female elk each summer from 2015 to 2022. Walk-in traps were baited with salt. We also trapped 1 female elk in Friend, OR in summer 2019. We used JagerPro camera systems attached to the trap gate to monitor traps and reduce bycatch (i.e., non-target animals and species; Keiter et al. 2022). We chemically immobilized captured elk using the drug combination BAM (Butorphanol [27.3 mg/ml]-azaperone [9.1 mg/ml]-medetomidine [10.9 mg/ml]), estimated age by examining the teeth, and attached a GPS collar (Litetrack Iridium B420 or GPS7000MA, Lotek, Newmarket, Ontario). We programmed all store-on-board collars to record a GPS location every 3 hrs; non-store-on-board GPS collars uploaded a GPS location to an online platform every 5 hrs. We programmed collars to provide an automated notification if a lack of movement over a fixed period (8 hrs) indicated animal mortality or the GPS collar was detached. When we detected a mortality signal, we recovered the collar and conducted a site investigation to determine the cause of death or collar failure. Site investigations included examinations of the carcass for physical trauma characteristic of predator-, vehicle-, or human-caused mortality and identification of other evidence of cause of death in the surrounding area such as tracks, caching behavior, etc.

Analytical methods

Given the relatively short distance between trap locations and high observed overlap between elk home ranges, collared elk did not necessarily represent independent samples and thus there is some degree of pseudo-replication in certain estimates. However, given the relatively small sample size of collared elk, we used all available data for estimates unless otherwise stated. We conducted all analyses in R (R Core Team 2022).

Survival and monitoring.-- We summarized and described the amount of time each GPS-collared elk was monitored and the timing and observed causes of death for elk that died during this project.

Home range size, location, and overlap with ski areas.-- We defined 2 seasonal home ranges for elk in this study: the summer/fall home range (hereafter, summer range) comprised the period in which elk occupied high elevation habitat in the Santiam WMU near Government Camp, Oregon. The winter/spring home range (hereafter, winter range) comprised the period in which elk occupied lower elevation habitat on or near the White River Wildlife Area (WRWA) in the White River WMU near Tygh Valley, Oregon. These seasonal ranges were entirely distinct based on the movements of elk we observed (i.e., elk never wintered in the area considered to be summer range and vice-versa). Using location data from each GPS collar, we identified the date when each elk began and completed its seasonal migrations. We censored potentially erroneous location data using thresholds for calculated Dilution of Precision (DOP) values. Specifically, we censored all 2D fixes with DOP ≥5 and all 3D fixes with DOP ≥10 as recommended by Lewis et al. (2007). We estimated home ranges with an adaptive Local Convex Hull estimator (a-LoCoH), with the “a” parameter set to the maximum Euclidean (straight-line) distance observed between any single animal’s locations during a single season (Getz et al. 2007). We constructed home ranges using all remaining locations outside of the migratory periods. We estimated separate summer and winter home ranges (95% isopleths) and core areas (50% isopleths) for all animals collared for ≥30 days within a season.

We calculated the mean home range and mean core area size for this elk herd in summer and winter. To avoid over-representing individuals that were collared for more than one year in our estimates, we calculated mean seasonal home range size estimates for the herd using only each individual’s most complete (total days monitored) seasonal dataset for both summer and winter ranges. We merged home ranges and core areas for all individuals to determine an overall herd range and herd core area for collared elk. We calculated the percent area overlap between the herd’s summer core use area and each permitted ski area in the vicinity of Mount Hood.

Migration timing, duration, and corridor identification.-- We calculated migration duration as the number of days between an animal leaving one seasonal range and arriving in the other. When calculating migration timing and duration, we excluded partial migrations. We defined partial migrations as periods when elk migrated partway between seasonal ranges but did not complete the migration or migrated to a seasonal range and quickly returned to their seasonal range of origin. Each elk that exhibited partial migration eventually completed the full migration to its alternate seasonal range. We recorded multiple seasonal migratory movements by the same individuals for animals that were collared for >1 yr. To identify migration corridors, we created movement tracks for animals during migration and buffered tracks by 200 m (similar to Proffitt et al. 2021). The 200 m buffer helped account for GPS error and the likely spread of the elk herd during migration. We estimated migration distances by measuring the Euclidean distance between seasonal home range centroids for each animal. We summarized migration distances by season and then by year with the expectation that if elk exhibited high home range fidelity there would be relatively little variation in migration distances between years.

Highway crossings.-- Given concerns regarding vehicle mortality as a potential cause of death for elk in this area, we estimated the number of instances in which GPS-collared elk crossed a major highway while on summer range. The two major state highways in the Mount Hood region are Highway 26 and Highway 35. To estimate the number of highway crossings, we calculated the number of intersections between elk movement segments and a major highway. We performed this analysis for all elk monitored for ≥30 days on summer range. We then estimated the median number of crossings per animal per 30-day period (crossings/elk/month).

RESULTS

Survival and monitoring

From 2015 to 2022, we captured and GPS-collared 15 female elk. One GPS collar failed, resulting in no data for that individual. One animal was captured and collared twice: once in 2015 and again in 2019. The average estimated age of elk upon initial capture was approximately 2.5 yr (range: 1 – 5 yr). The median amount of time a GPS collar was active was 270 days (n = 15 deployments), although we experienced high variation due to early collar failures, animal mortalities, and re-collaring of a single individual (range: 24 – 1,540 days).

Five female elk died while equipped with a functional GPS collar, and 1 additional elk died following GPS collar failure, resulting in 6 known mortality events (3 vehicle collisions, 2 cougar predations, 1 illegally poached). Four known mortalities for collared female elk occurred on summer range (3 vehicle collisions and 1 cougar predation), 1 mortality occurred at a migratory stopover location (cougar predation), and 1 elk was poached on its winter range (Fig. 1). Almost all recorded mortalities (5 of 6) occurred September – October, while 1 vehicle collision occurred in July.

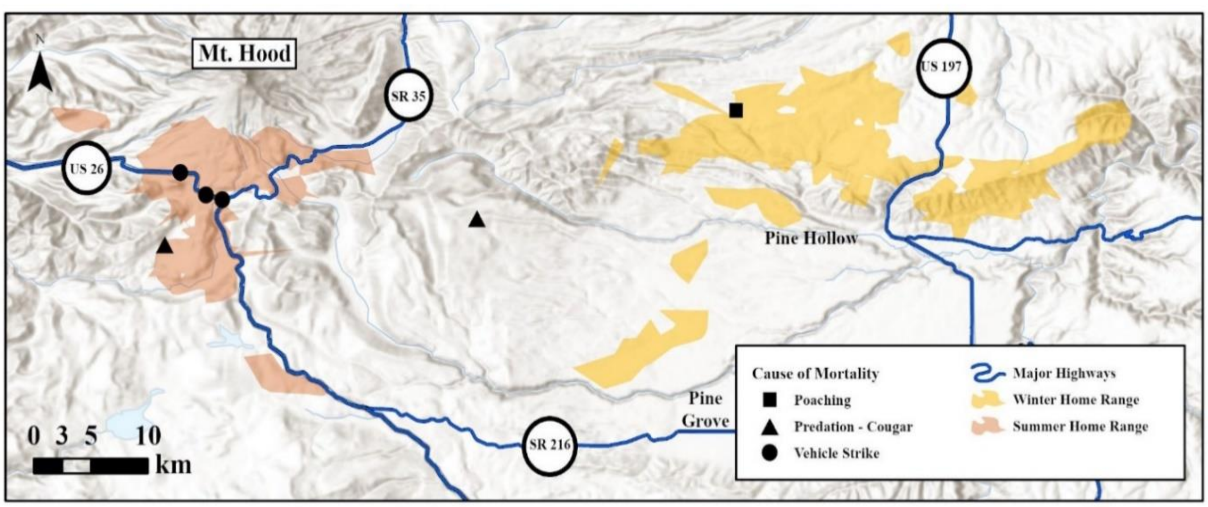


Fig. 1. Mortality locations and causes of death for GPS-collared female elk captured near Government Camp, Oregon, 2015-2023.

Home range size, location, and overlap with ski areas

The summer home ranges of elk in this study generally fell west of Highway 35 and south of Mount Hood. There was a high degree of overlap among the home ranges of elk collared across all 3 trap locations (Fig. 2). In addition, elk that were collared for multiple consecutive years showed high fidelity to their home ranges, as evidenced by high overlap of home ranges between years. We found that summer home ranges in the Santiam WMU tended to be smaller ($\bar{X}$ = 23.5 km^2, range = 9.7 – 40.3 km^2, n = 12 elk) than winter home ranges in the White River WMU ($\bar{X}$ = 35.1 km^2, range = 17.1 – 49.9 km^2, n = 9 elk).

We found variation in the percentage overlap between ski areas and herd-level summer core area (Fig. 3). Mount Hood Meadows overlapped the least with elk core area (19.6% overlap), while 95.4% of Teacup Lake Snow Park fell within elk core area. Approximately 58% of Mount Hood Skibowl and 58% of Timberline Lodge ski area fell within elk summer core area.

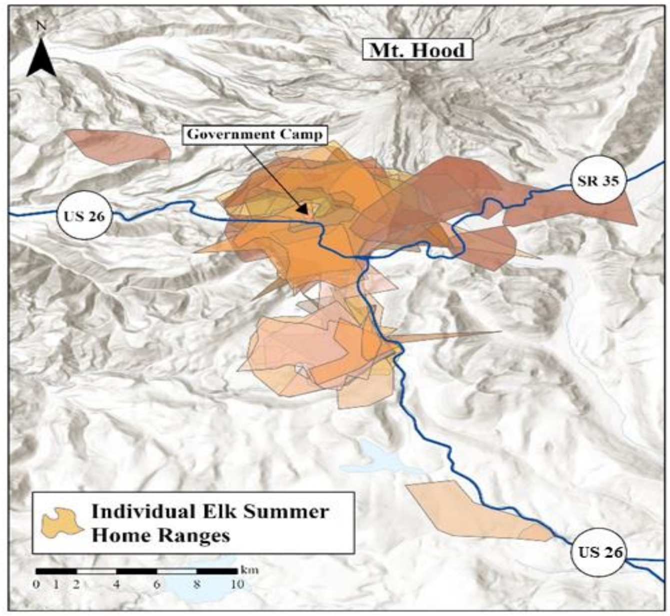


Fig. 2. Overlap of individual elk summer home ranges near Government Camp, Oregon, 2015-2023. Each polygon represents the summer home range of a female elk in one year.

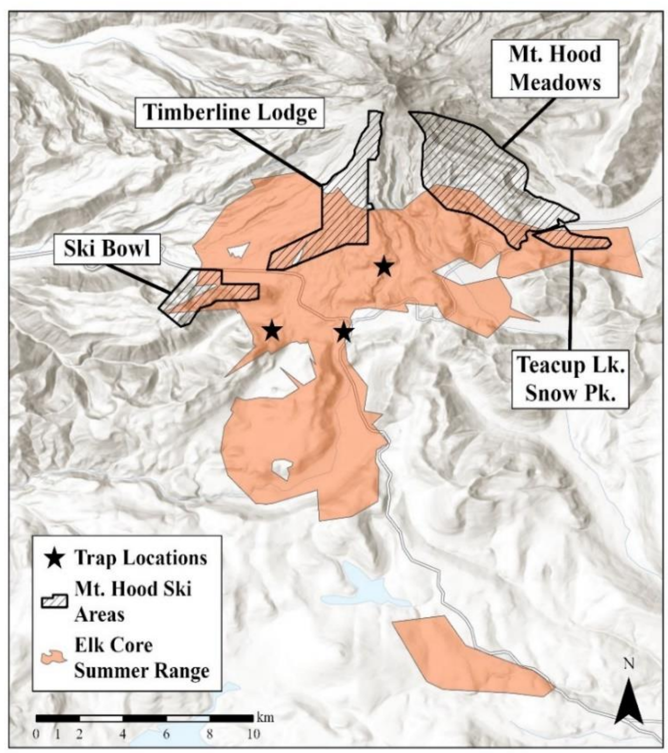


Fig. 3. Elk herd-level summer core area and overlap with permitted ski areas near Government Camp, Oregon, 2015-2023.

Migration timing, duration, and corridor identification

We gathered data on summer to winter range migration from 10 individual elk (18 migrations) and winter to summer range migration from 6 individual elk (14 migrations; Fig. 4). The median date on which elk departed their summer range near Mount Hood to migrate to the White River Wildlife Area was Nov. 11th, with relatively little variation evident across years (range of medians = Nov. 6th – Nov. 24th). The earliest an elk migrated from summer range to winter range was Oct. 18th, while the latest an elk migrated was Nov. 25th. When migrating from winter to summer range, elk were also relatively consistent in departure timing (range of medians = Apr. 16th – May 11th). The overall median date of winter range departure was April 30th, with the earliest documented departure on April 15th and the latest departure on May 15th.

We found that the duration of migrations was similar regardless of the direction of migration. Summer to winter range migration took elk a median of 4 days (range = 1 – 17 days, n = 18 migrations), while winter to summer range migration took elk a median of 3.5 days (range = 1 – 22 days, n = 14 migrations). We identified a few instances in which elk exhibited partial migrations: animals began migration but did not make it to their new seasonal range before turning back. Multiple animals also completed their migration from summer to winter range, returned to summer range, and then migrated back to winter range later in the season.

As might be expected given the high site fidelity exhibited, migration distances were similar regardless of migration direction. Summer to winter range migration averaged 37.9 km (range = 28.7 – 43.4 km, n = 18 migrations) while winter to summer range migration averaged 38.8 km (range = 36.8 – 43.5 km, n = 14 migrations). Overall, the average migration distance was 38.3 kilometers (32 total migrations, n = 9 elk). Elk tended to follow similar migratory paths regardless of the direction of migration (Fig. 4). Almost all winter to summer range migrations terminated near Salmon River Meadows to the south of Mount Hood, and almost all summer to winter range migrations were initiated near Barlow Pass. One elk repeatedly took a separate route to the north when migrating from winter range to summer range (Fig. 4).

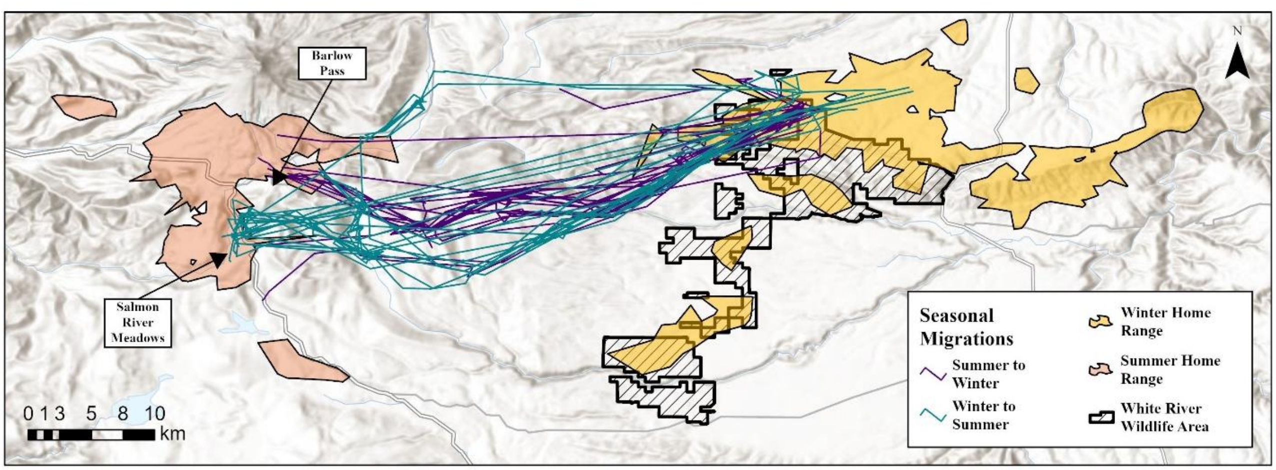


Fig. 4. Seasonal migrations by GPS-collared female elk captured near Government Camp, Oregon, 2015-2023.

Highway crossings

Of the 15 GPS-collared elk in this study, 12 were present on summer range for > 30 days. We estimated that these collared animals crossed a major highway a total of 416 times. We estimated a median highway crossing rate of 3.7 crossings per elk every 30 days, with relatively high variability among animals (range: 1.2 – 9.8 crossings/30 days). Our data suggested that ~84% of elk highway crossings occurred on Highway 26 between mile markers 52 and 58 (Figure 5).

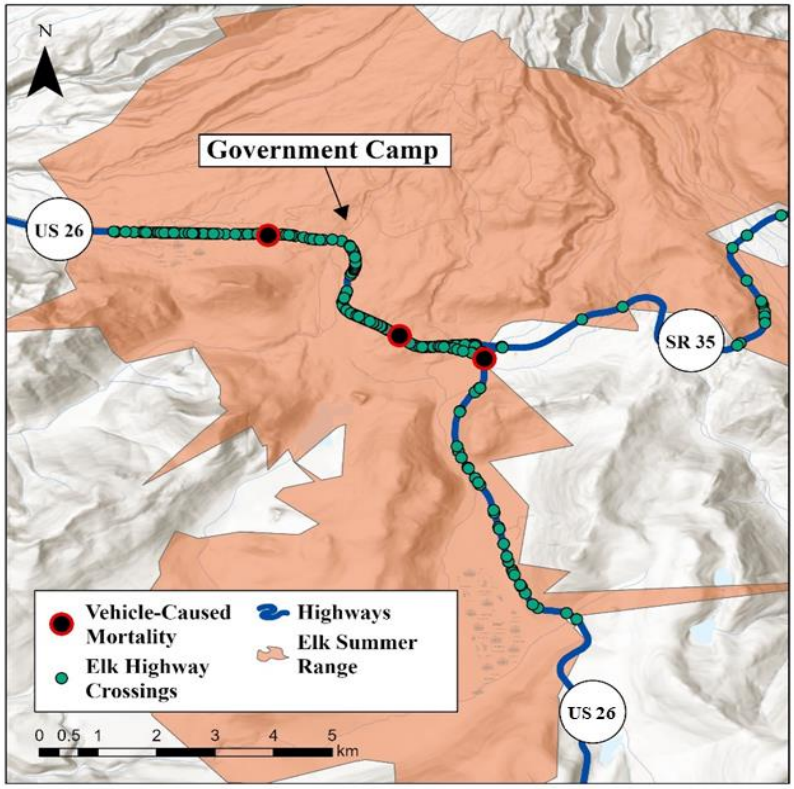


Figure 5. Predicted highway crossing locations and observed mortality sites for GPS-collared elk on their summer range near Government Camp, OR, 2015-2023.

DISCUSSION

Outdoor recreation contributed $601 million to the local economy in the Mount Hood and Columbia River Gorge tourism region in 2019 (Mojica et al. 2021). Due to the high economic value of outdoor recreation and increases in Oregon's human population, the Cascade Mountains have experienced increases in summer visitation and development in recent decades. Understanding how Cascade elk herds move through their habitat and may be affected by current and future human activity is critical if we hope to maintain healthy elk populations on the landscape. In this study, we evaluated causes of death for elk in the area surrounding Government Camp, summertime overlap of elk core use areas with permitted ski areas, and assessed seasonal migration and highway crossing patterns. Our results can be used to guide future permitting of development within the Mount Hood National Forest and address specific causes of mortality for elk in this area to sustain a robust local elk population.

We found that collared elk used a relatively large area in the vicinity of Government Camp during the summer, which overlapped heavily with existing permitted ski areas. In recent years, concessionaires managing these ski areas have proposed expanding their summertime recreation offerings, which would entail both habitat modification and increased presence of humans in these areas. Given the high overlap between elk summer range and ski areas we documented and known negative effects of outdoor recreation on elk (e.g., Wisdom et al. 2018, Procko et al. 2024), increased development and summertime use of these properties can be expected to affect local elk herds during a critical stage of their life history. We recommend that when development is permitted, it be sited in locations likely to have lower impacts on elk. For example, the work of Rowland et al. (2018) suggests that elk select for higher forage quality areas closer to forest cover and farther from roads allowing motorized traffic. As such, siting mountain biking trails in homogenous late successional habitats and away from known calving locations will likely disturb elk less than placing trails in or immediately adjacent to high quality forage areas. Adjusting diel use periods of recreation through restrictions to avoid periods of high elk activity could also potentially reduce disturbance.

Every elk captured on summer range in this study migrated to the White River Wildlife Area, suggesting that maintaining connectivity to this high-quality winter range habitat is critical to the continued persistence of the elk population near Government Camp. Moreover, elk collared in this study tended to use relatively consistent movement paths when travelling between their seasonal home ranges. Land development within this corridor could have an outsized impact on the behavior of these animals and lead to negative population-level consequences. We found that almost all elk migrated to Salmon River Meadows when travelling from winter range to summer range. Based upon previous studies of elk in the Cascade Mountains (Johnson et al. 2019) and communications with past ODFW biologists, we believe elk in this region likely give birth to calves in late May each year. As such, the area around Salmon River Meadows may be particularly important to this elk population as a site where calving occurs, given their migration to Salmon River Meadows in the weeks preceding and surrounding expected parturition. Future studies could use vaginal implant transmitters (VITs) and GPS collars programed with more frequent fix rates during migration periods to determine parturition locations and further delineate migratory corridors in this area.

Several partial migrations occurred when elk moved from winter range to summer range. We speculate that these partial migrations might have occurred when elk initiated migration but encountered snow or harsh environmental conditions at higher elevations, prompting their return to lower elevations where forage was more abundant. Partial migrations from summer to winter range also occurred occasionally. We documented some elk from this population completing their migration within a single day, while other migrations lasted multiple weeks. This suggests that while the distance can be travelled relatively quickly, the duration of migrations may be extended for other reasons, such as to take advantage of good forage quality or to wait for travel conditions to improve.

Elk in this population commonly initiated migration from summer to winter range in early- to mid-November. This timing is relatively close to the annual beginning of the any legal weapon male elk hunting season in Western Oregon (e.g., November 11 in 2023). As such, it appears that female elk may leave the Santiam WMU (where males can legally be hunted with a general season tag purchased over the counter) for the White River WMU (which is limited to controlled elk hunts only) prior to or soon after the beginning of rifle hunting season. The timing of the any legal weapon male elk hunting season was recently changed, and that change in timing may reduce the threat of human harvest as a source of mortality for male elk in this herd, if they migrate at the same time as females. None of the elk collared in this project were legally harvested, although sample sizes were low and harvest tags for female elk in this area were extremely limited.

Similar to previous research on female elk survival in the Cascade Mountains of Oregon (Stussy et al. 1994), we found that elk mortalities were most common in the fall. Vehicle collisions, cougar predation, and poaching were responsible for the observed mortalities of elk in this study. However, illegal poaching was our least common cause of death, unlike in the work of Stussy et al. (1994). Rather, our limited sample size seems to imply that vehicle collisions could pose a greater danger to this herd. Our data suggested that elk crossed Highways 26 and 35 relatively frequently on summer range (median = 3.7 crossings/elk/30 days). Elk in this population were present on summer range for approximately 6 months (early-May through early-November), suggesting that vehicle collisions during highway crossings could represent a serious risk to elk in the area surrounding Government Camp. Given the relatively low resolution of data (i.e., 1 location every 3 or 5 hours), data cleaning to remove potential erroneous points, and that analysis did not include migratory movements, we likely underestimated the true frequency with which elk crossed major highways. Our analysis of road crossings was also restricted to solely major highways and does not represent the additional risk incurred by elk when crossing other potentially busy roads within their summer range. We found that most crossings occurred along a 9.6 km stretch of Highway 26, which coincided with the mortality locations of the 3 collared elk that were killed in vehicle collisions (Figure 5). This suggests that additional steps to reduce elk-vehicle collisions in this specific geographic area (e.g., elk crossing warning signs, habitat modification, wildlife crossing structures and/or directional fencing), could have an outsized effect on the number of elk killed by vehicles near Government Camp. Although the small number of animals collared in this project (15 female elk) precludes a robust analysis of survival rates, it is somewhat troubling that a third of these elk died while actively GPS-collared. In large herbivores, it is common for adult female animals to have high survival rates (Gaillard et al. 2000). Stussy et al. (1994) previously estimated a mean annual survival rate of 89% for female elk in the Cascade Mountains. If the mortality rate we observed scales to the entire herd, this elk population could decline in future years. We suggest further efforts be undertaken to assess the population dynamics of this herd and determine if a need for further intervention exists.

Overall, observed space use patterns suggest that elk near Government Camp could be susceptible to negative effects from additional permitted development or increases in summertime recreation at ski areas. Our results can be used to help guide permitting of recreational activities that could impact elk summer range or elk behavior in this region. The leading documented cause of death for elk in this population was collisions with vehicles along Highway 26. Additional steps to address this source of mortality could result in fewer elk losses and reduced risk to human safety. This project also helped delineate specific migratory corridors that should be maintained to facilitate continued presence of this elk population.

ACKNOWLEDGMENTS

We are very grateful to all the ODFW employees (some of whom are no longer with the agency) who developed the initial study design, conducted field work, and found funding for this study. This includes, but is not limited to: Andrew Butler, Braden Erickson, Jerod Fox, Doug Kitchen, Kurt Licence, Tonya Moore, Steve Niemela, and Don VandeBurgh. Without their hard work, this study would not have been possible. We also thank the internal ODFW reviewers whose comments helped improve this bulletin substantially. Thanks also to the many volunteers who came into the field to assist with animal captures, and to deploy and remove corral traps, including OHA volunteers and members of the Confederated Tribes of Warm Springs. Funding for this project was provided by the Oregon Hunter's Association Pioneer and Hoodview Chapters, whose generous contributions allowed for more efficient completion of this research. Finally, thank you to the U.S. Forest Service for assisting with access and helping to provide initial guidance on this study.

REFERENCES

Bolger, D. T., W. D. Newmark, T. A. Morrison, and D. F. Doak. 2008. The need for integrative approaches to understand and conserve migratory ungulates. Ecology Letters 11(1):63-77.

Cook, J. G., B. K. Johnson, R. C. Cook, R. A. Riggs, T. Delcurto, L. D. Bryant, and L. L. Irwin. 2004. Effects of summer-autumn nutrition and parturition date on reproduction and survival of elk. Wildlife Monographs 155:1-61.

Cook, J. G., R. C. Cook, R. W. Davis, and L. L. Irwin. 2016. Nutritional ecology of elk during summer and autumn in the Pacific Northwest. Wildlife Monographs 195:1-81.

Gaillard, J. M., M. Festa-Bianchet, N. G. Yoccoz, A. Loison, and C. Toigo. 2000. Temporal variation in fitness components and population dynamics of large herbivores. Annual Review of ecology and Systematics 31(1):367-393.

Getz, W. M., S. Fortmann-Roe, P. C. Cross, A. J. Lyons, S. J. Ryan, and C. C. Wilmers. 2007. LoCoH: nonparameteric kernel methods for constructing home ranges and utilization distributions. PloS one 2(2):e207.

Johnson, B. K., D. H. Jackson, R. C. Cook, D. A. Clark, P. K. Coe, J. G. Cook, S. N. Rearden, S. L. Findholt, and J. H. Noyes. 2019. Roles of maternal condition and predation in survival of juvenile elk in Oregon. Wildlife Monographs 201:3-60.

Keiter, D. A., T. R. Stoddart, and D. H. Jackson. 2022. Use of cellular-linked cameras to monitor live-trapping of wildlife. Wildlife Society Bulletin 46(3):e1311.

Lewis, J. S., J. L. Rachlow, E. O. Garton, and L. A. Vierling. 2007. Effects of habitat on GPS collar performance: using data screening to reduce location error. Journal of Applied Ecology 44:663-671.

Mojica, J., K. Cousins, and T. Madsen. 2021. Economic analysis of outdoor recreation in Oregon. Earth Economics, Tacoma, WA.

Naylor, L. M., M. J. Wisdom, R. G. Anthony. 2009. Behavioral responses of North American elk to recreational activity. The Journal of Wildlife Management 73(3):328-338.

Phillips, G. E., and A. W. Alldredge. 2000. Reproductive success of elk following disturbance by humans during calving season. The Journal of Wildlife Management 64:521-530.

Procko, M. S. G. Winder, S. A. Wood, M. Sevigny, D. G. Collins, M. Alves, and L. R. Prugh. 2024. Quantifying impacts of recreation on elk (Cervus canadensis) using novel modeling approaches. Ecosphere 15:e4873.

Proffitt, K. M., A. B. Courtemanch, S. R. Dewey, B. Lowrey, D. E. McWhirter, K. L. Monteith, J. T. Paterson, J. Rotella, P. J. White, and R. A. Garrott. 2021. Regional variability in pregnancy and survival rates of Rocky Mountain bighorn sheep. Ecosphere 12(3):e03410.

R Core Team. 2022. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rowland, M. M., M. J. Wisdom, R. M. Nielson, J. G. Cook, R. C. Cook, B. K. Johnson, P. K. Coe, J. M. Hafer, B. J. Naylor, D. J. Vales, and R. G. Anthony. 2018. Nutrition and Habitat-Use Models for Elk Management in Western Oregon and Washington. Wildlife Monographs 199(1):1-69.

SE Group. 2022. Timberline Lodge Master Development Plan. https://www.timberlinelodge.com/images/pdf/Timberline_2022_Master_Development_Plan.pdf. Accessed February 10, 2024.

Shively, K. J., A. W. Alldredge, and G. E. Phillips. 2005. Elk reproductive response to removal of calving season disturbance by humans. The Journal of Wildlife Management 69(3):1073-1080.

Stussy, R. J., W. D. Edge, and T. A. O’Neil. 1994. Survival of resident and translocated female elk in the Cascade Mountains of Oregon. Wildlife Society Bulletin 22:242-247.

Thomas, J. W., J. F. Franklin, J. Gordon, and K. N. Johnson. 2006. The Northwest Forest Plan: origins, components, implementation experience, and suggestions for change. Conservation Biology 20(2):277-287.

Wisdom, M. J., H. K. Preisler, L. M. Naylor, R. G. Anthony, B. K. Johnson, and M. M. Rowland. 2018. Elk responses to trail-based recreation on public forests. Forest Ecology and Management 411:223-233.

OREGON
Fish & Wildlife

4034 Fairview Industrial Drive SE
Salem, OR 97302