Blue Mountains elk herd

Juvenile recruitment and mortality monitoring

Washington Department of Fish & Wildlife

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Introduction

Washington's Blue Mountains elk herd is an important natural resource that provides ecological, consumptive, aesthetic, and economic value. The Washington Department of Fish and Wildlife (WDFW, the Department) has been focused on this population since the 1980s due to concerns about productivity, poaching, predation, and nutrition in the herd (Zahn, 1992; WDFW, 2001; Myers et al, 1999; McCorquodale et al. 2011; WDFW, 2020). While the population grew steadily from 2000 – 2016, it declined to an estimated 4,396 elk in 2017 – 20% below WDFW population objectives - following a severe winter after two years of drought. The herd has been unable to rebuild to desired population levels, and was estimated at 25% or more below its population management objective of 5,500 elk in 2019, 2021, 2022, and 2024. In 2020, the population trended modestly up to 4,614, although this increase can be attributed to sampling variance (as discussed in "Methods"). Overall, the Blue Mountains elk herd population remains below the management objective and does not show evidence of rebounding (Figure 1). The Department has implemented actions to promote elk population growth, like reducing recreational and damage antlerless elk harvest and modifying cougar and black bear harvest regulations, while continuing long-standing habitat enhancement projects and protecting critical ranges on public lands.

Population declines motivated the Department to conduct an "at-risk" assessment of the Blue Mountains elk herd (WDFW 2021; see also WDFW 2015-2021 Game Management Plan). The assessment designates the Blue Mountains population to be "at-risk" and identified insufficient recruitment - juvenile survival to one year of age - as a primary factor limiting population stability or growth. This is especially true in the northern portion of the herd's core range (the northern core), made up of Game Management Units (GMUs) 162, 166 and 175. The assessment noted marginally sufficient recruitment for stability across the southern portion of the herd's core range (Figure 2).

In 2021, WDFW initiated juvenile elk survival and cause specific mortality monitoring in the northern core herd area (WDFW, 2021) to better understand what factors were limiting elk recruitment.

Background

Elk population growth is most strongly influenced by adult female survival, followed by juvenile survival; then finally, pregnancy rates (Gaillard et al. 2000, Proffitt et al. 2015). Because adult female survival is typically high and stable in most elk populations, juvenile survival, which is typically variable, has the potential to strongly influence population growth (Gaillard et al. 2000; Raithel et al. 2007). Juvenile mortality rates may fluctuate annually due to a combination of factors.

Predation is the primary cause of juvenile elk mortality across the species' range (Griffin et al. 2011), with cougars or black bears being the dominant predator depending on the system (Eacker et al. 2016; White et al. 2010; Barber-Meyer et al. 2008).

Climate and habitat can also drive long-term population dynamics (Brodie et al. 2013). Severe winters can directly impact elk of all ages, and summer precipitation and temperature can influence nutritional condition, which in turn influences pregnancy, juvenile survival, and ultimately, population performance (Parker et al. 2009; Griffin et al. 2011; Cook et al. 2004; Cook et al. 2013). For a population to grow, female juvenile recruitment must exceed adult female mortality (Raithel et al. 2007). When evaluating a population's potential for growth, wildlife managers commonly reference juvenile recruitment as an indicator of juvenile production and survival. Managers do so by calculating the ratio of juvenile elk to adult female elk seen during a late winter survey. This is called the recruitment ratio and is usually standardized as the number of juveniles to 100 adult female elk.

Assuming moderate adult female survival estimates (e.g., 87-88% annual survival) a recruitment ratio of approximately 25:100 juvenile elk to adult females is needed to achieve population stability, assuming 50% of the recruited juveniles are female. While juvenile to adult female ratios is highly correlated with juvenile elk survival, the ratio is also affected by harvest, pregnancy rate, and adult female survival (Caughley, 1974; Gaillard et al. 2000; Raithel et al. 2007; Harris et al. 2008; DeCesare et al. 2012, Lukacs et al. 2018). Many potential combinations of adult and juvenile survival (i.e., vital rates) can produce equivalent ratios, so managers cannot determine a population trend by only considering the recruitment ratios (Caughley, 1974). Assessing age-based survival estimates in conjunction with recruitment ratios provides wildlife managers more insight into population trend (Gaillard et al. 2000, Proffitt et al. 2014).

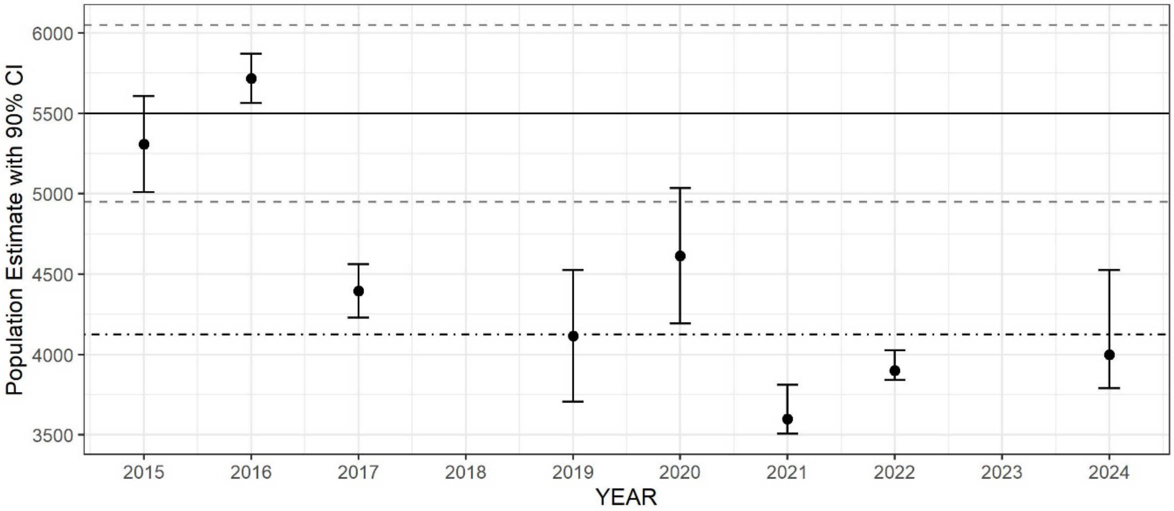

Figure 1: Blue Mountains elk herd population estimates with 90% confidence intervals from spring aerial surveys from 2015-2024. The solid line equals herd population objective, dashed lines equal +/- 10% of objective, and the dot-dashed line equals 25% below objective, or "at-risk.". Complete population aerial surveys were not conducted in 2018 or 2023.

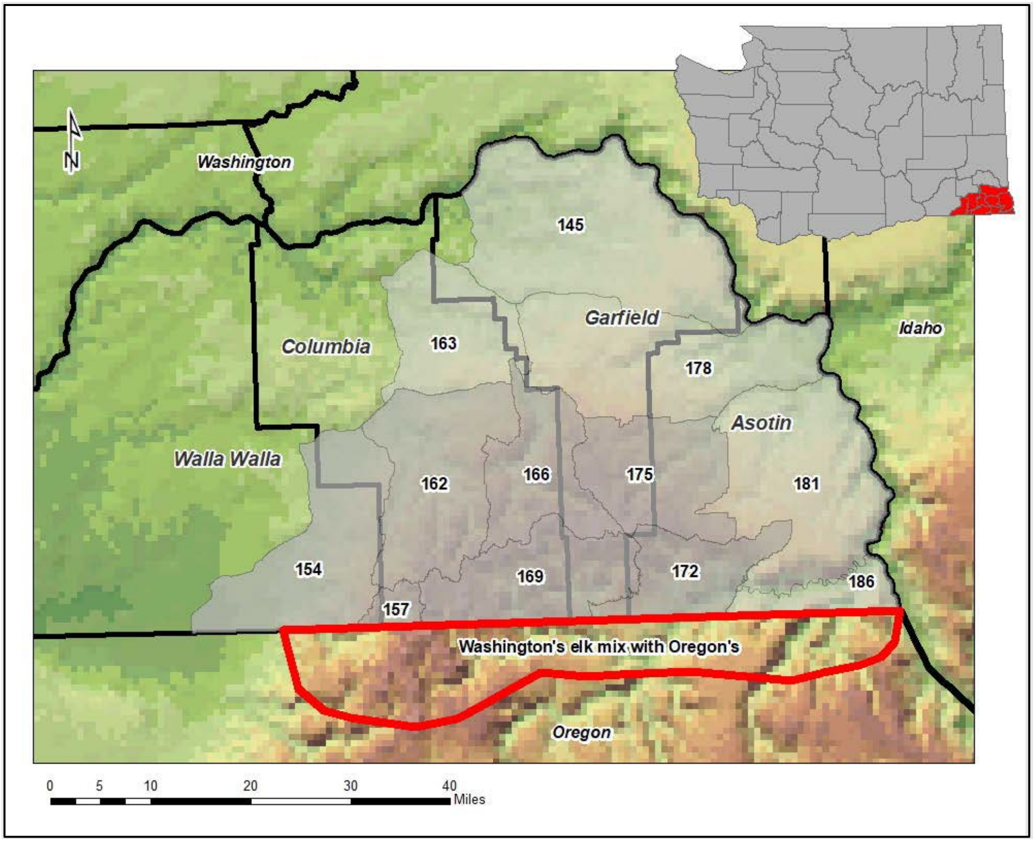

Figure 2: Blue Mountains Elk Herd with all Game Management Units (GMUs) identified and core GMUs highlighted in dark gray. Boundary of continuous habitat between Washington and Oregon illustrated within red polygon.

Problem statement

The Blue Mountains elk herd population meets the Department's "at-risk" designation, consistent with the predator-prey guidelines outlined in the Game Management Plan (GMP) (WDFW 2015). The at-risk assessment identifies juvenile survival as the most likely factor inhibiting the Blue Mountains elk population from achieving population objectives. In 2021, the Department initiated an investigation to quantify juvenile elk survival and primary sources of mortality. This report summarizes the findings of this investigation and provides the basis for evaluating what mortality factors are limiting juvenile elk survival, specifically whether predation and carnivore management should be considered to promote elk population growth.

Monitoring objectives

The objectives of this project are to:

- Annually evaluate population performance by conducting detection corrected (see "Population Monitoring" for more information) "all herd" abundance surveys or northern core recruitment ratio surveys.
- Estimate juvenile elk survival and cause-specific mortality rates from birth to one year old to evaluate the influence of different mortality sources on elk juvenile survival.

Monitoring methods

Population monitoring

The Department uses aerial techniques to estimate abundance during spring "green-up" (e.g., early to mid-March) using a stratified random sampling design. These abundance estimates are modeled using a "sightability" framework that applies group-specific correction factors to what is counted from the air to account for groups which were likely missed during the survey (McCorquodale et al. 2013). Correction covariates include group size, percent snow cover, and percent canopy cover (e.g., smaller groups in thick canopy cover are difficult to detect compared with large groups in the open). Sample units are classified by the expected density of elk that managers expect to find in an area, with a "high" density defined as ≥ 86 elk, "medium" density at 36-85 elk, and "low" density at < 36 elk. WDFW prioritizes sampling high-density units over medium- or low-density units (e.g., annually, WDFW aims to survey 100% of the high-density units, 80% of the medium-density units, and 50% of the low-density units). In-flight covariate data are recorded to inform the abundance corrections, and total abundance (including of un-flown units) is estimated from data collected during aerial surveys.

Managers attempt to minimize sources of sampling error, but it is not uncommon for sampling uncertainty to contribute largely to variations in annual estimates derived from sightability models. This is illustrated by the associated 90% confidence intervals. The survey area shares continuous habitat with Oregon on the herd's southern border and elk move freely across this jurisdictional boundary. Although surveys are restricted by winter conditions, the population is not geographically and demographically closed between years and movement of elk between states might influence survey results and estimated herd size. Due to these challenges, population trends over time are more informative than a single population estimate.

Calf survival monitoring

We captured elk calves in the northern core of the Blue Mountains population during parturition (i.e., late May, early June; Myers et al. 1999, Johnson et al. 2019). We attempted to match sampling distribution in each GMU to recent (2019 to 2023) population proportions generated by annual survey estimates within these areas; where GMUs 175 (avg. est. = 512), 166 (avg. est. = 344), and 162 (avg. est. = 359) would receive 50%, 25%, and 25% of the collars available, respectively.

We employed two capture methods 1) locating and capturing calves by hand, observing behavior of solitary adult females from the ground; and 2) locating adult females with calves from a helicopter and netting the calves. In 2021, ground captures began on May 18 before transitioning to aerial captures on June 2. Staff postponed operations until June 11 due to the difficulty of locating calves from the air. In 2022 and 2023, ground captures began on May 17 and 18, and aerial captures began on June 7 and 10. Calves up to three days old were captured by hand while older calves were captured via aerial methods. Every year, captures were concluded on June 15.

All captured elk calves were blindfolded, fitted with a MINI GPS neck collar (Vectronic Aerospace, Germany), weighed, ear tagged, and were assessed and photographed to verify age. Age classes were assigned by the capture crews (WDFW and Leading Edge Aviation) based on activity, size, tooth eruption, and hoof and navel appearance (Johnson 1951) and verified by photo evaluation of hooves (Rayl pers. comm, Ganz, pers. comm.) before being categorized in one of four age categories (zero to three days old, four to six days old, seven to 10 days old, and older than 11 days old). We estimated birth dates by subtracting estimated age at capture from the capture dates.

We received mortality notifications when a GPS collar remained motionless for four hours, and we attempted field investigations to identify cause of death within 24 hours of notification. We categorized the following mortality sources: predation (by cougar, black bear, coyote, wolf, bobcat, or an unknown carnivore), unknown, non-predation, and human caused. We classified mortalities as predation when we found clear evidence of antemortem hemorrhaging at bite or claw wounds, and classified the carnivore as described by Stonehouse et al. (2016). We collected DNA samples from calves that had been predated by swabbing for presumed saliva in wounds, bite marks on the GPS collar, ear tag, or remaining bone; and any other location of interest (Murphy et al. 2000; Dalén et al. 2004; Davidson et al. 2014). In 2022, DNA sampling was done only when we could not identify the carnivore species in the field. In 2023 and 2024, we took DNA samples after all predation events and during any other investigation where DNA collection could provide additional information. We used conclusive single carnivore DNA analysis results to verify the carnivore species when field investigators concluded predation was the mortality cause, but the carnivore was unknown. We used DNA from lethal wounds only (i.e., sites with antemortem hemorrhaging). We did not use samples from sites without hemorrhaging to assign a carnivore species as the cause of a mortality because scavengers could also leave behind DNA at the carcass. When possible and necessary, we transported intact juvenile elk carcasses to the Washington Animal Disease Diagnostic Laboratory (WADDL) at Washington State University for a necropsy to be performed to determine cause of death.

We estimated survival rates at 30-day intervals until our annual aerial surveys (i.e., early March). At this point, juvenile elk are considered recruited into the population because they have survived high-risk times during the first year of life. This results in a 300-day time interval between May 18 – March 27 the following year. To align survival and survey recruitment estimates, study years were defined as the last year of these time intervals (i.e., 2022 represents May 18, 2021 - March 27, 2022; 2023 represents May

18, 2022 – March 27, 2023; and 2024 represents May 18, 2023 – March 27, 2024). Survival was estimated using the Kaplan-Meier (KM) estimator with the R-4.0.3 package *survival* (R Core Team, 2019; Therneau, 2021). We estimated survival based on sex, capture GMU, capture method, and capture age class.

Monitoring results

Population monitoring results

Following the “at-risk” designation of the Blue Mountains elk herd, WDFW conducted complete surveys in March 2022 and March 2024, and a partial survey in March 2023. In 2024, WDFW surveyed 17 of 18 high-density units, five of nine medium-density units, and six of 16 low-density units. The survey generated an estimate of 3,999 elk (90% CI: 3,790 – 4,526) and demonstrates a stable population trend compared to the 3,901 (90% CI: 3,843 – 4027) estimate observed in 2022 (Figure 1). Recruitment for the Blue Mountains herds increased slightly in 2024, with an estimate of 22.3 juveniles per 100 adult females (90% CI: 21.8 – 22.8) compared to the 2022 estimate of 17.2 juveniles per 100 adult females (90% CI: 16.9 – 17.5) (Table 1). In 2023, only a partial population survey was conducted due to a late-notice cancelation by the originally scheduled helicopter vendor; an “all herd” estimate was not calculated in 2023. In 2023, estimated recruitment ratios were seven, 14, and 19 juvenile elk per 100 adult females in GMU’s 162, 166, and 175, respectively (Table 1).

Table 1. Blue Mountains average recruitment ratio estimate comparison between the northern core GMUs and overall herd from 2017 to 2024.

GMU	Avg. recruitment ratio (ARR): 2000-2016	ARR: 2017	ARR: 2019	ARR: 2020	ARR: 2021	ARR: 2022	ARR: 2023	ARR: 2024
162	30	15	21	12	18	13	7	19
166	31.4	14	17	19	16	19	14	19
175	26.1	22	16	27	24	13	19	19
All herd[a]	27.7	17.8	23.8	22	24.6	17.2	15.1	22.3

[a] Value for 2023 represents a partial survey for the northern core units of the herd area. See text under “population monitoring results”.

Calf monitoring results

We captured 342 neonate calf elk (i.e., newly born elk) during spring 2021, 2022, and 2023. Our investigation is focused on annual survival, so a study year in text and tables is represented by the year following capture (e.g., data from animals captured in 2021 is termed “study year 2022”). We captured 150 females, 180 males, and 12 calves of undetermined sex across GMUs 162, 166, 175, and 181 (Table

2 and Table 3). Captures where sex was unidentified are associated with aerial captures, which can occasionally require reduced handling time (i.e., conditions may require releasing an animal before all data are collected). Younger age classes were predominantly captured by hand, whereas older age classes by aerial capture (Table 4 and Table 5). Average weight at capture for age categories of zero through three days, four through six days, seven through 10 days, and over 11 days were 18.8 (*SD* = 3.5), 25.5 (*SD* = 5.4), 31.6 (*SD* = 5.8), and 39.6 (*SD* = 4.5) kilograms, respectively (Table 6). When combining birth dates across years, the mean birth date occurred on May 30 (*SD* = 6.2 days) and varied minimally among study years. In 2021, the mean birth date was May 31 (*SD* = 6.3 days); in 2022, the mean birth date was and May 29 (*SD* = 6.4 days); and in 2023, the mean birth date was May 28 (*SD* = 5.4 days).

We identified GMU-level survival differences that were potentially a function of age at capture, because juveniles in GMU 166 were captured later than GMUs 162 and 175. Therefore, calves captured in GMU 166 were typically older and presumably less vulnerable to predation, which could bias the estimated survival rate (Gilbert et al. 2014). In 2023 and 2024, we reduced this potential bias by balancing our samples within the zero through year days old age class in GMU 166, and the average age at capture declined from 8.9 to 5.8 and 5.5 days, respectively. Moreover, capture of neonates three days old or younger increased during subsequent years from 8% to 43.8% and 36.5%, respectively.

Table 2. Sample distribution by GMU.

Study year	GMU 162	GMU 166	GMU 175	GMU 181
2022	33	26	65	1[a]
2023	32	16	54	0
2024	30	18	67	0
All years	95	60	186	1

[a] Captured on the border between GMU 175 and 181; included in GMU 175 for all subsequent analyses.

Table 3. Sample distribution by sex.

Study year	Female	Male	Unknown
2022	65	57	3
2023	44	50	8
2024	41	73	1
All years	150	180	12

Table 4. Number of elk sampled by ground capture.

Study year	0 – 3 days old	4 – 6 days old	7 – 10 days old	> 11 days old	Total
2022	22	0	0	0	22

2023	34	11	0	0	45
2024	41	9	1	0	51
All years	97	20	1	0	118

Table 5. Number of elk sampled by aerial capture.

Study year	0 – 3 days old	4 – 6 days old	7 – 10 days old	> 11 days old	Total
2022	16	30	35	22	103
2023	2	20	16	19	57
2024	1	25	35	3	64
All years	19	75	86	44	224

Table 6. Sample distribution by age class (days) and average weights (kg).

Study Year	0-3 Days	Average/ SD[a]	4-6 Days	Average/ SD[a]	7-10 Days	Average/ SD[a]	≥11 Days	Average/ SD[a]
2022	38	19.7/3.5	30	27.3/3.6	35	33.0/3.0	21	38.0/2.9
2023	36	18.4/2.6	31	25.1/3.7	16	33.1/3.1	19	42.0/5.2
2024	42	18.3/4.0	34	24.5/7.3	36	29.7/8.0	3	37.8/4.1
All years	116	18.8/3.5	95	25.5/5.4	87	31.6/5.8	44	39.6/4.5

[a] Values on the left of the forward slash are the average and values on the right are the standard deviation.

We right censored (i.e., removed at the time of occurrence) from our analysis calves that “shed” their GPS collars prematurely (n = 13, 2022; n = 35, 2023; n = 62, 2024), and whether or not these calves survived is unknown. Shed collars include those that ceased GPS or VHF communication, were found caught on barbed-wire, or were unrecoverable due to wildfire. We observed an increase in shed collars during 2023 (33.3%) and 2024 (52.2%) compared to 2022 (6.4%). Potential explanations include vendor modifications of the GPS collars used in 2023 and 2024, designed to ensure the collar expands as the calf grows, as intended; or because few juveniles survived past three months of age in 2022, when rates of shed collars may increase (K. Huggler, University of Idaho, pers comm; N. Rayl, Colorado Parks and Wildlife, pers comm). We removed four (2022), two (2023), and one (2024) juvenile elk from analysis because cause of death was associated with capture or collar issues and not natural sources of mortality.

We documented predation as the leading cause of mortality (n = 152) among 192 total mortality events (Table 7 and Table 8). Among all mortality notifications (actual mortalities and collar loss, and excluding delayed notifications caused by software), we conducted 235 of 290 site investigations within one day of notification. We conducted 81 of 111, 69 of 84, and 85 of 95 site investigations within one day of notification, with an average response time of 1.4, 0.94, and 1.25 days during 2022, 2023, and 2024, respectively.

Table 7. Count of mortalities classified as predation, by carnivore species, and other non-predation sources.

Study year	Cougar	Bear	Cougar/ Bear	Coyote	Wolf	Wolf/ Bear	Bobcat	Other	Total[a]
2022	57	9	5	3	1	1	1	22	99
2023	34	1	1	0	1	0	0	11	48
2024	33	1	3	1	0	0	0	7	45
All years	124	11	9	4	2	1	1	40	192

[a] Total includes all mortalities (i.e., predation and non-predation caused)

Table 8. Count of all mortality classified as other.

Study year	Exertional myopathy	Infection	Starvation	Unknown Consumed	Unknown Fire	Unknown Intact	Unknown Traum	Unknown	Harvest
2022	1	5	1	7	3	5	0	0	0
2023	0	0	0	5	0	2	3	1	0
2024	0	3	0	1	0	0	2	0	1
All years	1	8	1	13	3	7	5	1	1

We submitted DNA samples from 101 predation, five unknown consumed, and one unknown mortality investigations to the University of Washington (UW) for analysis. We also submitted DNA samples to UW from four shed collars and one killed, but apparently abandoned, neonate elk (WDFW staff observation).

DNA analysis confirmed the field determination of predator-specific cause of mortality in 69 cases. In 20 cases of predation mortalities without an identified carnivore species, laboratory analysis identified cougar (11 mortalities), bear (three mortalities), coyote (one mortality), cougar/bear mix (four mortalities), and wolf/bear mix (one mortality) as the causative carnivore.

Results from DNA analysis was used to correct the in-field assigned causative carnivore in six instances; one from coyote to bobcat, one from wolf to cougar, two from cougar to cougar/bear, and two from bear to cougar/bear. In two cases, DNA results were negative; in these cases, we retained the investigation determination of “cougar-caused.” In four cases, DNA evidence was superseded either by the field investigation determining mortality was due to capture-related issues (i.e., collar issues identified under censoring); or WADDL necropsy results. Based on DNA results and corresponding site investigations, we changed the cause of mortality from “unknown, but consumed” to “cougar-caused” for one case, but four other cases remain unknown. In one case, the field investigation identified a significant drag trail and a shed collar, which suggested unknown mortality, but evidence was insufficient to assign cause of death; therefore, we maintained the unknown designation. In another case, we retained the “shed collar” designation despite identifying domestic dog/wolf and bear, due to inconclusive evidence on-site. All other cases (n = 10) were negative for DNA. DNA collected from an abandoned elk calf identified cougar as the cause of death, but we did not include this elk in our analysis because it was abandoned by its dam.

In 2022 we investigated 16 mortalities where the carcass was intact, and 13 were transported to WADDL for cause of death determination. WADDL pathologists diagnosed three incidences of exertional myopathy: one attributed to acute severe skeletal necrosis 20 days post capture and identified as non-capture related; one that exhibited severe myocardial and renal necrosis 12 days post-capture, with the chronic nature indicating possible relation to the capture event; and one case of myopathy four days post-capture that exhibited signs of starvation, attributed to capture-related abandonment. The lab identified five cases as infection, with one involving a protozoan; one viral pneumonia, one umbilical infection, and two with clinical signs of hemorrhagic disease, but no clinical confirmation. One case was identified as starvation, and four cases had various clinical findings that could not be attributed to any specific cause of death. One additional sample of the respiratory tract, heart, and rumen was submitted where predation was the field investigation determination; the lab found no significant findings to alter that determination. This was the only predation mortality for which we submitted samples to WADDL to rule out myopathy or disease as an underlying pathology. Cause of death for two intact carcasses were determined as unknown after field investigation only, and one intact carcass was determined as starvation based on the field investigation.

Nine mortalities investigated during 2023 and 2024 were transported to WADDL, as well as one non-sampled neonate elk found dead while conducting ground captures. WADDL pathologists identified three cases as septicemia, with two diagnoses being secondary to an umbilical infection (one case being from the non-sample neonate). WADDL pathologists identified three cases as trauma with unclear cause, and two cases as a bacterial infection causing pneumonia, with one of these cases also illustrating pericarditis. In one case, investigators found mild epicardial and myocardial hemorrhaging as well as a bladder infection, but neither were severe enough to cause death. In one case no clear evidence of death was found, and the diagnosis remains open.

We estimated annual juvenile elk survival of 13.6% (95% CI: 8.3% - 22.1%), 47.5% (95% CI: 38.0% - 59.4%), and 52.5% (95% CI: 42.6-64.8) at 300 days for 2022, 2023, and 2024, respectively. Survival estimates significantly varied by year and we identified differences when comparing survival estimates of capture GMU, age class, and nominal differences in capture method during 2022 and 2023, but not in 2024 (Figure 3; Tables 9-11). We documented differences in survival among capture GMU during all study years. During 2022, differences were attributed to capturing in GMU 166 later than 162 and 175. We observed increased survival in GMU 175 when compared to GMUs 162 and 166 during 2023, while survival estimates for both GMU 166 and GMU 175 were significantly higher than 162 in 2024 (Table 10).

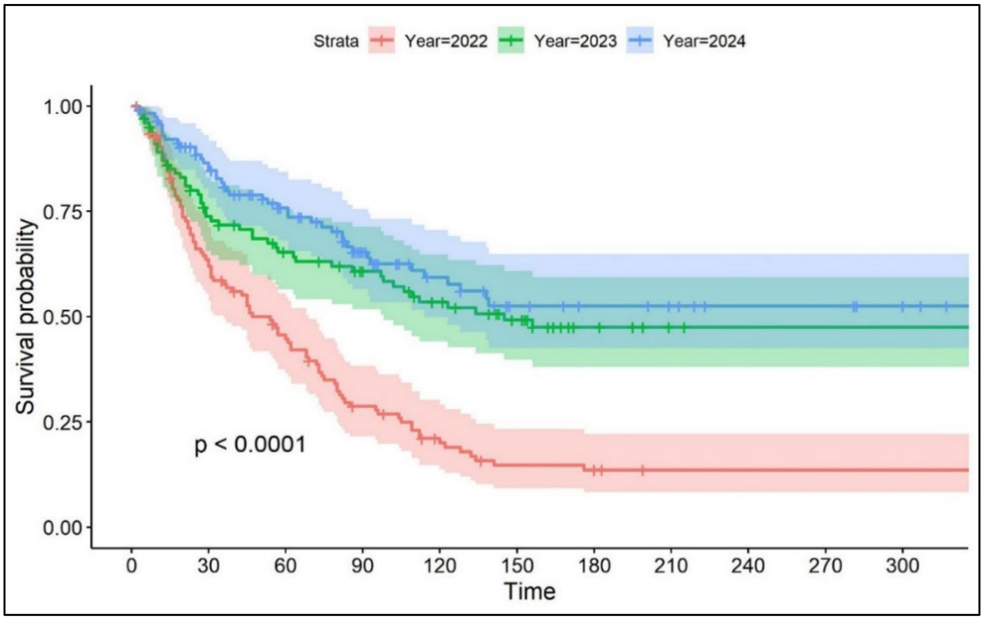

Figure 3: Kaplan-Meier estimates of survival probabilities and associated 95% confidence intervals for juvenile elk in the northern core GMUs of the Blue Mountains of Washington.

Table 9. Kaplan-Meier estimates of 30-day survival probabilities and associated 95% confidence intervals for juvenile elk in the northern core GMUs of the Blue Mountains of Washington.

		2022			2023			2024		
≈Calendar Date	**Days Since Birth**	**Survival**	**Lower CI**	**Upper CI**	**Survival**	**Lower CI**	**Upper CI**	**Survival**	**Lower CI**	**Upper CI**
June 30	30	0.62	0.54	0.71	0.74	0.66	0.83	0.85	0.78	0.92
July 30	60	0.44	0.36	0.54	0.65	0.57	0.76	0.76	0.68	0.84
Aug. 29	90	0.29	0.22	0.38	0.61	0.52	0.71	0.65	0.57	0.76
Sept. 28	120	0.20	0.14	0.29	0.53	0.44	0.65	0.59	0.50	0.71
Oct. 28	150	0.15	0.09	0.23	0.49	0.40	0.61	0.53	0.43	0.65
Nov. 27	180	0.147	0.08	0.22	0.475	0.38	0.59	0.53	0.43	0.65
Dec. 27	210	0.136	0.08	0.22	0.475	0.38	0.59	0.53	0.43	0.65
Jan. 26	240	0.136	0.08	0.22	0.475	0.38	0.59	0.53	0.43	0.65
Feb. 25	270	0.136	0.08	0.22	0.475	0.38	0.59	0.53	0.43	0.65
March 27	300	0.136	0.08	0.22	0.475	0.38	0.59	0.53	0.43	0.65

Table 10. Kaplan-Meier estimates of annual survival probabilities, sample size, and associated 95% confidence intervals by GMU for juvenile elk.

	GMU 162			GMU 166			GMU 175		
Study Year	Survival	Samples	95% CI	Survival	Samples	95% CI	Survival	Samples	95% CI
2022	10.3	33	3.5-30.1	26.3	26	13.1-52.9	10.4	66	4.8-23.3
2023	22.1	32	9.1-53.0	10.4	16	1.8-60.4	68.7	54	57.0-82.7
2024	20.5	30	7.1-59.4	64.2	18	44.8-92.1	64.0	67	51.8-79.1

Table 11. Kaplan-Meier estimates of annual survival probabilities, sample size, and associated 95% confidence intervals by age category at capture for juvenile elk.

	0-3 Days			4– 6 Days			7-10 Days			> 11 Days		
Study Year	Survival	Samples	95% CI	Survival	Samples	95% CI	Survival	Samples	95% CI	Survival	Samples	95% CI
2022	9.0	38	3 – 26.5	5.8	30	1 - 33	17.0	35	8 - 37	22.0	18	9 - 56
2023	31.8	36	19 - 54	67.4	31	52 - 88	47.1	16	28 - 81	45.7	22	25 - 83
2024	52.2	42	37.2-73.1	53	34	36.5-77	60.5	36	44.4-82.3	50	3	13-100

Discussion

This investigation documented an overall juvenile survival estimate of 36.8% averaged across all years (2022-2024). Based on this estimate, we expect population stability or minimal growth in the Blue Mountains elk herd, assuming adult female survival of ≥0.87 and pregnancy rates of ≥90% (Cook et al. 2013), and is generally supported by our aerial survey data during this period (Figure 1). We also documented varying juvenile elk survival among years, which is typical of ungulates (Gaillard et al. 2000, Griffin et al. 2011).

In 2022, annual juvenile survival was just 13.6% and few calves survived to the spring to be counted in that year's aerial survey. As a result, the aerial survey recruitment ratio was low (13-19 juveniles:100 adult females) and below a level that typically supports population stability (25:100). Together, these estimates suggest that juvenile survival limited recruitment and population growth in the study area in that year.

In 2023 and 2024, estimated juvenile survival was relatively high (47.5% and 52.5%, respectively) which should result in correspondingly higher estimates of juveniles to adults from aerial survey data.

However, in both 2023 and 2024 our aerial survey recruitment ratios remained similar to 2022 (7-19 and 19 juveniles:100 adult females, respectively).

Based on a crosswalk calculation of juvenile survival to expected recruitment ratio (see Proffitt et al. 2015), juvenile survival in 2023 and 2024 should correspond to a recruitment ratio of more than 35:100 juveniles to adult females. The observed incongruency among our survival and recruitment ratio estimates is similar to Myers et al. (1999), where survival estimates averaged 47% between 1993 and 1997, but recruitment ratios only averaged 19.6. Estimated survival and recruitment ratios also vary by GMU, but our sample size limits further analyses at this scale.

Potential causes for the discrepancy between our estimated survival rate and recruitment ratio in 2023 and 2024 include survey or sampling variance, censoring, or undocumented parameters associated with recruitment ratios. We attempted to minimize survey sampling variance and ensure year-to-year comparability of recruitment ratio estimates by using consistent survey methodology and staff, and an experienced helicopter pilot. Our methods also minimize sampling variation associated with opportunistic neonate captures by concentrating capture effort on the zero to three days old age class to reduce the potential to overestimate survival rates (i.e., it is possible to bias survival estimates by underrepresenting the youngest age classes, which are more vulnerable to mortality; Chitwood et al. 2017; Gilbert et al. 2014). Right-censoring also could bias survival estimates if these events are not independent of mortality, or if sample size became insufficient to quantify winter mortality.

We attempted to account for this by collecting DNA samples on all shed collars where mortality was suspected to ensure correct classification for analysis. Additionally, we increased the number of marked individuals in all years by 25% above the initial sample size goal of approximately 100 collars to account for collar shedding (i.e., right-censoring) and to maintain adequate sample size for analysis of over-winter survival. When study years are combined, 56 collared individuals (2022 = 12, 2023 = 22, 2024 = 22) survived until winter (Nov. 27 [day 180] to March 27 [day 300]). Despite this sample size across the study area, no additional mortalities were documented during this period. However, censoring yielded low sample sizes at the individual GMU level, with GMU 175 retaining many of the remaining collars, while GMUs 162 and 166 had very few by the end of the monitoring window. This unbalanced spatial distribution may have reduced our ability to detect late winter mortalities in some portions of the study area.

Lastly, while recruitment ratios are predictive of juvenile survival (Harris et al. 2008), they are a function of fecundity (usually referenced as pregnancy rate) and juvenile and adult female survival. If calf survival is relatively high, as in 2023 and 2024, then a lower-than-expected recruitment ratio in the same area could be the product of reduced fecundity (i.e., there are fewer juveniles born). This is often caused by poor nutrition in summer and autumn, especially in drier ecosystems; or, less likely, due to an increase in adult female survival (Cook et al. 2013; Johnson et al. 2013; WDFW 2021).

Ungulate adult female survival is typically high and stable, and a population’s trajectory is often the result of variation in juvenile survival and corresponding recruitment. Therefore, the sources and associated rates of mortality that determine juvenile survival are important for understanding population dynamics. The primary source of juvenile mortality in our study was predation, specifically by cougars, similar to Myers et al. (1999) in the same general study area, but lower than Johnson et al. (2019) in the Blue Mountains of Oregon (Table 12). Myers et al. (1999) identified predation as compensatory, meaning that predation mortality was “compensated” by a reduction in another source of mortality (i.e., overall survival remains similar). For example, compensatory mortality is expected when there are nutritional constraints, because animals that die by predation were likely to die later due to malnutrition. Alternatively, Johnson et al. (2019) identified predation as partially additive, where an increase in predation mortality is not fully compensated by reductions in other sources and therefore reduces, or limits, survival.

Table 12. Proportion of total mortalities of juvenile elk attributed to predation and cougar for three research efforts: 1) Department’s Blue Mountains (BM) northern core; 2) Myers et al. 1999; 3) Johnson et al. 2019.

Study	Years of Study	Sample Size	Survival Rate	Proportion Predation*	Proportion Cougar*
BM, 2022	2021-2022	125	13.6	77.8	57.6
BM, 2023	2022-2023	102	47.5	77.1	70.8
BM, 2024	2023-2024	115	52.5	84.4	73.3
BM, Overall	2021-2024	342	36.8	79.8	66.8
Myers et al., 1999	1992-1997	242	47.0	77.6	48.6
Johnson et al., 2019 (NE)	2001-2007	360	18 – **	92	73

*Among all predation and non-predation sources.

**Johnson et al (2019) estimated survival using a different analysis with only minimum and maximum annual estimates being reported. The author identified the NE study area as the lower estimate within the range, although it is difficult to determine if this was an annual or overall survival estimate.

In 2022, the first year of our study, severe environmental conditions (e.g., drought, wildfire) likely pre-disposed juvenile elk to higher predation mortality risk, resulting in more than twice the number of predation and non-predation mortalities observed in subsequent years. Juvenile survival in 2023 and 2024 likely reflects more normal conditions and corresponding survival and mortality rates (Myers et al. 1999; see also Raithel et al. 2007). Following our first year of calf survival monitoring, and documenting low survival attributed primarily to cougar predation, the Department adopted modified cougar harvest regulations for cougar population management units (PMUs) in the Blue Mountains. These modified regulations permitted a harvest limit of two cougars per season within population management units 9, 10, and 11 but retained existing harvest quotas for the 2022 and 2023 hunting seasons. Despite these changes, cougar harvest remained similar to the 10-year average and only one hunter met the two-cougar harvest limit in the 2022 and 2023 hunting seasons (Table S 1). As such, we do not suspect that the modified cougar harvest regulations led to a decrease in cougar density and does not appear to explain the increased calf survival we documented in 2023 or 2024.

As discussed in the Blue Mountains “at-risk” assessment (WDFW, 2021) and now illustrated in our juvenile elk cause-specific mortality monitoring, several independent and interconnected factors influence the dynamics of an elk population. The available information – consistently low recruitment ratios and one of three years of poor survival – indicates that the capacity for this population to grow to its objective level is hindered and highly variable. Given the exceptionally low calf survival in 2022, it is reasonable to conclude that predation (primarily caused by cougars), acted with stochastic environmental factors to limit this population’s growth in that year. Subsequent years of our study likely reflect more typical conditions. The corresponding survival and mortality rates in the years after 2022 (i.e., 2023 and 2024) do not suggest that juvenile survival, and its associated mortality sources, were primarily limiting population growth in those years.

Our study was limited to investigating juvenile survival and cause-specific mortality, but juvenile survival is just one of several vital rates influencing population trajectory (e.g., adult female survival and pregnancy rates). For example, bottom-up constraints (i.e., nutrition) can increase age at first reproduction and reduce adult female pregnancy rates (Gaillard et al. 2000), which could explain the incongruence between our recruitment ratios and survival estimates. To improve our understanding of this population and to inform future management, measures of climate, bottom-up, and top-down forces and their interactive effect on population performance would need to be pursued simultaneously. Depending on available resources, this may include investigations of:

1. Survival of both adult female elk and their calves (i.e., collaring cow-calf pairs).
2. Adult female pregnancy rates, nutritional condition (e.g., body fat), and habitat use.
3. Survival and mortality risk as functions of covariates like adult female body condition and adult female habitat use before and after calving.
4. Climatic influences (e.g., winter severity, spring and/or summer precipitation, and/or drought severity) on forage quality and quantity, and on individual elk nutritional condition, reproductive performance, and population dynamics.
5. Cougar densities at the cougar PMU, GMU, or elk herd level to determine the degree to which predation may be influencing elk population dynamics.
6. Developing elk population models (e.g., with the data sets listed above) to model changes in vital rates (e.g., elk mortality) at scales relevant to management decisions (Clark 2014, Eacker et al. 2017, Lehman et al. 2018, Proffitt et al. 2015).

Literature cited

Barber-Meyer, S.M., D.L. Mech, P.J. White. 2008. Elk calf survival and mortality following wolf restoration to Yellowstone National Park. Wildlife Monographs. 169:1-30.

Beausoleil, R. A., L. S. Welfelt, I. N. Keren, B. N. Kertson, B. T. Maletzke and G. M. Koehler. 2021. Long-Term Evaluation of Cougar Density and Application of Risk Analysis for Harvest Management. Journal of Wildlife Management 85:462-473.

Brodie, J., H. Johnson, M. Mitchell, P. Zager, K. Proffitt, M. Hebblewhite, M. Kauffman, B. Johnson, J. Bissonette, C. Bishop, J. Gude, J. Herbert, K. Hersey, M. Hurley, P. M. Lukacs, S. McCorquodale, E. McIntire, J. Nowak, H. Sawyer, D. Smith, P. J. White. 2013. Relative influence of human harvest, carnivores, and weather on adult female elk survival across western North America. Journal of Applied Ecology. 50:295-305.

Caughley, G. 1974. Interpretation of age ratios. Journal of Wildlife Management 38:557-562.

Chitwood, M.C., M.A. Lashley, C.S. DePerno, and C.E. Moorman. 2017. Considerations on neonatal ungulate capture method: potential for bias in survival estimation and cause-specific mortality. Wildlife Biology. 2017:1-4.

Clark, D. A. 2014. Implications of cougar prey selection and demography on population dynamics of elk in northeast Oregon. Dissertation, Oregon State University, Corvallis, USA.

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, R. C., J. G. Cook, D. J. Vales. B. K. Johnson, S. M. McCorquodale, L. A. Shipley, R. A. Riggs, L. L. Irwin, S. L. Murphie, B. L. Murphie, K. A. Schoenecker, F. Geyer, P. B. Hall, R. D. Spencer, D. A. Immell, D. H. Jackson, B. L. Tiller, P. J. Miller, L. Schmitz. 2013. Regional and seasonal patterns of nutritional condition and reproduction in elk. Wildlife Monographs. 184:1-44.

Dalén, L., Götherström, A., & Angerbjörn, A. 2004. Identifying species from pieces of faeces. Conservation genetics. 5:109-111.

Davidson, G. A., Clark, D. A., Johnson, B. K., Waits, L. P., & Adams, J. R. 2014. Estimating cougar densities in northeast Oregon using conservation detection dogs. The Journal of Wildlife Management. 78:1104-1114.

Decesare, N. J., M. Hebblewhite, M. Bradley, K. G. Smith, D. Hervieux, and L. Neufeld. 2012. Estimating ungulate recruitment and growth rates using age ratios. Journal of Wildlife Management 76:144-153.

Eacker, D. R., M. Hebblewhite, K. M. Proffitt, B. Jimenez, M. S. Mitchell, and H. S. Robinson. 2016. Landscape-level effects of risk factors on annual elk calf survival in a multiple carnivore system. The Journal of Wildlife Management 80:1345-1359.

Eacker, D. R., P. M. Lukacs, K.M. Proffitt, and M. Hebblewhite. 2017. Assessing the importance of demographic parameters for population dynamics using Bayesian integrated population modeling. Ecological Applications 27:1280–1293.

Fowler, P. E. 2001. Blue Mountains Elk Herd. Wildlife Program, Washington Department of Fish and Wildlife, Olympia. 47pp.

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. 31:367-393.

Gilbert, S.L., M.S. Lindberg, K.J. Hundertmark, and D.K. Person. 2014. Dead before detection: addressing the effects of left truncation on survival estimation and ecological inference for neonates. Methods in Ecology and Evolution. 5:992-1001.

Griffin K., M. Hebblewhite, H. Robinson, P. Zager, S. Barber-Meyer, D. Christianson, S. Creel, N. Harris, M. Hurley, and D. Jackson. 2011. Neonatal mortality of elk driven by climate, predator phenology, and predator diversity. Journal of Animal Ecology 80:1246–1257.

Harris, N. C., M. J. Kauffman, and L. S. Mills. 2008. Inferences about ungulate population dynamics derived from age ratios. Journal of Wildlife Management 72:1143–1151.

Hatter, I. W. 2020. Revisiting the recruitment-mortality equation to assess moose growth rates. Alces, 56:39-47

Hurley M. A., M. Hebblewhite, J. M. Gaillard, S. Dray, K. A. Taylor, W. K. Smith, P. Zager, and C. Bonenfant. 2014. Functional analysis of normalized difference vegetation index curves reveals overwinter mule deer survival is driven by both spring and autumn phenology. Philosophical Transactions of the Royal Society Bulletin. 369.

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.

Lehman, C. P., C. T. Rota, J. D. Raithel, and J. J. Millspaugh. 2018. Pumas affect elk dynamics in absence of other large carnivores. Journal of Wildlife Management 82:344–353.

Lukacs, P. M., M. S. Mitchell, M. Hebblewhite, B. K. Johnson, H. Johnson, M. Kauffman, K. M. Proffitt, P. Zager, J. Brodie, K. Hersey, A. A. Holland, M. Hurley, S. McCorquodale, A. Middleton, M. Nordhagen, J. J. Nowak, D. P. Walsh, and P. J. White. 2018. Factors influencing elk recruitment across ecotypes in the western United States. Journal of Wildlife Management. 82:698-710.

McCorquodale, S.M., P.A. Wik, P.E. Fowler. 2011. Elk survival and mortality causes in the Blue Mountains of Washington. The Journal of Wildlife Management. 75:897-904

McCorquodale, S.M., S.M. Knapp, M.A. Davison, J.S. Bohannon, C.D. Danilson, W.C Madsen. 2013. Mark-resight and sightability modeling of a western Washington elk population. The Journal of Wildlife Management. 77:359-371.

Myers, W.L., B. Lyndaker, P.E. Fowler, and W. Moore. 1999. Investigations of calf elk mortalities in southeast Washington Final Federal Aid to Wildlife. Restoration report PR Project WW-96-R. Olympia, Washington. 21 pp.

Murphy, M. A., L. Waits, and K. Kendall. 2000. Quantitative evaluation of fecal drying methods for brown bear DNA analysis. Wildlife Society Bulletin. 28:951-957.

Parker, K. L., P. S. Barboza, M. P. Gillingham. 2009. Nutrition integrates environmental response of ungulates. Functional Ecology. 23:57-69.

Proffitt, K. M., J. A. Cunningham, K. L. Hamlin, and R. A. Garrott. 2014. Bottom-up and top-down influences on pregnancy rates and recruitment of northern Yellowstone elk. Journal of Wildlife Management 78:1383-1393.

Proffitt, K. M., B. Jimenez, C. Jourdonnais, J. A. Gude, M. Thompson, M. Hebblewhite, and D. R. Eacker. 2015. Evaluating bottom-up and top-down effects on elk survival and recruitment in the southern Bitterroot Valley, Montana. Final Report, Montana Fish Wildlife and Parks, Helena, USA.

R Core Team (2019) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Raithel, J. D., M. J. Kauffman, and D. H. Pletscher. 2007. Impact of spatial and temporal variation in calf survival on the growth of elk populations. Journal of Wildlife Management. 71:795-803.

Rickbeil, G. J., J. A. Merkle, G. Anderson, M. P. Atwood, J. P. Beckmann, E. K. Cole, A. B. Courtemanch, S. Dewey, D. D. Gustine, M. J. Kauffman, D. E. McWhirter, T. Mong, K. Proffitt, P. J. White, and A. D. Middleton. 2019. Plasticity in elk migration timing is a response to changing environmental conditions. Global Change Biology. 25:2368-2381.

Stonehouse, K.F., Anderson, C.R., Peterson, M.E., and Collins, D.R. 2016. Approaches to field investigations of cause-specific mortality in mule deer. Colorado Parks and Wildlife. Tech. Pub. No. 48.

Therneau, T. 2021. A Package for Survival Analysis in R. R package version 3.2-13, https://cran.r-project.org/package=survival.

Washington Department of Fish and Wildlife. 2001. Blue Mountains Elk Herd. Wildlife Program, Washington Department of Fish and Wildlife, Olympia. 47pp.

Washington Department of Fish and Wildlife. 2015. Game Management Plan, July 2015 – June 2021. Wildlife Program, Washington Department of Fish and Wildlife, Olympia. 159pp.

Washington Department of Fish and Wildlife. 2020. Blue Mountains Elk Herd. Wildlife Program, Washington Department of Fish and Wildlife, Olympia. 71 pp

Washington Department of Fish and Wildlife. 2021. Blue Mountains Elk Herd: At-Risk Assessment. Wildlife Program, Washington Department of Fish and Wildlife, Olympia. 71 pp

White, C. G., P. Zager, and M. W. Gratson. 2010. Influences of predator harvest, biological factors, and landscape on elk calf survival in Idaho. The Journal of Wildlife Management. 74:355-369.

Zahn, H. M. 1993. An initial analysis of elk reproductive tracts collected in Washington state. Washington Department of Fish and Wildlife, Olympia. 19pp.

Table S 1. Hunter harvest of cougars in the Blue Mountains, organized by PMU and GMU from 2011-2012 through the 2022-2023 season (excluding non-hunting mortality).

PMU	**9**				**10**					**11**				
Year	**145**	**166**	**175**	**178**	**149**	**154**	**157**	**162**	**163**	**169**	**172**	**181**	**186**	***Total***
2010-11	1	2	1	5	0	1	0	3	2	0	1	0	0	***16***
2011-12	0	1	0	0	0	1	0	3	0	1	3	2	0	***11***
2012-13	0	3	0	4	0	6	0	2	0	0	0	4	0	***19***
2013-14	0	1	2	3	1	3	0	5	1	0	1	2	1	***20***
2014-15	3	4	0	0	1	1	0	2	0	0	0	1	0	***12***
2015-16	3	2	0	0	0	2	0	4	1	1	2	2	1	***18***
2016-17	1	1	2	2	1	2	0	6	2	1	4	2	0	***24***
2017-18	1	3	2	0	1	4	0	9	1	0	1	2	0	***24***
2018-19	2	3	2	0	0	8	0	7	3	2	0	1	1	***29***
2019-20	0	3	1	1	1	4	0	1	0	0	0	2	1	***14***
2020-21	2	4	2	4	0	3	0	2	0	0	1	3	0	***21***
2021-22	2	2	0	3	0	9	0	2	0	0	2	2	0	***22***
2022-23	3	5	1	2	1	6	0	1	2	0	0	2	0	***23***
2023-24	2	1	2	0	1	5	0	7	2	0	1	6	1	***28***