2014-2022 Long-term Mule Deer Population Monitoring in the Eastern Sierra

Jane S. McKeever, Cody P. Massing, David W. German, Mary M. Conner, Daniel P. Taylor, and Thomas R. Stephenson

Mule deer in the Round Valley herd near Bishop, California. Photo credit: Elizabeth Siemion.

Executive Summary

This report summarizes a long-term multiple data source mule deer monitoring project in the eastern Sierra Nevada conducted during 2014-2022. Our approach to deer herd management and conservation incorporates hybrid monitoring and provides more precise population estimates and the ability to detect changes in the deer population trajectory over time. Results of this project provide natural resource managers and decision-makers with the information necessary to responsibly evaluate the potential effects of various management decisions as they relate to the viability of eastern Sierra mule deer populations.

During 2014-2022, we captured a total of 1,207 female mule deer in six herds in the eastern Sierra. Most animals were fitted with a colored VHF or GPS collar to assist in marking the animals for mark-resight population estimates and determining cause-specific mortality. Annual survival was low within the six deer herds; estimates of annual female survival ranged from 0.55-0.90 (mean was 0.75 for all years and herds). Consistent with low survival rates, population estimates suggested population declines for herds in which multiple surveys were completed. For all mortalities, cause of death was not able to be determined 64% (452/705) of the time. The primary known cause of death was mountain lion predation (69%, n=174), followed by vehicle collision (19%, n=47). Nutritional condition was quantified during captures in each herd annually and provided a measure of nutritional status and proximity to nutritional carrying capacity. Average body fat in females during spring captures was generally low in most years and

herds (mean was 4.66% for all years, IFBFat scaled), which is also predictive of declining populations based on previous studies.

We constructed an integrated population model (IPM) that included mark-resight estimates and population vital rates to estimate and project population size and growth rate. Long-term population modeling, utilizing an IPM approach, gives CDFW the ability to model future population sizes under different environmental conditions, determine if populations are stable, increasing, or decreasing, and evaluate management strategies, including hunting tag allocations. We created an IPM template and user manual that is available for other wildlife managers in the state.

Locations from GPS collars defined winter and summer ranges and the migratory routes between them for the six herds we studied. On their migratory routes, many deer were hit by motor vehicles on the major highway in the valley, US Highway 395. To document where deer successfully cross the highway and where there are deer-vehicle collisions, CDFW deployed high fix rate GPS collars on deer and evaluated their migratory pathways as they pertain to US Highway 395. Those pathways detail migration routes and assist us in providing recommendations for creating wildlife crossing structures.

Introduction

The California Department of Fish and Wildlife (CDFW) has been monitoring mule deer (*Odocoileus hemionus*) populations in the eastern Sierra Nevada since the 1950s (see Appendix 5 for historical studies). Beginning in 2014, the monitoring program was expanded to encompass more mule deer herds and monitor populations by combining different techniques into a comprehensive integrated approach, in order to assess the health of deer populations more accurately. This new approach, termed the multiple data source project, combined disparate methods to provide more precise population estimates, which allow wildlife managers to make better informed management decisions. Data from this approach has been used to construct an integrated population model (IPM; Besbeas et al. 2002, White and Lubow 2002, Gauthier et al. 2007, Schaub et al. 2007). The IPM gives us the ability to model future population sizes under different environmental conditions and determine if populations are stable, increasing, or decreasing. To complement the IPM approach using an independent metric, we monitor nutritional condition annually during captures by measuring body fat in female deer post-winter.

The mule deer that inhabit the eastern Sierra are composed of six deer herds, generally based on where each exists on the landscape during the winter season (October-May; CDFG 1963). From north to south those deer herds are: West Walker River (WWR), East Walker River (EWR), Mono Lake (MLK), Casa Diablo (CDB), Round Valley (RVD), and Goodale (GDL; Figure 1). More recently, for management and conservation purposes these six deer herds have been combined into the East Sierra Deer Conservation Unit (ESDCU; CDFW 2020a).

Within the ESDCU, CDFW has been capturing and studying mule deer in the Round Valley herd outside of Bishop since 1950 (Appendix 5). This long-term data set has given scientists the opportunity to learn a great deal about mule deer, including predator-prey dynamics (Pierce et al. 2000, 2004, 2012; Monteith et al. 2014), the importance of fat reserves and nutrition (Stephenson et al. 2002; Monteith et al. 2009, 2011, 2013, 2014), and migratory behavior (Monteith et al. 2011, 2014). Past research suggests that survival and recruitment of mule deer in the eastern Sierra is determined more by resource availability than by predation pressure (Monteith et al. 2009, Pierce et al. 2012). As a proxy for resource availability, continual data on deer nutritional condition is essential to allow for the interpretation of population dynamics in the area. Nutritional condition was measured by quantifying body fat of adult females post winter. This measure was shown to predict adult female survival, reproduction, as well as the abundance of males, and the overall population trajectory in the Round Valley herd (Monteith et al. 2009, 2014).

In addition to being one of the most popular game animals in the eastern Sierra, mule deer are a valuable part of the ecosystem. They likely play an important role in shaping local plant communities (Ripple and Beschta 2008, Morano et al. 2019) and are the primary prey of mountain lions (*Puma concolor*), which are abundant in the region (Pierce et al. 2000, 2004; Davis et al. 2012). Because mule deer are the most abundant ungulate prey in the Sierra Nevada, they support a large mountain lion population that also preys on Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*; Johnson et al. 2013). Sierra bighorn are federally endangered and live only in the Sierra Nevada mountains. A single mountain lion that chooses to focus primarily on bighorn sheep rather than mule deer can have a devastating effect on small bighorn sheep populations (Wehausen 1996, Hayes et al. 2000, USFWS 2007, Gammons et al. 2021). Due to the large numbers of mountain lions in the region (Stephenson et al. 2022), they are a primary threat to the recovery of Siera bighorn.

Understanding the health of mule deer populations in the eastern Sierra is important, not only for determining levels of harvest and tag quotas, but also for establishing a baseline to use for comparison as conditions change over time. Ecosystem dynamics can change rapidly from anthropogenic causes such as development and climate change, as well as from natural causes, including the influx of new species into an area, or natural succession such as pinyon-juniper encroachment (Morano et al. 2019). Since the reintroduction of gray wolves (*Canis lupus*) to central Idaho and Yellowstone (Fritts et al. 1997), biologists have seen movements of wolves into novel areas (CDFW 2020b). In recent years, wolves have begun to disperse into California from neighboring states and reproduce (CDFW 2020b). Gray wolves were extirpated in California by the mid-1920s, and it is uncertain if they were ever present in the eastern Sierra (Schmidt 1991), but they likely occurred wherever there was adequate ungulate prey. Due to the abundance of prey and low levels of anthropogenic changes in the eastern Sierra, dispersers from wolf packs in California may eventually move into the eastern Sierra. In fact, wolf OR93 was in Mono County on February 25, 2021, although he did not stay long and was out of the eastern Sierras by mid-March. In August 2023, there was a confirmed wolf pack in Tulare County, which produced offspring. As cervids are the primary prey of wolves (Kunkel et al. 1999, Smith et al. 2004), mule deer populations could be greatly affected by the arrival of wolves. It will be valuable to have a long-term dataset of mule deer populations in the region to allow comparison of population trends and deer health before and after the potential arrival of wolves. Baseline data will also be essential as environmental conditions change as a result of climate change.

We developed the current project as a long-term population monitoring effort planned to run from 2014-2032, and this report describes the work completed from January 2014 to December 2022. Our overarching goal was to develop population estimates and trends for the primary herds in the eastern Sierra and to provide insights into what was driving population change. The long-term aim is to recommend a hybrid population monitoring approach that enhances our understanding of these populations. The multiple data source project currently focuses on the six eastern Sierra herds, and CDFW utilizes population estimates and vital rates, such as survival and recruitment, to determine population growth rate and overall herd health. After nine years of capture in the three southern-most herds and six years of capture in the northern-most herds, we are summarizing many of our findings in this report.

Data and summaries in this report are preliminary and are subject to change contingent upon further interpretation, analyses, and review.

Study Area and Population

The project area includes the entire East Sierra Deer Conservation Unit (ESDCU; CDFW 2020a) within Mono and Inyo counties, CA, as well as the eastern portion of Tulare, Fresno, Madera, and Tuolumne counties (occupied on summer range) and western portions of the state of Nevada, including the counties of Douglas, Lyon, and Mineral (occupied on winter range; Figure 1). Elevations range from 10,000-14,000 ft along the Sierra crest to 4,000 ft in the eastside valleys. The ESDCU encompasses approximately 12,033 km^2 (4,646 mi^2), of which 94% is public land and 6% is private land. Deer in this study inhabit eight California hunt zones during some portion of the year: X9a, X9b, X12, X8, D8, D7, D6, and D5 (Figure 1). However, because these deer are available on the winter range during the hunt season, for this study, we primarily focus on hunt zones X9a, X9b, and X12. A detailed description of each of the six deer herd units can be found in Appendix 1.

Mule deer that inhabit the ESDCU are primarily migratory deer, summering at high elevations (≥7,000 ft) in the Sierra Nevada and migrating to lower elevations in winter and spring. In the northern portion of the ESDCU, some deer migrate farther east to winter and spring ranges in Nevada. Mule deer follow vegetative green-up in spring along an elevational gradient into the Sierra Nevada mountains, sometimes summering on the west side of the Sierra crest (Figure 9; Monteith et al. 2011, 2014). In fall, they travel to lower elevations, where they can forage when mountains are covered in snow. The timing of their migration depends upon current weather patterns as well as individual knowledge of migration routes (Monteith et al. 2011).

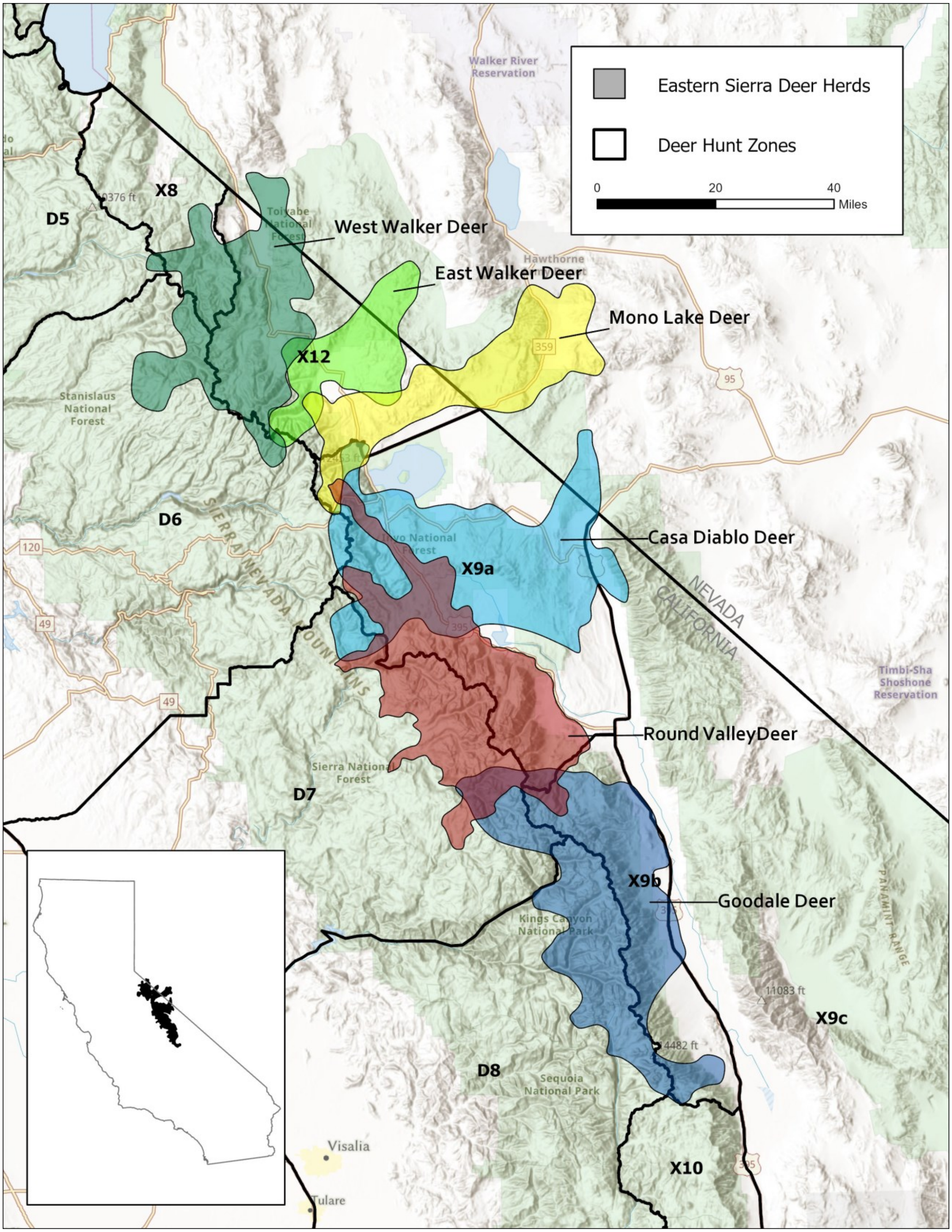


Figure 1. Mule deer summer and winter home ranges by herd in the eastern Sierra Nevada, California. Data from GPS-collared female mule deer 2016-2021.

Capture Effort

We conducted a total of nine spring capture efforts between March 14 and April 1 of each year, and one fall capture in early December 2022. Using a contracted helicopter, pilot, and crew, we captured adult (≥ 1 year old) female mule deer on winter range in CDB, RVD, and GDL beginning in 2014, with the addition of WWR, EWR, and MLK herds beginning in 2017. The capture crew used a net-gun fired from a helicopter for capture (Krausman et al. 1985), and each mule deer was blindfolded and hobbled before transport by helicopter to basecamp, a central processing station. In basecamp, we weighed and measured deer, took blood samples to test for disease exposure, and assessed pregnancy status by ultrasonography. We measured subcutaneous rump fat using ultrasonography and palpation, and estimated body fat (Cook et al. 2007, 2010). Each deer was released with a VHF or GPS collar. Our goal was to maintain approximately 60 collared deer in each herd for estimating abundance using mark-resight. Based on a power analysis to determine adequate sample size in order to detect a ≥32% decline in population size over a 5-year period, a minimum of 60 collared animals were necessary. To estimate survival using optimal allocation for precise estimates (CV ≤ 0.10), a minimum of 30 collared deer in each herd was needed.

Between 2014 and 2022, we captured 1,207 female mule deer in the six herds (Table 1). From 2014-2015 most (n=201) captured animals were released with VHF collars, and from 2016-2021 most (n=830) captured animals were released with GPS collars. In 2022, we deployed a mix of VHF (n=57) and GPS (n=99) collars. Both types of collars were equipped with mortality sensors and were brightly colored to assist in sightability in mark-resight surveys. A total of 20 deer (1.7% of total) died or were euthanized due to injuries during the capture event or died on the day following capture (Table 1). As of December 2022, there were 344 collared deer in the ESDCU (Table 2).

It took approximately 3 years in the southern herds to accumulate ≥ 60 collars; conversely, in the northern herds WWR was the only herd in which we met our goal, and that was only in 2018 and 2019 (Table 2). Although we attempted to keep 60 deer collared in each herd, the number varied and fell below 60 when mortality was high, or we were unable to collar sufficiently due to weather and logistics.

Table 1. Number of female mule deer captured each year. The number of direct capture mortalities (animals that died on the day of capture or on the day following capture) is shown in parenthesis. Most captured animals were fitted with a VHF or GPS collar.

Deer Herd	GDL	RVD	CDB	MLK	EWR	WWR	Total
2014	31	31 (1)	31 (1)	0	0	0	93 (2)
2015	35 (1)	38	39	0	0	0	112 (1)
2016	30	30	31 (1)	0	0	0	91 (1)
2017	30	26 (1)	16	27	15	43 (3)	157 (4)
2018	24 (1)	27 (1)	19	19 (1)	14	49	152 (3)
2019	25	25	26 (1)	41	50 (1)	29 (2)	196 (4)
2020	26 (1)	29	25	18	6	26	130 (1)
2021	20 (1)	20	18	14	21 (1)	25	118 (2)
2022	45 (1)	25	32	8	26	22 (1)	158 (2)
Total	266 (5)	251 (3)	237 (3)	127 (1)	132 (2)	194 (6)	1207 (20)

Table 2. Collared female mule deer alive in each herd as of December of each year, 2014-2022. Highlighted cells indicate years and herds in which our target number of collars for mark-resight abundance estimation were met (≥60).

Deer Herd	GDL	RVD	CDB	MLK	EWR	WWR	Total
2014	27	23	26	--	--	--	76
2015	53	53	55	--	--	--	161
2016	64	72	69	--	--	--	205
2017	69	72	70	16	11	34	272
2018	66	74	67	22	15	65	309
2019	66	57	71	45	37	62	338
2020	56	58	58	48	29	59	308
2021	50	48	56	50	35	55	294
2022	77	51	67	45	47	57	344

Capture Results: Body Condition and Morphology

During spring captures, on average deer weighed 51.0 kg, were 151.0 cm long, and 90.7 cm in girth. Excluding the deer processed in the field (and thus pregnancy was not assessed), most females were pregnant (96.2%, n=1032/1073). Deer were pregnant with one fetus (28%), two fetuses (68%), and, in a single case, 3 fetuses.

Body weight, body-condition score, and the measure of subcutaneous rump fat were combined to estimate ingesta-free body fat, scaled (IFBFat, Cook et al. 2010). IFBFat is a measure of nutritional condition and has implications for reproduction, survival, and population performance in mule deer herds (Monteith et al. 2013, 2014; Stephenson et al. 2020). Mean IFBFat scaled (hereafter, body fat) varied by herd and by year (Figure 2). The severe winter of 2016/17, which was the second wettest year on record in the Sierra Nevada (Anderson 2017), coincided with lower body fat in all six herds (Figure 2). The 2018/19 long, cold winter was also wetter than usual, and again, all six herds were similarly low in body fat that year (Figure 2). In 2018, body fat in the RVD deer herd rebounded more markedly than other herds. Body fat estimated for the GDL herd was relatively high the first three years of the project, had a dramatic drop in 2017, and remained low until 2022 (Figure 2). More investigation is needed to determine whether this fluctuation is due to a decrease in body fat in the GDL herd, or if it is a product of capture location. Capture locations and basecamps are strategically located throughout the GDL spring range, however the extent of the winter range, at 500 km^2, makes distributing captures evenly throughout the area impractical when there are only one or two days of captures. Further analysis is planned to assess the role of precipitation and temperature on forage production and its influence on nutritional condition of among deer herds.

Monteith et al. (2014) described animal-indicated nutritional carrying capacity using estimates of body fat in mule deer in the RVD herd. Monteith et al. (2014) found that a mean March IFBFat of ≥ 6.7% predicted a population increase during the following year in the RVD herd. We further categorized nutritional limitation using mean levels of body fat by herd (Cook et al. 2021). March body fat above 6.7% indicated minimal nutritional limitation, below 4% indicated severe nutritional limitation where poor fawn survival occurs (Monteith et al. 2014), and between 4 and 6.7% was categorized as moderate nutritional limitation. The majority of our body fat measures fell below the 6.7% threshold and into the moderate and severe nutritional limitation categories, which is predictive of declining populations experiencing poor adult survival and/or poor recruitment. Only GDL, RVD, and WWR ever averaged body fat above 6.7%, and for those only during 1 (WWR), 2 (RVD), and 3 (GDL) out of 9 years of the reporting period (Figure 2). More than half of our samples were in the severe nutritional limitation category. For comparison, ultrasound was used to predict body fat in the Round Valley herd during 1996-2008 and those values ranged between 5.3 and 9.9%. The low levels of body fat in March among most herds that we report suggests that nutritional quality of winter ranges, or some combination of winter and summer ranges, has declined in recent years.

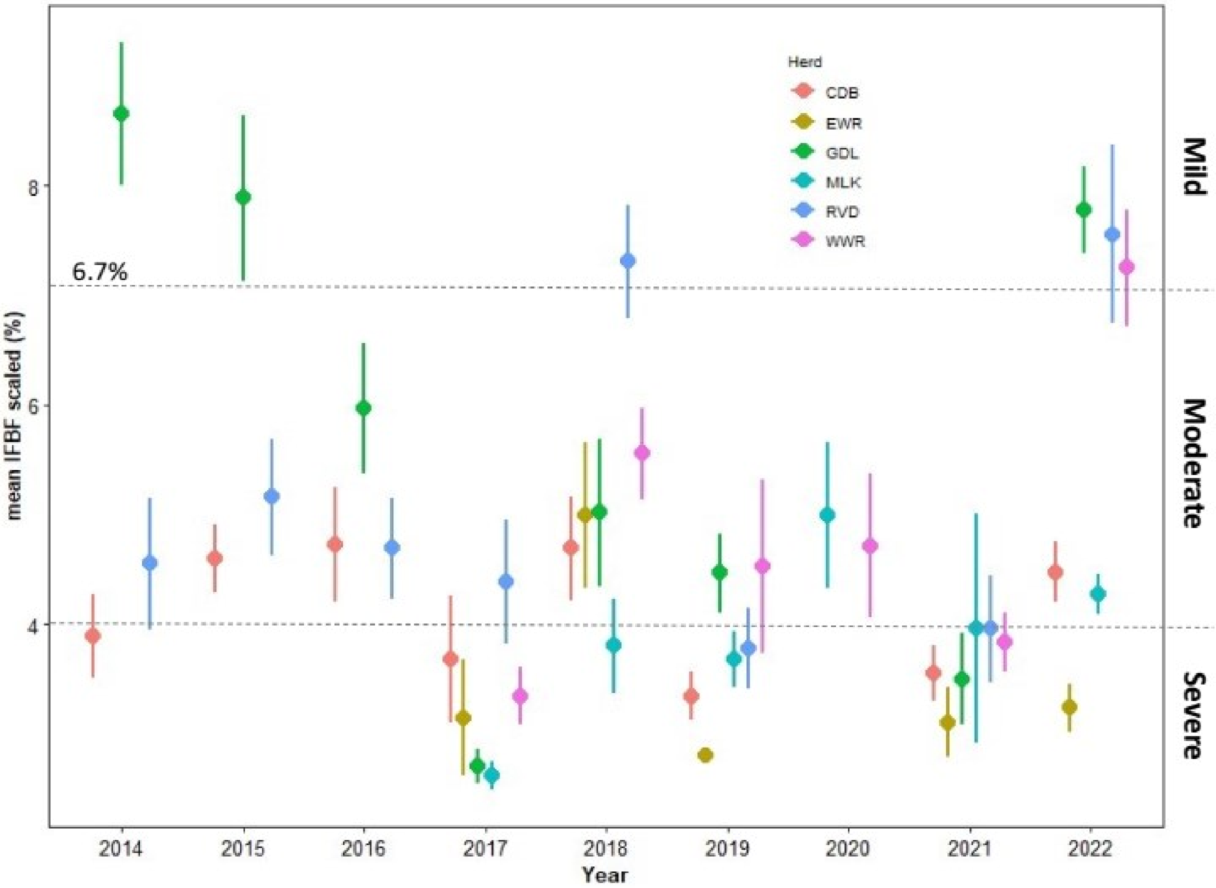


Figure 2. Average (± SE) ingesta-free body fat (IFBFat scaled) for female eastern Sierra mule deer captured in six herds, 2014-2022. Measurements were taken on live animals in March/April captures each year. The dashed line at 6.7% indicates a level of body fat below which can be indicative of declining populations, and the dashed line at 4% indicates the upper limit of severely low body fat. Mild, Moderate, and Severe describe categories of nutritional limitation based on body fat percentages.

Cause-Specific Mortalities

We investigated collared deer mortalities to determine cause-specific mortality among all herds. Beginning in 2016 when most captured deer were released with GPS collars, it became more feasible to determine cause-specific mortality, so we increased our focus on investigating mortalities, but mortality investigations did not become a priority until 2020. This study was originally designed with the focus on gathering survival rates; when it became clear that survival was low, we began to emphasize determining cause-specific mortality. Much greater effort and personnel are required to promptly determine cause of death. The GPS collars sent a mortality notification in the form of an email after an animal remained still for 8 hours, making it possible for personnel to investigate the mortality in a timely manner. For investigations that occurred within a week of death, about 35% of the mortality causes were unknown (n=79/225), and quite often the only sign of a deer was the collar and nothing else. For all mortalities, cause of death was not able to be determined 64% (452/705) of the time. This is fairly consistent with other cause-specific mortality studies (Bleich and Taylor 1998, Shaefer et al. 2000, Cain III et al. 2018). The primary known cause of death was mountain lion predation (69%), followed by vehicle collision (19%, Figure 3). Four collared animals were recorded as dying from starvation, and that determination was made because animals were investigated very soon after death (1-3 days) and had not been scavenged. Cause of death can be difficult to determine after scavenging due to the lack or destruction of evidence left behind. Encountering an intact carcass was rare, and only occurred in 35 mortality investigations; all others had been scavenged, consumed, or no carcass could be found at all.

Cause of death varied in different herds (Figure 3). For instance, deer in GDL died from vehicles in 7% of mortalities, but deer in RVD, the neighboring herd to the north, died from vehicles 27% of the time (Figure 3).

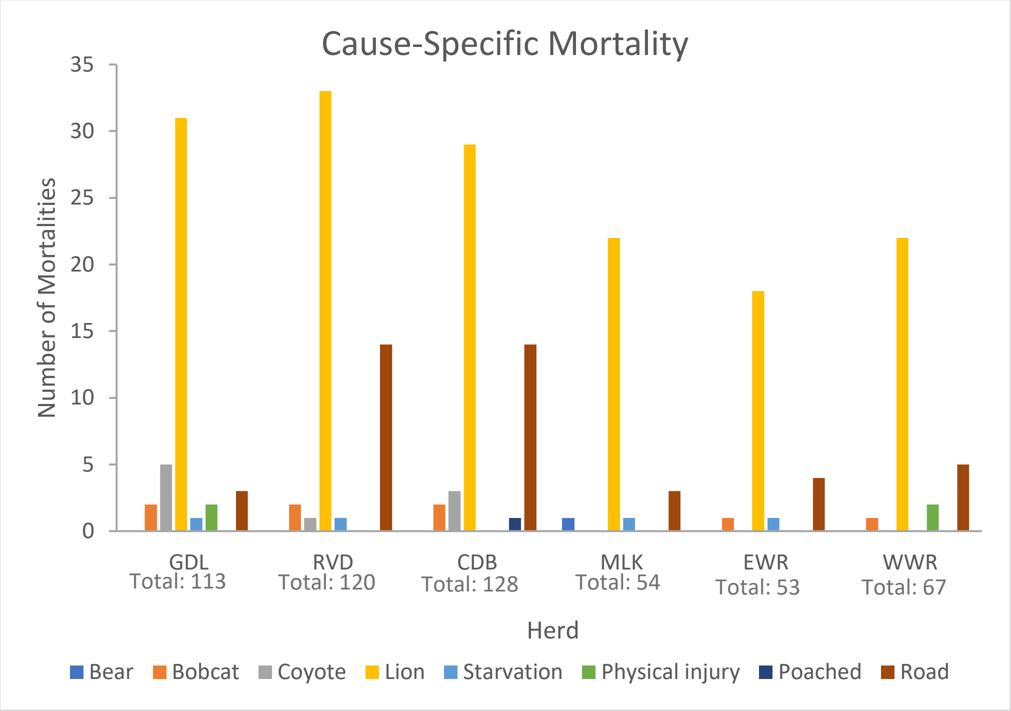


Figure 3. Number of known mortality causes in collared female mule deer from 2014-2022 in six herds in the eastern Sierra, excluding animals that died due to capture-related causes and animals that were censored. The totals under each herd are the total number of mortalities that were investigated, including those in which cause could not be determined.

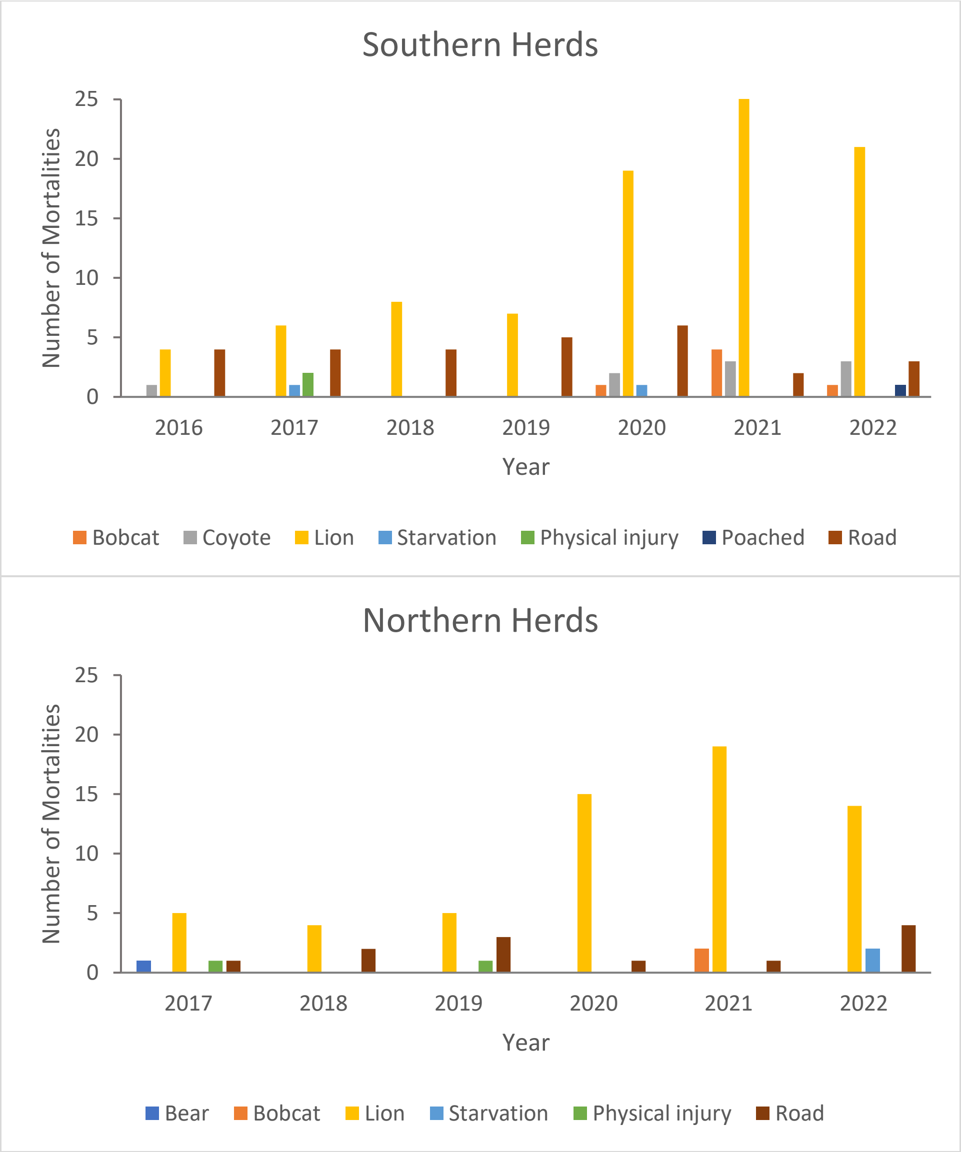


Figure 4. Known causes of death for collared female mule deer 2016-2022 for southern herds (top: Goodale, Round Valley, and Casa Diablo), and 2017-2022 for northern herds (bottom: Mono Lake, East Walker, and West Walker). Efforts to investigate mortalities varied over the years.

The number of animals preyed upon by lions and killed in vehicle collisions varied over the years in the northern and southern herds, as did our effort and ability to investigate mortalities (Figure 4). The effort to investigate cause-specific mortality was higher in the southern herds than the northern herds, due to both a higher number of deer collared in the southern herds as well as proximity of staff to the southern herds and land access (public vs. private landowner). WWR, EWR, and MLK mortalities that occurred in Nevada were given lower priority to investigate due to distance to travel and private landowner access issues.

During mortality investigations, we rated bone marrow to roughly quantify fat reserves at time of death (n=149 necropsies in which bone marrow was investigated). Most often the bone investigated was the femur, but occasionally a different long bone was used. To rate bone marrow, we used the Riney method to denote a numerical value to the texture and color of bone marrow fat in long bones (Kirkpatrick 1980). A Riney score of “0” for either color or texture would suggest that an animal was in very poor condition, while the best score would be 3, and indicate the animal had more fat reserves. To analyze, we used only the texture score because we speculate that texture data is more predictive of body fat, so marrow condition from low to high ranged from 0-3.

For all collared mortalities that were investigated within 30 days and had bone marrow ratings, animals killed by predation had an average Riney texture score of 2.1 (SE=0.12, n=66), and animals whose cause of death was unknown had an average Riney texture score of 2.0 (SE=0.12, n=22). Previous studies have suggested that mule deer in the eastern Sierra are limited more by resources than by predation (Monteith et al. 2009, Pierce et al. 2012). We observed a high rate of lion predation as the proximate cause of death. One of our interests in quantifying nutritional condition was to use nutritional status to inform whether predation was additive or compensatory (i.e., whether predation replaces starvation for animals in poor condition). Our data on the poor nutritional status of many herds suggests that nutrition could be influencing vulnerability to predation. We are currently working on a more complete, complex analysis on the interaction of predation and nutrition.

Survival

We monitored adult female survival using the GPS collar data, as well as telemetry during fixed-wing flights conducted three times annually: in April, August, and January.

We used two different methods to estimate herd-specific annual survival, one was a Kaplan Meier staggered-entry estimator (Kaplan and Meier 1958, Pollock et al. 1989), comparing the number of known live deer to known dead deer on monthly iterations. The other method was a model averaging approach using Program MARK, in which we constructed all possible combinations of models with herd, season, and year effects and then used model-averaged estimates of survival (see Appendix 2). For this report, we focus on the Kaplan Meier survival method because we believe this method better represents the realistic yearly fluctuations of survival, and how these estimates vary by herd. In both survival analyses, we eliminated all animals that died within 14 days of capture.

To estimate annual survival, we determined through simulations that we needed at least 30 collared mule deer in a herd (see Appendix 2). After the first year of capture in the southern herds our sample size of 30 collared deer was met (Table 2). It took 2 capture years in EWR and MLK to obtain a sample size ≥ 30 animals (Table 2). Survival estimates are not as robust in years that sample sizes were below 30. For all herds in all years, the coefficient of variation (CV) of the estimate of annual survival was below 0.16.

Annual survival varied between years and herd units (Figure 5). Southern herds exhibited an overall downward trend from 2014-2019 (e.g., RVD: 0.83 in 2014 to 0.64 in 2019), and then appeared more stable from 2019-2022 but remained below levels needed for population growth (Figure 5). For comparison, annual survival was 0.87 in RVD during 1998-2008 (Monteith et al. 2014). For all herds, survival estimates tended to be low most years and were consistent with survival found in declining populations.

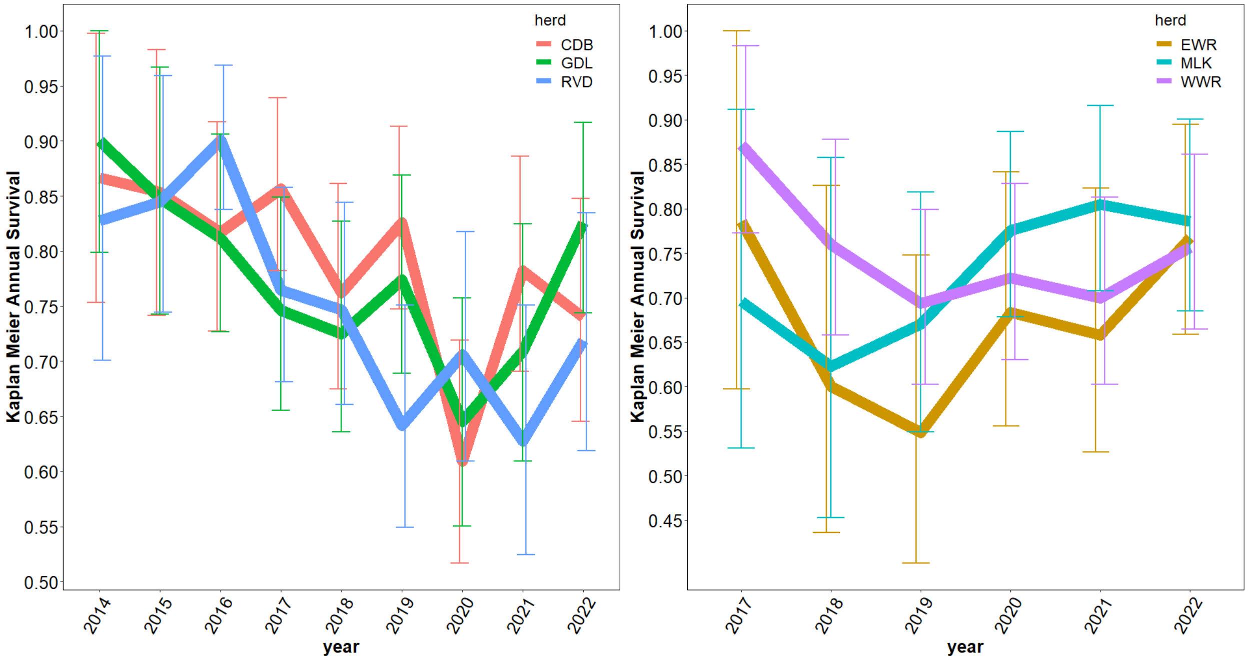


Figure 5. Kaplan Meier annual survival estimates for female mule deer in eastern Sierra herds, 2014-2022. Error bars are standard error.

Population Surveys

Helicopter-based and ground-based population surveys took place on winter (January) or spring (late-February to early April) range, when deer were most concentrated at lower elevations in areas with more visibility and better access (ground survey only) for observers. For all surveys, excluding the surveys conducted by Nevada Department of Wildlife (NDOW), the number and color of marks observed were recorded.

There were winter and spring ground or helicopter surveys in each year of the reporting period. We performed a total of 58 ground surveys (28 winter and 30 spring), and 15 helicopter surveys (6 winter and 9 spring, Appendix 4). However, not all deer herds were surveyed equally. The three southern deer herds (CDB, RVD, and GDL) were surveyed by ground or helicopter in all years and each season, whereas the three northern deer herds (WWR, EWR, and MLK) were surveyed inconsistently, due to poor conditions for ground surveys or helicopter surveys not being completed by NDOW. In spring 2019, a helicopter survey for estimates of abundance occurred in all herds. This was the only helicopter survey, and thus population estimate, for the WWR, EWR, and MLK herds.

We estimated population size by mark-resight, utilizing collars as marks in the populations. Over the duration of this project, VHF and GPS collars began to fail, so live deer with non-functioning collars became “unknowns”. We could not be certain whether unknowns were alive or dead. To account for the potential unknown marks being on the landscape, we used the previous year’s annual survival rate to estimate the proportion of the unknowns that could be alive and added this proportion to the number of live marked deer. Animals that were not observed for two years (through telemetry or GPS) were censored two months after their last observation.

We used the CV to compare the quality of an estimate across populations of different sizes; a high CV indicates a low-quality estimate, and thus we limited our reporting to CV ≤ 0.20. A higher resight probability also indicates a better estimate, and, concomitantly, also has a lower CV. For all reported surveys, the probability of resighting marks ranged from 0.28-0.81; the best CV (0.05) and the best resight probability (0.81) were from the 2019 spring helicopter survey in RVD (Table 3).

We had more successful population surveys in the RVD herd (Table 3). Round Valley offers optimal conditions for surveys because of the concentration of deer on an unforested winter range. The Round Valley herd can be surveyed by helicopter in 4 hours compared to several other eastern Sierra herds that require multiple days to survey and have low sightability. The RVD population ranged from 2,777 in 2016, to 1,865 in 2022 (Table 3), a 33% decline over 6 years. In RVD and GDL, the population estimates bounced around during 2016-2019, and estimates after 2019 show a decline in abundance (Figure 6). This population decline is consistent with survival estimates found in all herds (Figure 5).

In 2020, Stewart et al. (2022) used fecal DNA capture-recapture to estimate abundance on winter range in the RVD herd. Using fecal DNA to estimate abundance has shown success in other deer herds (Furnas et al. 2018, Pfeiler et al. 2021), but it has its limitations (Stewart et al. 2022). In RVD, using fecal DNA capture-recapture, the model-averaged estimate of abundance was 2,728 (95% CI = 2,009-4,436; CV = 0.20). The fecal DNA estimate exceeded the estimate obtained using aerial mark-resight (RVD 2020, Table 3) and was not as precise (CV of 0.20 versus 0.06). In GDL, we were not able to determine a population estimate using fecal DNA due to logistical constraints, while helicopter mark-resight was more successful (Stewart et al. 2022).

Although there are benefits to traditional ground survey and fecal DNA methods (e.g., less cost, greater time to classify deer; see Conner and McKeever 2020), a helicopter survey in most herds during most seasons is preferred due to its ability to cover the entire survey area in less time using fewer staff. In addition, the resulting estimates of abundance and composition are available almost instantly. A helicopter survey provides a more complete survey and our mark-resight approach accounts for missed animals. Within each deer herd, the helicopter surveys resulted in more deer being observed and lower CVs. The primary complication in relying on helicopter surveys has been the inconsistency in having a helicopter contract in place that provides a helicopter when needed.

Table 3. Mark-resight estimates of abundance by deer herd from helicopter or ground (*) surveys that resulted in an estimate with CV ≤ 0.20, in the eastern Sierra, 2016-2022. For years with multiple surveys resulting in a CV ≤ 0.20, the winter survey is shown.

Herd	Year	Season	Marks in Herd	Deer Observed	Marks Observed	Pop Est	SE (PopEst)	L95%CI	U95%CI	CV	Resight Probability
RVD	2016*	Winter	53	822	15	2777	560	1954	4217	0.20	0.28
RVD	2018*	Winter	71	1092	30	2538	334	2020	3357	0.13	0.42
RVD	2019	Spring	72	2416	59	2945	158	2716	3357	0.05	0.82
RVD	2020	Spring	55	2064	45	2509	152	2297	2922	0.06	0.82
RVD	2022*	Spring	71	919	35	1832	208	1509	2344	0.11	0.49
CDB	2016	Spring	76	555	29	1423	194	1122	1900	0.14	0.38
CDB	2019	Spring	84	1191	40	2460	268	2037	3107	0.11	0.48
GDL	2016	Winter	52	2043	23	4500	661	3509	6173	0.15	0.44
GDL	2019	Spring	65	2313	32	4633	558	3773	6011	0.12	0.49
GDL	2020	Spring	62	1800	35	3141	334	2632	3973	0.11	0.57
MLK	2019	Spring	61	616	27	1365	184	1086	1823	0.13	0.44
EWR	2019	Spring	54	767	32	1279	136	1076	1624	0.11	0.59
WWR	2019	Spring	84	1984	46	3589	342	3048	4414	0.10	0.55

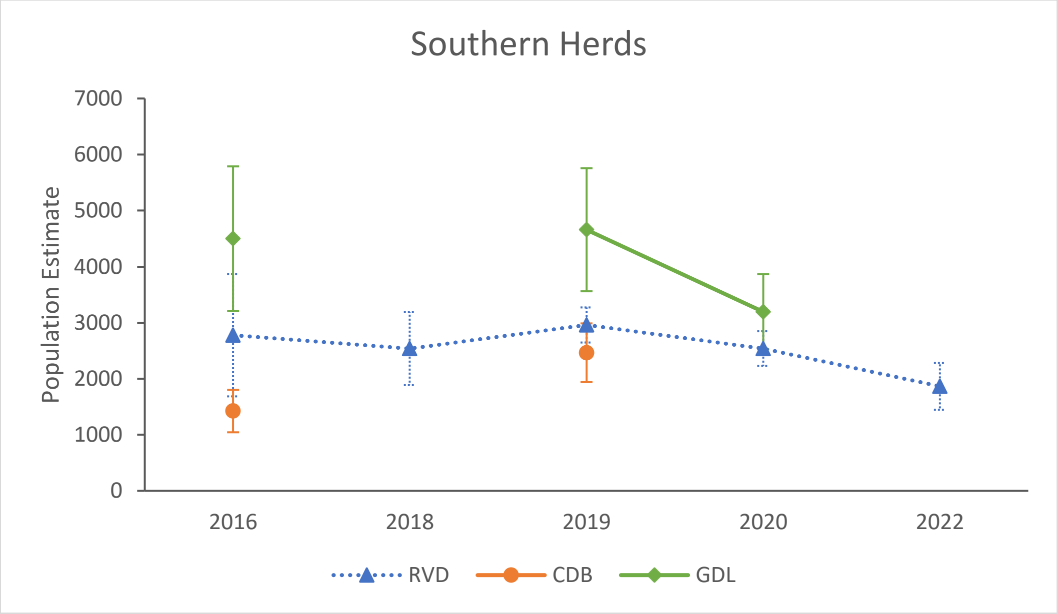


Figure 6. Mark-resight estimates of abundance for the GDL, RVD, and CDB deer herds that resulted in a CV ≤ 0.20, in the eastern Sierra, 2016-2022. For years with multiple surveys resulting in a CV ≤ 0.20, only the winter survey is shown.

Age and Sex Composition

During winter surveys, conducted prior to January 15, we classified deer as fawn (<1 year old), adult female (doe), adult male (buck), or unclassified, and we further classified bucks by antler class. We estimated a winter ratio of adult males to adult females (buck:doe ratio) and a ratio of fawns to adult females (fawn:doe ratio). The benefit of a January survey was obtaining buck:doe ratios and antler classification on bucks. During spring surveys, we classified deer as fawn, adult, or unclassified and estimated the spring fawn:doe ratio using the previous winter's buck:doe ratio, increasing uncertainty in these estimates. Spring surveys also helped us to estimate winter fawn survival rates.

We used all estimates of age and sex composition regardless of CV (Table 4). Although the capture and collar efforts in WWR, EWR, and MLK did not commence until 2017, surveys for composition in those herds occurred as early as 2014. For all deer herds, buck:doe ratios ranged from 0.16 to 0.50, and fawn:doe ratios ranged from 0.20 to 0.50 in winter surveys (Table 4, Figure 7). Fawn:doe ratios tended to be low and were generally unlikely to support increasing populations (Gill et al. 2001). Our fawn:doe ratios tended to be lower than those observed by Monteith et al. (2014) since 1995. Poor nutritional condition may be influencing poor recruitment.

For the majority of surveys, the winter results were more robust, based on CV. Composition ratios that indicated the estimated spring fawn:doe ratio was higher than the previous winter's fawn:doe ratio are problematic, yet comparing the CVs in such cases gives us a better understanding of the accuracy and precision of the estimate (Table 4). In fact, in all years in which the fawn:doe ratio was higher in the spring than winter (5 times), the CV of the ratio in the spring was higher, and in some cases very high (Table 4), thus corroborating that the estimates during those periods were poor.

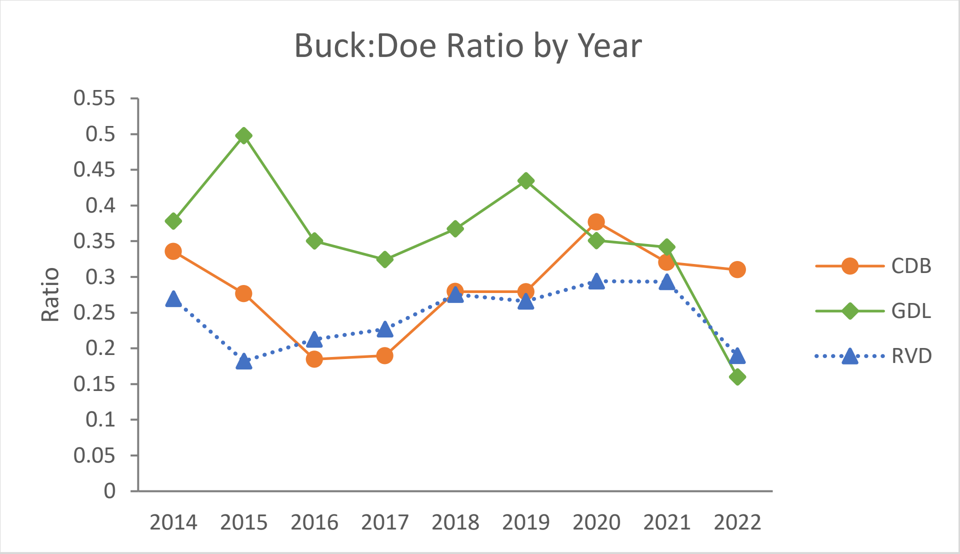
Over time, there was a consistent decrease in the total number of deer observed and classified during surveys in GDL. GDL typically had the highest buck:doe ratios throughout the reporting period, ranging between 0.32-0.50 (Figure 7), however, the 2022 GDL buck:doe ratio of 0.16 was well below the average of the eight previous winter surveys (average of 0.38). RVD also had a low buck:doe ratio in 2022. The CVs of the January 2022 buck:doe estimates for both RVD and GDL were the highest for each of the herds, indicating a relatively less robust estimate. The low buck:doe ratio in the most recent survey at GDL may reflect the small sample size (n=241) that resulted from poor survey conditions.

Table 4. Mule deer herd composition and age class ratios from ground and helicopter surveys during winter and spring in the eastern Sierra, 2014-2022, for surveys with counts >20 animals. Spring fawn:doe ratio was calculated using the previous winter's buck:doe ratio.

		Winter					**Spring**				
Deer Herd	Year	Buck:Doe Ratio	Ratio CV	Fawn:Doe Ratio	Ratio CV	Total Deer	Fawn:Adult Ratio	Ratio CV	Fawn:Doe Ratio	Ratio CV	Total Deer
RVD	2014	0.27	0.12	0.40	0.09	837	0.16	0.10	0.20	0.18	821
RVD	2015	0.18	0.14	0.20	0.08	776	0.13	0.10	0.16	0.22	977
RVD	2016	0.21	0.09	0.23	0.07	1439*	0.16	0.09	0.19	0.17	1189
RVD	2017	0.23	0.16	0.23	0.09	692	0.09	0.16	0.11	0.21	868
RVD	2018	0.28	0.11	0.24	0.07	1092	0.17	0.10	0.22	0.12	874
RVD	2019	0.27	0.12	0.24	0.13	894	0.15	0.07	0.20	0.14	1229
RVD	2020	0.29	0.11	0.38	0.06	801	0.19	0.10	0.25	0.15	781
RVD	2021	0.29	0.14	0.39	0.11	622	0.22	0.09	0.29	0.13	734
RVD	2022	0.19	0.16	0.24	0.14	610	0.15	0.10	0.18	0.19	919
CDB	2014	0.34	0.15	0.32	0.10	438	0.17	0.41	0.23	0.39	68
CDB	2015	0.28	0.19	0.25	0.12	459	0.21	0.22	0.27	0.30	91
CDB	2016	0.18	0.18	0.30	0.14	314	0.14	0.12	0.17	0.12	698*
CDB	2017	0.19	0.26	0.26	0.15	198	0.13	0.20	0.15	0.42	211
CDB	2018	0.28	0.12	0.38	0.16	267	0.31	0.21	0.39	0.32	115
CDB	2019	0.28	0.30	0.37	0.17	112	0.14	0.06	NA	NA	1191**
CDB	2020	0.38	0.37	0.38	0.16	107	0.12	0.40	0.16	0.40	122
CDB	2021	0.32	0.13	0.29	0.09	366	0.15	0.22	0.20	0.35	232
CDB	2022	0.31	0.29	0.33	0.11	380	0.27	0.12	0.36	0.26	232
GDL	2014	0.38	0.16	0.31	0.09	805	0.18	0.09	0.24	0.14	700
GDL	2015	0.50	0.22	0.31	0.10	407	0.11	0.14	0.16	0.14	616
GDL	2016	0.35	0.07	0.21	0.06	2455*	0.14	0.08	0.19	0.13	1214
GDL	2017	0.32	0.19	0.21	0.09	515	0.07	0.13	0.09	0.16	808
GDL	2018	0.37	0.14	0.21	0.12	541	0.17	0.10	0.23	0.16	946
GDL	2019	0.43	0.12	0.32	0.09	510	0.15	0.12	0.22	0.15	649
GDL	2020	0.35	0.13	0.27	0.09	611	0.13	0.13	0.18	0.17	450
GDL	2021	0.34	0.26	0.26	0.22	187	0.14	0.19	0.19	0.18	391
GDL	2022	0.16	0.31	0.20	0.22	241	0.21	0.16	0.25	0.27	189
MLK	2014	0.16	0.31	0.29	0.11	185**					
MLK	2015	0.23	0.24	0.50	0.09	135**					
MLK	2017						0.18	0.31	NA	NA	46
MLK	2019						0.16	0.09	NA	NA	616**
MLK	2021						0.20	0.24	NA	NA	53
MLK	2022						0.15	0.20	NA	NA	23
EWR	2016						0.21	0.29	NA		91
EWR	2018						0.25	0.26	NA		74
EWR	2019						0.14	0.07	NA		767**
EWR	2020						0.19	0.21	NA		25
EWR	2021						0.24	0.04	NA		92
EWR	2022						0.26	0.11	NA		34
WWR	2014	0.26	0.19	0.29	0.08	642**	0.11	0.19	NA		344
WWR	2015	0.26	0.15	0.38	0.07	248**	0.13	0.28	NA		196
WWR	2016						0.15	0.15	NA		362
WWR	2017	0.16	0.18	0.32	0.06	1117**	0.15	0.11	NA		268
WWR	2018						0.19	0.18	NA		209
WWR	2019	0.18	0.15	0.24	0.10	676**	0.15	0.06	0.17	0.12	1984**
WWR	2020						0.20	0.15	NA		230
WWR	2021						0.31	0.09	NA		414
WWR	2022						0.21	0.16	NA		327

*Helicopter and ground survey combined

**Helicopter survey



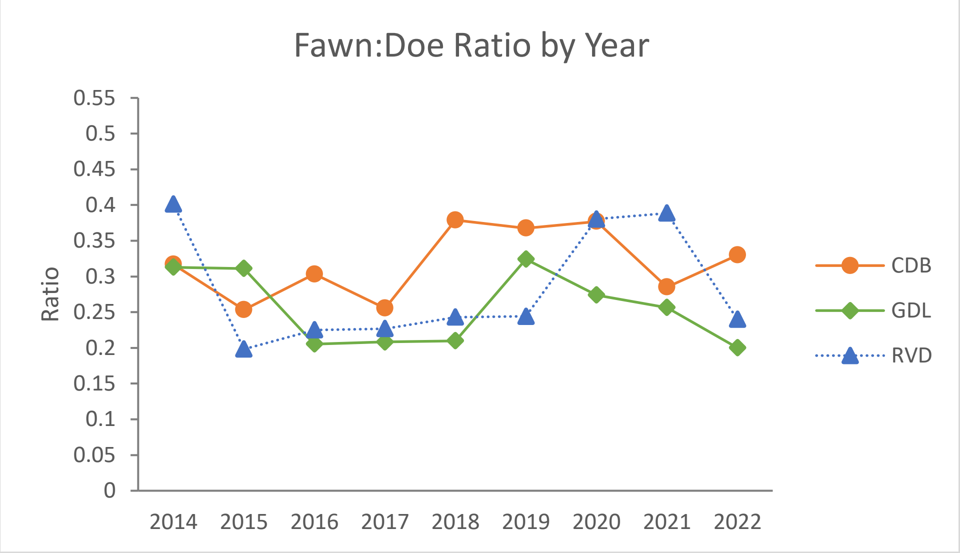


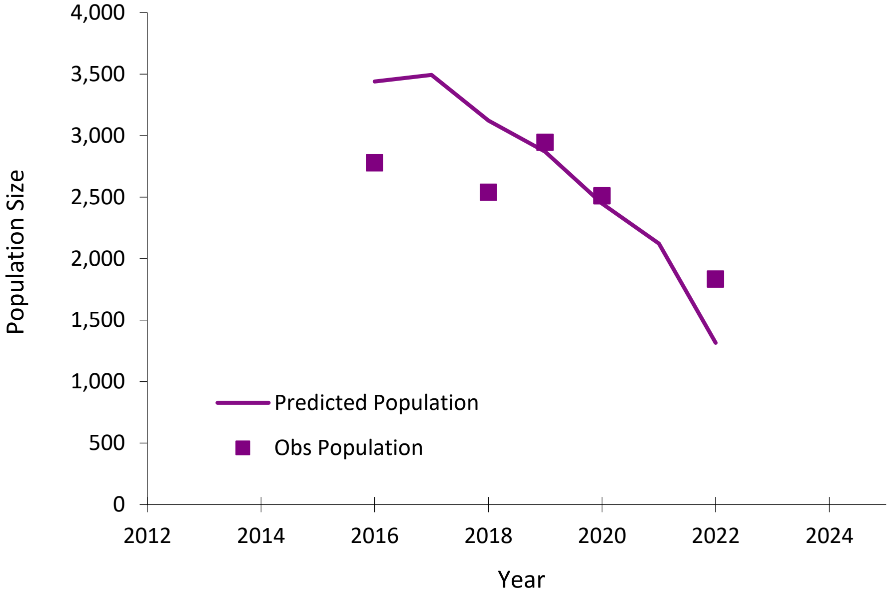
Figure 7. Buck:doe (top) and fawn:doe (bottom) ratios for southern eastern Sierra mule deer herds during winter surveys, 2014-2022. See Table 4 for CVs of estimates.

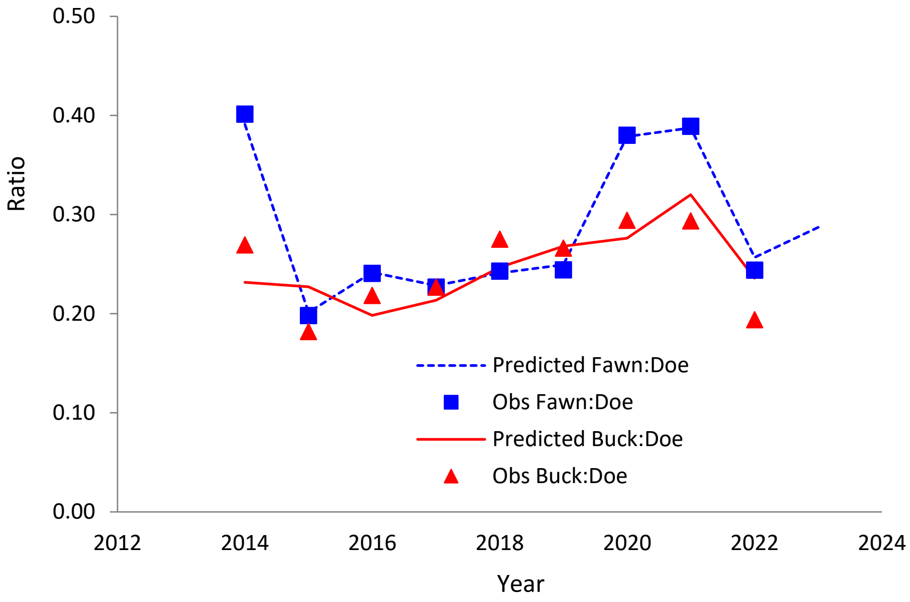
Integrated Population Models

IPMs have become more prevalent in wildlife management as long-term data sets continue to grow (Arnold et al. 2018). Population vital rates, including survival and recruitment, are used in a matrix model to estimate and project population sizes and to estimate λ (lambda, the population growth rate; Gotelli 2001, Morris and Doak 2002). The IPM is a useful tool for wildlife managers as we continue to fulfill CDFW's goal to manage and conserve California's deer herds. Incorporating data from multiple sources over time, the IPM provides data-driven recommendations for hunting tag quota levels that are based on predicted harvest. Thus, managers can use it parametrically to compare different harvest regimes and their relative risk in order to evaluate and create management recommendations. We developed a template and a user manual for the IPM, which is available to CDFW managers upon request. See Appendix 3 for details.

The IPMs developed for each of the six eastern Sierra mule deer herds had both retrospective and prospective goals. Retrospectively, we used a model selection approach to identify trends in vital rates and create a model that best fit all of the observed data. Prospectively, we used the best model from the retrospective analysis to project the population forward a year under different harvest scenarios and environmental conditions. For example, we determined harvest levels needed to achieve different management objectives of minimum buck:doe ratios, such as 20 bucks per 100 does and 25 bucks per 100 does. We also ran the model to determine harvest levels to achieve a desired λ (typically 1.0) under different environmental conditions. Then, for each harvest level, we used harvest success data for each herd to determine tag allocations (Table 5).

Based on our modeling with these six deer populations, at least five years of abundance estimates are needed to integrate with vital rate data to make robust population predictions (Gill et al. 2001). Because helicopter surveys were unable to be conducted as proposed, only RVD had enough years of field-collected mark-resight data for robust population size predictions (Figure 8). Observed (field-based) and predicted estimates indicate a decline in RVD population size from 2019-2022 (Figure 8, Table 3). This decline is also seen in estimates of both fawn and adult survival (Figure 8). We recognize that the models don’t appear to represent reality in all years, but models still provide useful information.





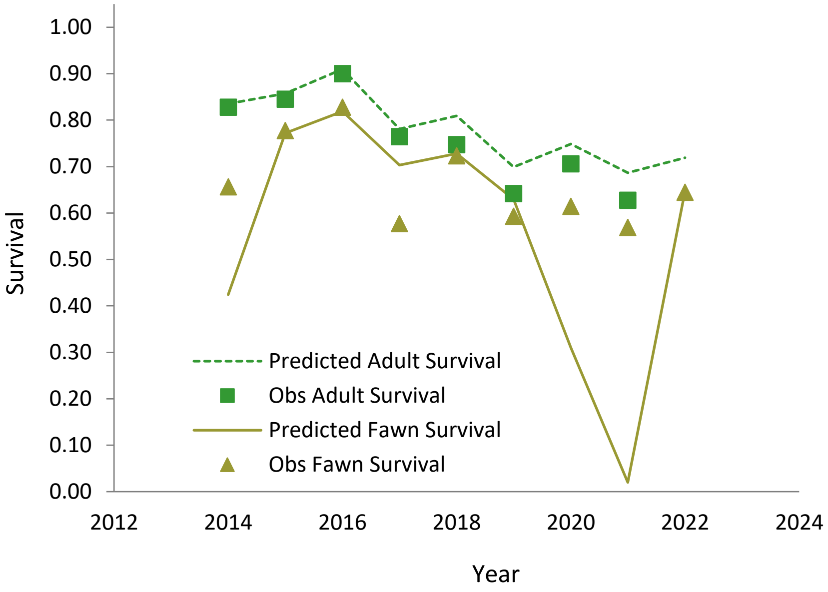


Figure 8. Integrated population model (IPM) outputs for the RVD mule deer herd using data collected from 2014-2022, with predicted and observed (obs) estimates. From top to bottom: population size; fawn:doe and buck:doe ratios; adult and fawn survival.

We used outputs from the top IPM model to project future population size, and we used this projection to evaluate harvest levels that would meet different management objectives (Table 5). Selecting target buck:doe ratios of 0.20 and 0.25, we projected population size estimates by varying vital rates to simulate different environmental conditions (mild, moderate, and severe), using previous harvest levels (Table 5). RVD and CDB represent hunt zone X9a, so to project the population forward we first ran IPMs separately by herd, and then we combined the two herds' projected buck harvests and population sizes to determine a tag quota recommendation for the individual hunts within the hunt zone (Table 5). Using previous reported harvest data, we estimated that typically 65% of the bucks taken are from CDB, and 35% of the bucks taken are from RVD within X9a. In addition to the general season and the archery season (A16) hunts, there are two late season hunts within the RVD herd, G39 and J12. We fixed the tag quotas for these two hunts at 2 tags and 10 tags, respectively (Table 5). Both late season hunts have high success rates, and that harvest was directly subtracted from total tag allocation prior to allocating to the X9a and A16 hunts. We also ran the model with no buck harvest, for comparison (Table 5, last line). Under severe environmental conditions with no restriction on buck:doe ratio, the RVD population is still decreasing at a similar rate (λ=0.78), thus buck harvest is not what is driving the overall population trajectory.

Table 5. Hunting tag allocations in deer hunt zone X9a for the 2023 hunt season. Harvest levels are based on projecting forward from January 2023 to January 2024, from the integrated population models (IPM) for RVD and CDB deer herds. The X9a hunt zone covers both the RVD and CDB herds, so these herds' IPM outputs are combined. Environment is the environmental condition for the time period. Pop Size is the estimated total population size, including all bucks, does, and fawns that would result from the given scenario inputs and buck harvest in the fall of 2023. λ (lambda) is the population growth rate resulting from each environmental scenario. Total harvests are based on the 2022 hunt success in each hunt. The bottom scenario is the projection without a buck harvest, for comparison.

Scenario Inputs		**RVD Projections for January 2024**			**CDB Projections for January 2024**			**Combined Projections for X9a**		**2023 Tag Allocation X9a**				
Target Buck:Doe	**Environ-ment**	λ	Pop Size	Buck Harvest	λ	Pop Size	Buck Harvest	Total Pop Size	Total Buck Harvest	X9a General	A16 Archery	G39	J12	Tag Total X9a
0.20	**mild**	1.06	1127	89	1.01	1074	115	2201	204	339	38	2	10	389
0.20	**moderate**	0.90	953	72	0.89	947	102	1900	174	289	32	2	10	333
0.20	**severe**	0.74	786	52	0.78	826	90	1612	142	236	26	2	10	274
0.25	**mild**	1.09	1163	53	1.04	1,108	80	2271	133	219	24	2	10	255
0.25	**moderate**	0.93	985	40	0.92	978	71	1963	111	182	20	2	10	214
0.25	**severe**	0.77	814	25	0.80	854	62	1668	87	141	16	2	10	169
NA	**severe**	0.78	837	0	0.86	916	0	1753	0	0	0	0	0	0

Movement, Migration, and Mitigation

We used GPS data to investigate deer migration routes, home range sizes, and habitat use. All herds had well-defined winter ranges. During the most severe periods of winter, deer in the 6 herds moved to shrub communities at elevations below 6,000 feet on the east side of the Sierra Nevada and avoided deep snow for long periods. During summer, deer typically climbed to subalpine habitats at elevations between 8,000 and 11,000 feet. Summer ranges tended to be more dispersed and varied among individuals (Figures 9-10). Consequently, migration routes to summer ranges varied but were consistent for individual deer (Figures 11-14). Monteith et al. (2011) found that individual RVD deer consistently followed the same routes year to year, which agrees with our findings.

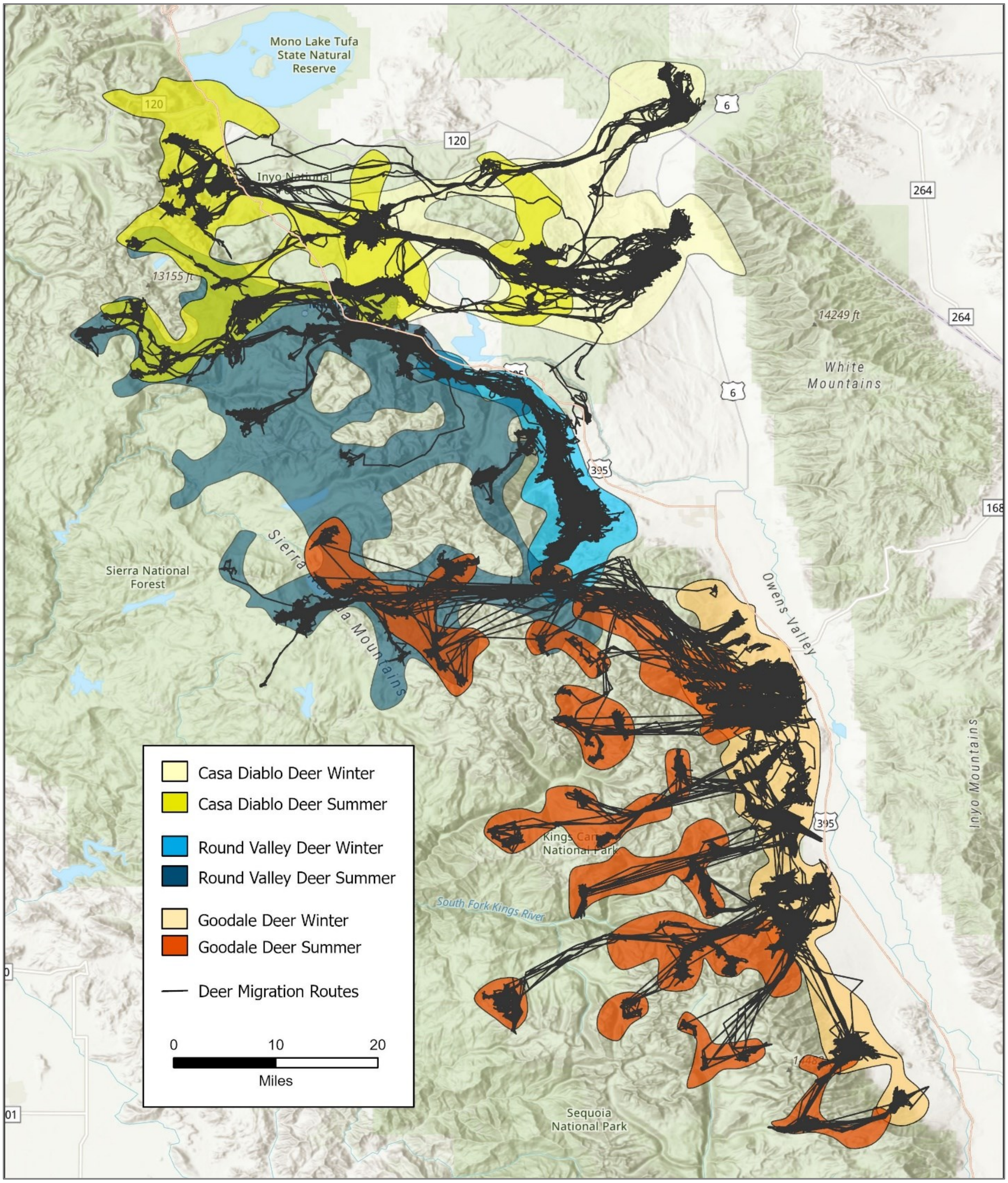


Figure 9. Mule deer summer and winter home ranges with migration routes in the three southern herds, CDB, RVD, and GDL, in the eastern Sierra Nevada, California. Data from GPS-collared female mule deer 2016-2023.

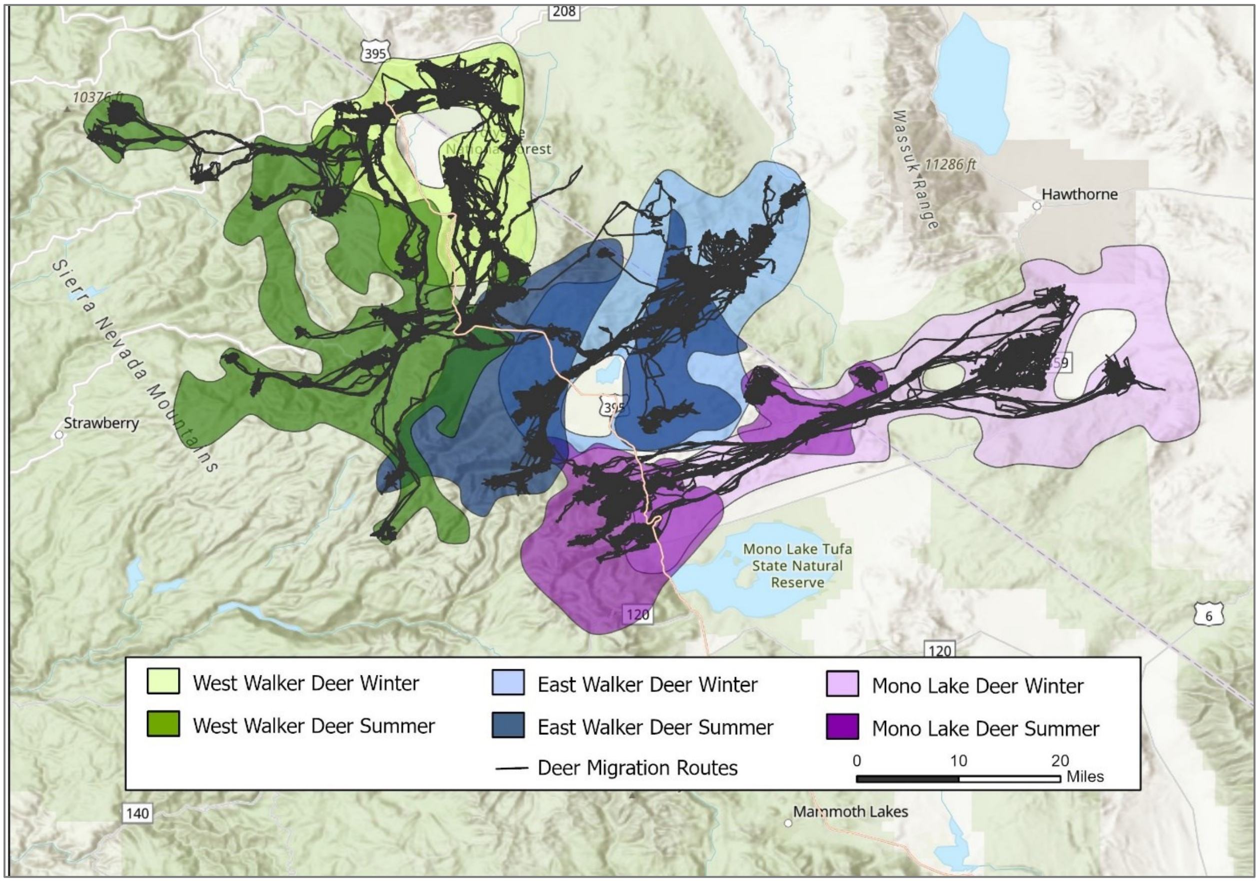


Figure 10. Mule deer summer and winter home ranges with migration routes in the three northern herds, WWR, EWR, and MLK, in the eastern Sierra Nevada, California. Data from GPS-collared female mule deer 2016-2023.

The second most common known cause of death for deer in this study was deer-vehicle collisions, which primarily occurred on US Highway 395. University of California, Davis identified US Highway 395 in the eastern Sierra as an area with several substantial deer-vehicle collision hotspots (Shilling and Waetjen 2015, Shilling et al. 2019), and many deer-vehicle collisions happened during seasonal migrations (Waetjen and Shilling 2017). From 2002-2018, the California Department of Transportation (Caltrans) recorded 2,048 deer vehicle collisions along 195 km of US Highway 395 within Mono County. Approximately 33% of these deer-vehicle collisions were recorded along a 14 km section of US Highway 395 in Long Valley, Mono County, California, termed the Mammoth Lakes 395 Wildlife Crossings project area (MWC). This 4-lane section of highway bisects the migration corridors of the RVD and CDB herds that annually move between lower elevation winter range and higher elevation summer range in the Sierra (Figure 9; Kucera 1988, Monteith et al. 2011). However, there are summer resident deer that remain within the MWC and cross the highway multiple times to access resources (Kucera 1988, Monteith et al. 2011). Caltrans identified this section of highway as the highest priority location for the implementation of wildlife crossing structures along US Highway 395 in Mono County.

Protection of migratory populations has been a growing conservation concern (Kauffman et al. 2018). Human development, including roadways, threatens populations and their migration patterns. If knowledge of migration routes are lost by populations, they can be very difficult to reestablish, and this threatens the very existence of unique populations that learned their migratory behavior over many generations and likely prior to the establishment of modern highways where collisions occur. The development of wildlife crossing structures has become an increasingly necessary and fundamental component of wildlife conservation throughout the United States. Increased human development and expansion has led to an ever-growing transportation network, which has created a variety of both direct and indirect ecological impacts to local wildlife populations.

Within the MWC, Taylor (2023) utilized GPS-collared deer movement data and created an RSF (Resource Selection Function) to model deer highway crossing locations and identify successful and unsuccessful crossing locations, with the goal of reducing both the barrier effect that roads create and deer-vehicle collisions (Figures 11-14). To determine the spring and fall migration paths, Taylor (2023) identified the track of each animal (Figures 11-14). Taylor (2023) found that each deer had fidelity to its migration route and took the same route to and from summer range. CDFW provided recommendations to Caltrans for the locations of wildlife crossing structures and associated fencing to mitigate deer-vehicle collisions and facilitate deer movement across US Highway 395.

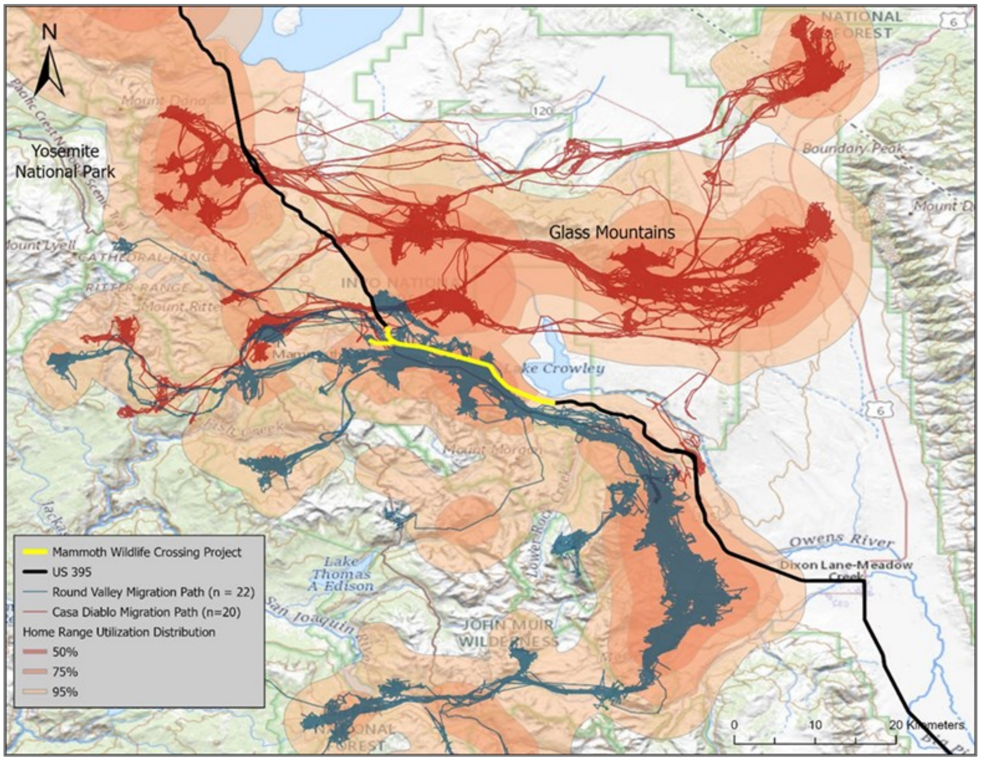


Figure 11. Casa Diablo and Round Valley female mule deer home ranges, migration pathways, and their spatial relationships to US Highway 395, from Taylor (2023).

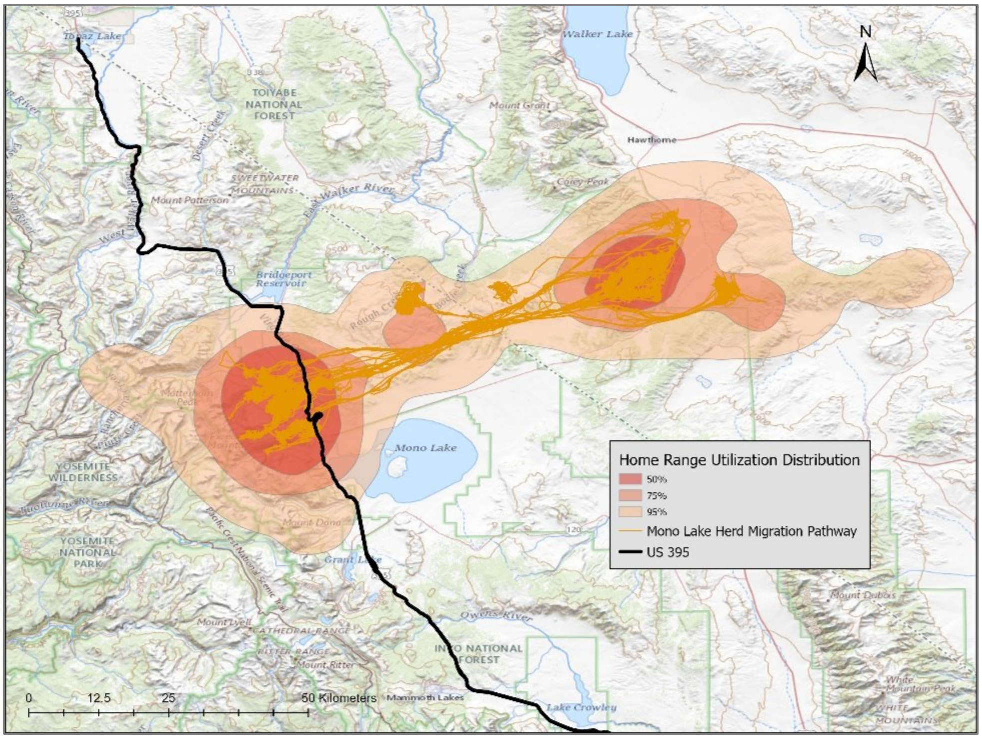


Figure 12. Home range and migration pathways for female mule deer from the Mono Lake herd, and their spatial relationship to US Highway 395, from Taylor (2023).

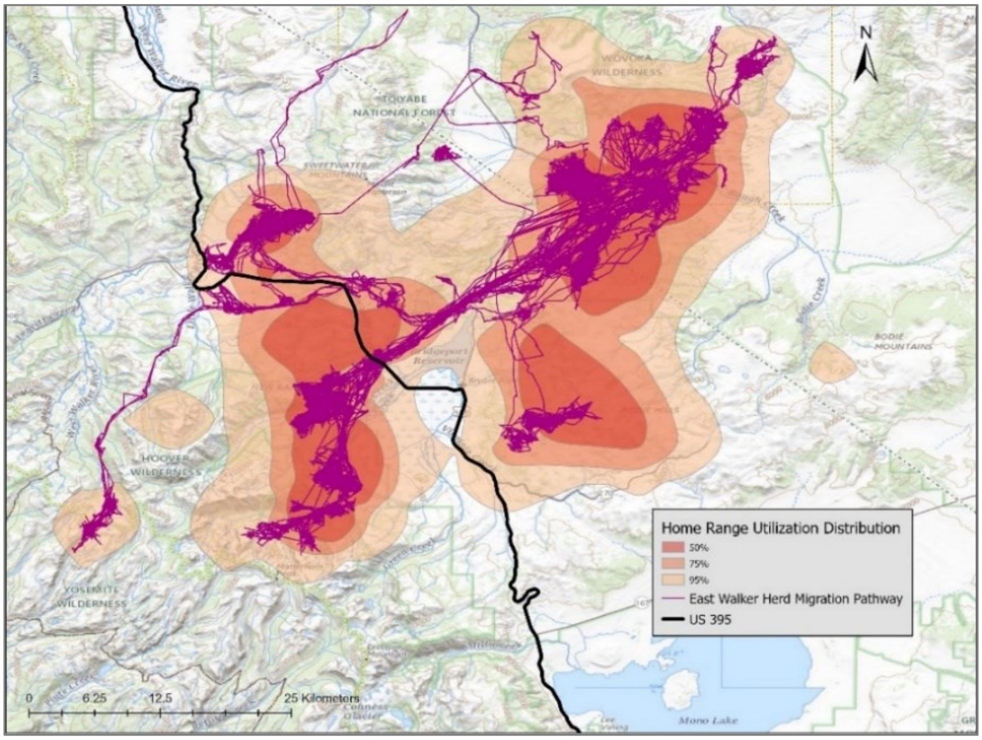


Figure 13. Home range and migration pathways for female mule deer from the East Walker herd, and their spatial relationship to US Highway 395, from Taylor (2023).

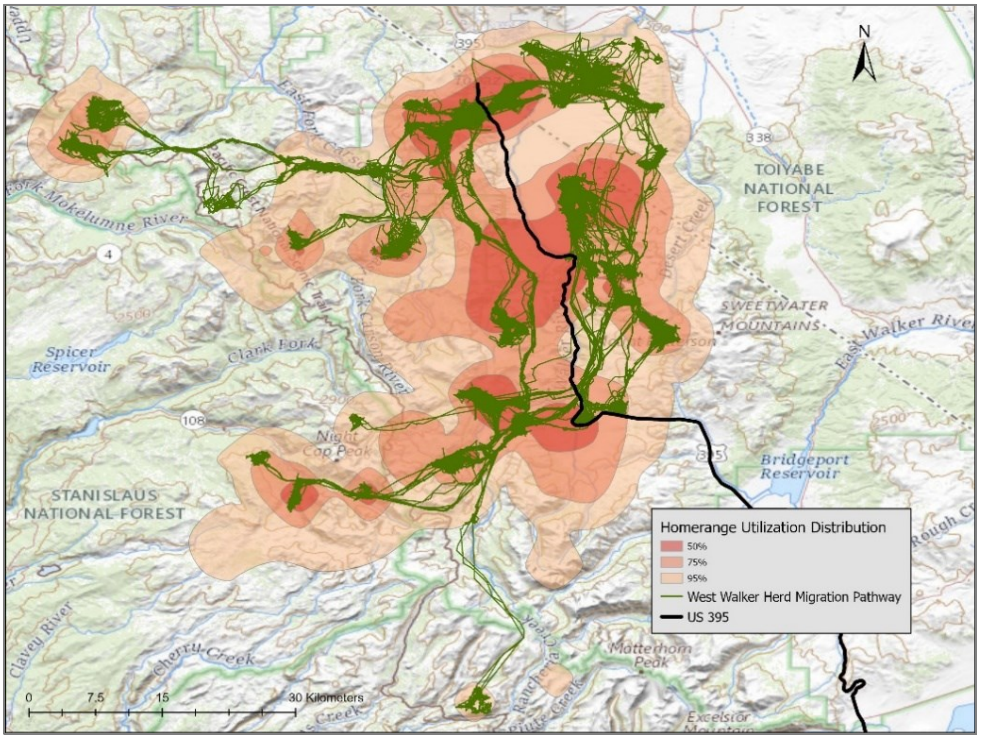


Figure 14. Home range and migration pathways for female mule deer from the West Walker herd, and their spatial relationship to US Highway 395, from Taylor (2023).

Management Recommendations

To meet our goal of long-term population monitoring, we recommend continuing to capture and maintain at least 60 collared deer in each of the six herds in the study. The highest priority is to maintain the population monitoring study within the three southern herds, GDL, RVD, and CDB, as we have acquired more complete data for them. However, to adequately determine tag quotas within all eastern Sierra hunt zones, we should continue to monitor all six deer herds.

Monitoring for cause-specific mortality is time-consuming and time-sensitive, however, the information is important as we anticipate the arrival of grey wolves as an additional predator, and as we monitor for pre- and post-construction of wildlife crossings along US Highway 395. We plan to continue our efforts to investigate mortalities as soon as possible after they occur. We will continue to combine our data on cause-specific mortality and nutritional condition to refine our understanding of compensatory and additive mortality. This knowledge is critical to our determination of what drives population change.

We plan to expand upon the IPM and use it to identify the vital rates that are most influential on λ and jointly evaluate the importance of extrinsic and intrinsic factors on the overall population performance (i.e., rate of population change). Incorporating body fat (IFBFat) into the model will complete the use of attributes that are currently collected. In addition, objective measures of environmental conditions would strengthen the model, as well as the actual measure of fawn survival (rather than the estimate that is currently used).

Our approach to monitoring these deer populations is to determine population growth rate by estimating the vital rates of a population, namely herd composition and adult female survival. However, even if the ultimate goal of a monitoring plan is to track population changes via vital rates, population size must be estimated occasionally to convert the rate of population change to easily interpretable numbers of mule deer and, more importantly, to validate models and recalibrate population models. During the reporting period, most herds (4/6) had ≤ 2 estimates of population size. Understanding that the IPM was developed as a reasonable trade-off between data that can be "easily" collected and what is needed to predict mule deer populations for management purposes, it continues to be very important to estimate abundance more regularly (e.g., at least every third year). A helicopter survey has been demonstrated as an effective method across all populations to observe deer and collect data for population size estimates.

An updated interstate agreement between CDFW and NDOW would help coordinate regular mule deer survey efforts, provide an avenue for more investigations of cause-specific mortalities that occur in Nevada, and promote better communication between the two agencies.

Data management and dissemination is vital to the conservation and management of these migratory deer. GPS collar data provide valuable insight into habitat use, especially in critical habitat and wildlife corridors. Incorporating the map layers produced from GPS collar data into CDFW's Biogeographic Information and Observation System Biogeographic (BIOS) will provide an avenue for CDFW, conservation groups, and the public to utilize this information.

Monitoring and research of the RVD herd may be one of the longest-term research projects ever conducted on the ecology and management of mule deer, with data on population dynamics, patterns of migration, cause of mortality, and life history. Capture and collaring efforts to date have resulted in over 2,100 deer collared across all ESDCU herds. Estimates and indices of abundance and winter and spring herd composition have been obtained almost continuously since 1950 for RVD. The development of the multiple data source project in 2014, as described in this report, has expanded population estimates for deer herds in the eastern Sierra and given us a better understanding of the underlying processes that affect population change. We feel it is imperative to continue collection of this long-term dataset without interruption to facilitate effective monitoring and management of mule deer in the eastern Sierra.

Resulting Research

There were two manuscripts, two theses, and one poster presentation produced during this reporting period. Research is detailed below.

Taylor, D. P. 2023. Quantifying the impacts and assessing the permeability of a divided four-lane highway on migratory mule deer. [Master's Thesis, Utah State University].

Using GPS data from survey collars and high-fix rate collars deployed on adult female mule deer from 2016-2022, Taylor (2023) delineated home range and migration corridors for five eastern Sierra mule deer herds, with focus along US Highway 395 and in the Mammoth Wildlife Crossing area. Results will be used to determine best placement of wildlife crossing structures to minimize the effect of the anthropomorphic barriers caused by the highway.

Stewart, A. M. 2022. Comparing fecal DNA capture-recapture methods to traditional mark-resight methods for estimating abundance of mule deer on winter ranges. [Master's Thesis, Utah State University].

Stewart, A. M., M. M. Conner, J. S. McKeever, A. Ellsworth, R. S. Crowhurst, C. W. Epps, and T. R. Stephenson. 2022. Comparing fecal DNA capture-recapture to mark-resight for estimating abundance of mule deer on winter ranges. Journal of Wildlife Management e22350.

During 2020, Stewart et al. (2022) compared the use of fecal DNA capture-recapture to helicopter mark-resight estimates in the RVD deer herd. Population abundance estimates from aerial mark-resight surveys were more precise in RVD (CV = 0.066) compared to abundance estimates from fecal DNA capture-recapture (CV = 0.204); yet, when accounting for the cost of each method, based on simulations to obtain a CV = 0.10, fecal DNA capture-recapture was about 63% less expensive than aerial mark-resight. However, Stewart et al. (2022) also found that the fecal DNA capture-recapture method had drawbacks, such as requiring a good understanding of deer occurrence under different weather patterns, the ability to predict weather events, and scheduling sampling around wet weather.

Conner, M. M. and J. S. McKeever. 2020. Are composition surveys for mule deer along roads or from helicopters biased? Lessons from the field. Wildlife Society Bulletin 44(1):142-151.

In 2015 and 2016, to investigate the potential for biased surveys on RVD winter range, we conducted a random-route ground survey, a traditional road and walking loop ground survey, and then a subsequent helicopter survey. Conner and McKeever (2020) found the traditional road surveys had a negative bias in buck:doe ratio, probably due to inadequate road coverage throughout the winter range, and survey area boundaries should not be stagnant year after year but should be adjusted with consideration of winter and forage conditions.

Shirkey, N., B. Munk, J. McKeever, T. Taylor, M. Morrison, and T. Stephenson. 2019. Post-capture mortalities in Rocky Mountain mule deer associated with traumatic coccygeal injuries resulting from helicopter netgun capture: A tail of two deer. Poster presented at the 68th Annual International Wildlife Disease Association Conference, Tahoe, CA.

Using capture data from 2014-2019, Shirkey et al. (2019) identified factors that played a role in capture-related mortalities. Injuries identified as severe life-threatening accounted for 10% of the mortalities and increased a deer's chance of dying within 15 days by 9-fold. The majority of capture injuries were associated with trauma to the sacral and caudal vertebrae. These injuries were not initially noticeable and were often only identified after closer exam of rectal, anal, and tail tone palpation. The closer examination was fully implemented into capture processing in 2019. Another factor identified in capture mortalities was overactive behavior of the deer which likely lead to capture myopathy. Overactivity increased a deer's chance of dying within 15 days of capture by 5.4-fold (Shirkey et al. 2019).

Acknowledgements

Helicopter captures were completed by J. D. Pope of Leading Edge Aviation LLC (Clarkston, WA). The helicopter surveys were flown by D. Everson of Air Shasta Rotor & Wing (Redding, CA), and the fixed wing services were conducted by G. M. Pope of Black Mountain Air Services (Bishop, CA). Field assistance was provided by K. Anderson, E. Brandell, M. Brown, T. Calfee, A. Davis, C. Davis, J. Davis, V. Davis, T. DelBosco, A. Ellsworth, A. Evans, J. Fusaro, D. Gammons, J. Kolek, A. Lapp, A. Lawrence, J. Lawson, J. Leary, A. Johnson, T. Johnson, P. Johnston, S. Maple, B. O'Connor, E. Otto, W. Philbrook, S. Pfeiler, S. Rankins, B.

Regan, E. Siemion, A. Stoerp, A. Sturgill, G. Taylor, J. Weissman, A. Wicks, and numerous other CDFW staff, including volunteers from CDFW's Natural Resources Volunteer Program, and V. Chadwick and J. Rolfe from the Sierra Nevada Bighorn Sheep Foundation. Capture planning and effort would not have been successful without the assistance from the CDFW Wildlife Health Laboratory, especially B. Gonzales, L. Konde, E. Lantz, B. Munk, and N. Shirkey. We especially thank M. Morrison and T. Taylor for their assistance with and coordination of captures, surveys, and fieldwork. We thank K. Anderson for creating many of the maps in this document. We dedicate this report to the memory of our colleagues Kevin O'Connor, Clu Cotter, Tom Stolberg, and Mike Donovan who were committed to mule deer conservation. Funding for captures, collars, aerial surveys, and fieldwork was provided by the California Department of Fish and Wildlife's Big Game Management Account, Federal Assistance in Wildlife Restoration grants, the California Deer Association, and USGS Secretarial Order 3362.

Literature Cited (*includes citations in appendices*)

Anderson, M. 2017. Hydroclimate Report: Water Year 2017.

Arnold, T. W., R. G. Clark, D. N. Koons, and M. Schaub. 2018. Integrated population models facilitate ecological understanding and improved management decisions. Journal of Wildlife Management 82:266-274.

Besbeas, P., S. N. Freeman, B. J. T. Morgan, and E. A. Catchpole. 2002. Integrating mark-recapture-recovery and census data to estimate animal abundance and demographic parameters. Biometrics 58:540-547.

Bleich, V. C., B. M. Pierce, J. L. Jones, and R. T. Bowyer. 2006. Variance in survival of young mule deer in the Sierra Nevada, California. California Fish and Game 92(1):24-38.

Bleich, V. C. and T. J. Taylor. 1998. Survivorship and cause-specific mortality in 5 populations of mule deer.

Bowden, D. C., A. E. Anderson, and E. Medin. 1984. Sampling plans for mule deer sex and age ratios. Journal of Wildlife Management 48:500-509.

Bowyer, R. T., D. K. Person, and B. M. Pierce. 2005. Detecting top-down versus bottom-up regulation of ungulates by large carnivores: implications for biodiversity. Pages 342-361 in J. C. Ray, K. H. Redford, R. S. Steneck, and J. Berger, editors. Large carnivores and the conservation of biodiversity. Island Press, Washington DC, USA.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference. Second edition. Springer-Verlag, New York, New York, USA.

Cain III, J. W., J. B. Ashling, and S. Liley. 2018. Survival and cause-specific mortality of translocated female mule deer in southern New Mexico, USA. Wildlife Research 45:325-335.

California Department of Fish and Game (CDFG). 1963. Deer Management Handbook. State of California.

California Department of Fish and Wildlife (CDFW). 2015. California State Wildlife Action Plan 2015 Update. California Department of Fish and Wildlife, Sacramento, USA. https://wildlife.ca.gov/SWAP/Final

California Department of Fish and Wildlife (CDFW). 2020a. Department of Fish and Wildlife deer conservation and management plan. California Department of Fish and Wildlife, Sacramento, USA. *In Review*.

California Department of Fish and Wildlife (CDFW). 2020b. California's known wolves, past and present. February 2020. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=177186&inline

Conner, M. M. and J. S. McKeever. 2020. Are composition surveys for mule deer along roads or from helicopters biased? Lessons from the field. Wildlife Society Bulletin 44:142-151.

Cook, R. C., T. R. Stephenson, W. L. Myers, J. G. Cook, and L. A. Shipley. 2007. Validating predictive models of nutritional condition for mule deer. Journal of Wildlife Management 71:1934-1943.

Cook, R. C., J. G. Cook, T. R. Stephenson, W. L. Meyers, S. M. McCorquodale, D. J. Vales, L. L. Irwin, P. B. Hall, R. D. Spencer, S. L. Murphie, K. A. Schoenecker, and P. J. Miller. 2010. Revisions of rump fat and body scoring indices for deer, elk, and moose. Journal of Wildlife Management 74:880-896.

Cook, R. C., J. Oyster, K. Mansfield, and R. B. Harris. 2021. Evidence of summer nutritional limitations in a northeastern Washington moose population. Alces 57:23-46.

Davis, J. L., S. W. Carlson, C. C. Coolahan, and D. L. Orthmeyer. 2012. Sierra Nevada Bighorn Sheep Recovery Program: The Role of USDA Wildlife Services, 1999-2011. Sacramento.

Doherty, P. F., G. C. White, and K. P. Burnham. 2012. Comparison of model building and selection strategies. Journal or Ornithology 152 (Supplement 2):S317-S323.

Furnas, B. J., R. H. Landers, S. Hill, S. S. Itoga, and B. N Sacks. 2018. Integrated modeling to estimate population size and composition of mule deer. The Journal of Wildlife Management 82:1429-1441.

Gammons, D. J., J. L. Davis, D. W. German, K. Denryter, J. D. Wehausen, and T. R. Stephenson. 2021. Predation impedes recovery of Sierra Nevada bighorn sheep. California Fish and Wildlife Special CESA issue:444-470.

Gauthier, G., P. Besbeas, J. D. Lebreton, and B. J. T. Morgan. 2007. Population growth in snow geese: a modeling approach integrating demographic and survey information. Ecology 88:1420-1429.

Gill, R. B., T. D. I. Beck, C. J. Bishop, D. J. Freddy, N. T. Hobbs, R. H. Kahn, M. W. Miller, T. M. Pojar, and G. C. White. 2001. Declining mule deer populations in Colorado: reasons and responses. Colorado Division of Wildlife Special Report, Number 77:DOW-R-S-77-01, Fort Collins, USA.

Gotelli, N. J. 2001. A primer of ecology. Third edition. Sinauer Associates, Sunderland, Massachusetts, USA.

Hayes, C. L. , E. S. Rubin, M. C. Jorgensen, R. A. Botta, and W. M. Boyce. 2000. Mountain lion predation of bighorn sheep in the Peninsular Ranges, California. The Journal of Wildlife Management 64:954-959.

Johnson, H. E., M. Hebblewhite, T. R. Stephenson, D. W. German, B. M. Pierce, and V. C. Bleich. 2013. Evaluating apparent competition in limiting the recovery of an endangered ungulate. Oecologia 171:295-307.

Jones, F. L. 1954. The Inyo-Sierra deer herds. A final area report. Federal Aid in Wildlife Restoration, Project California W41-R, Big Game Studies.

Kaplan, E. L., and P. Meier. 1958. Nonparametric estimation from incomplete observations. Journal of the American Statistical Association 53:448-457.

Kauffman, M. J., J. E. Meacham, H. Sawyer, A. Y. Steingisser, W. J. Rudd, and E. Ostlind, editors. 2018. Wild Migrations: Atlas of Wyoming's Ungulates. Oregon State University Press, Corvalis, Oregon.

Kirkpatrick, R. L. 1980. Physiological indices in wildlife management. Pages 105-107 in S. D. Schemnitz, editor. Wildlife management techniques manual. Fourth Edition. The Wildlife Society, Washington D.C., USA.

Krausman, P. R., J. J. Hervert, and L. L. Ordway. 1985. Capturing deer and mountain sheep with a net-gun. Wildlife Society Bulletin 13:71-73.

Kucera, T. E. 1988. Ecology and population dynamics of mule deer in the eastern Sierra Nevada California. Ph.D. dissertation, University of California, Berkeley.

Kucera, T. E. 1992. Influences of sex and weather on migration of mule deer in California. Great Basin Naturalist 52:122-130.

Kucera, T. E. 1997. Fecal indicators, diet, and population parameters in mule deer. Journal of Wildlife Management 61:550-560.

Kunkel, K. E., T. K. Ruth, D. H. Pletscher, and M. G. Hornock. 1999. Winter prey selection by wolves and cougars in and near Glacier National Park, Montana. Journal of Wildlife Management 63:901-910.

Monteith, K. L., V. C. Bleich, T. R. Stephenson, and B. M. Pierce. 2009. Population dynamics of mule deer in the eastern Sierra Nevada: implications of nutritional condition. DHMPIP 608.08 Post-Completion Report, California Department of Fish and Game.

Monteith, K. L., V. C. Bleich, T. R. Stephenson, B. M. Pierce, M. M. Conner, R. W. Klaver, and R. T. Bowyer. 2011. Timing of seasonal migration in mule deer: effects of climate, plant phenology, and life-history characteristics. Ecosphere 47:1-34.

Monteith, K. L., T. R. Stephenson, V. C. Bleich, M. M. Conner, B. M. Pierce, and R. T. Bowyer. 2013. Risk-sensitive allocation in seasonal dynamics of fat and protein reserves in a long-lived mammal. Journal of Animal Ecology 82:377-388.

Monteith, K. L., V. C. Bleich, T. R. Stephenson, B. M. Pierce, M. M. Conner, J. G. Kie, and R. T. Bowyer. 2014. Life-history characteristics of mule deer: effects of nutrition in a variable environment. Wildlife Monographs 186:1-62.

Morano, S., K. M. Stewart, T. Dilts, A. Ellsworth, and V. C. Bleich. 2019. Resource selection of mule deer in a shrub-steppe ecosystem: influence of woodland distribution and animal behavior. Ecosphere 10(11):e02811.

Morris, W. F., and D. F. Doak. 2002. Quantitative conservation biology: theory and practice of population viability analysis. Sinauer Associates, Sunderland, Massachusetts, USA.

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

Pfeiler, S. S., M. M Conner, J. S. McKeever, R. S. Crowhurst, C. W. Epps, G. P. Mulcahy, E. P. Meredith, and T. R. Stephenson. 2021. Estimating abundance of desert mule deer using fecal DNA-based capture-recapture. Western North American Naturalist 81:40-53.

Piasecke, J. R. and L. C. Bender. 2009. Relationships between condition of adult females and relative carrying capacity for Rocky Mountain elk. Rangeland Ecology and Management 62:145-152.

Pierce, B. M., V. C. Bleich, and R. T. Bowyer. 2000. Selection of mule deer by mountain lions and coyotes: effects of hunting style, body size, and reproductive status. Journal of Mammalogy 81:462-472.

Pierce, B. M., R. T. Bowyer, and V. C. Bleich. 2004. Habitat selection by mule deer: forage benefits or risk of predation? Journal of Wildlife Management 68:533-541.

Pierce, B. M., V. C. Bleich, K. L. Monteith, and R. T. Bowyer. 2012. Top-down versus bottom-up forcing: evidence from mountain lions and mule deer. Journal of Mammalogy 93:977-988.

Pollock, K. H., S. R. Winterstein, C. M. Bunck, and P. D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53:7-15.

Ripple, W. J. and R. L. Beschta. 2008. Trophic cascades involving cougar, mule deer, and black oaks in Yosemite National Park. Biological Conservation 141:1249-1256.

Schaefer, R. J., S. G. Torres, and V. C. Bleich. 2000. Survivorship and cause-specific mortality in sympatric populations of mountain sheep and mule deer. California Fish and Game 86:127-135.

Schaub, M., O. Gimenez, A. Sierro, and R. Arlettaz. 2007. Use of integrated modeling to enhance estimates of population dynamics obtained from limited data. Conservation Biology 21:945-955.

Schmidt, R. H. 1991. Gray wolves in California: their presence and absence. California Fish and Game 77:79-85.

Shilling, F. M. and D. P. Waetjen. 2015. Wildlife-vehicle collision hotspots at US highway extents: scale and data source effects. In: Seiler A, Helldin J-O (Eds) Proceedings of IENE 2014 International Conference on Ecology and Transportation, Malmö, Sweden. Nature Conservation 11:41-60. oi:10.3897/natureconservation.11.4438

Shilling, F. M., C. Denney, and D. Waejten. 2019. Automated analysis of wildlife-vehicle conflict hotspots using carcass and collision data. University of California Davis, Research Report no. UCD-17-13: doi: 10.7922/G27D2SCT

Shirkey, N., B. Munk, J. McKeever, T. Taylor, M. Morrison, and T. R. Stephenson. 2019. Post-capture mortalities in Rocky Mountain mule deer associated with traumatic coccygeal. Presented at WDA Conference.

Smith, D. G., T. D. Drummer, K. M. Murphy, D. S. Guernsey, and S. B. Evans. 2004. Winter prey selection and estimation of wolf kill rates in Yellowstone National Park, 1995-2000. The Journal of Wildlife Management 68:153-166.

Stephenson, T. R., B. C. Bleich, B. M. Pierce, and G. P. Mulcahy. 2002. Validation of mule deer body composition using in vivo and post-mortem indices of nutritional condition. Wildlife Society Bulletin 30:557-564.

Stephenson, T. R., D. W. German, E. F. Cassirer, D. P. Walsh, M. E. Blum, M. Cox, K. M. Stewart, and K. L. Monteith. 2020. Linking population performance to nutritional condition in an alpine ungulate. Journal of Mammalogy 101:1244-1256.

Stephenson, T. R., P. Johnston, C. P. Massing, D. W. German, K. Anderson, and L. E. Greene. 2022. Sierra Nevada Bighorn Sheep Recovery Program Annual Report 2021-22. California Department of Fish and Wildlife, Bishop, CA.

Stewart, A. M. 2022. Comparing fecal DNA capture-recapture methods to traditional mark-resight methods for estimating abundance of mule deer on winter ranges. Master's Thesis, Utah State University.

Stewart, A. M., M. M. Conner, J. S. McKeever, A. Ellsworth, R. S. Crowhurst, C. W. Epps, and T. R. Stephenson. 2022. Comparing fecal DNA capture-recapture to mark-resight for estimating abundance of mule deer on winter ranges. The Journal of Wildlife Management 87(2):e22350.

Taylor, D. P. 2023. Quantifying the impacts and assessing the permeability of a divided four-lane highway on migratory mule deer. Master's Thesis, Utah State University.

Taylor, T. 1988. Migration and seasonal habitats of the Casa Diablo deer herd. The Casa Diablo deer herd study. California Department of Fish and Game, Bishop, CA. 49pp.

Taylor, T. J. 1991. Ecology and productivity of two interstate deer herds in the eastern Sierra Nevada. East Walker and Mono Lake deer study. Hill Bill Contract #7027. California Department of Fish and Game. 154pp.

Taylor, T. J. 1996. Condition and reproductive performance of female mule deer in the central Sierra Nevada. Cal Fish and Game 82(3):122-132.

Taylor, T. J. 1997. West Walker deer herd study, Final Report. 1992-1995. Report to the CA Fish and Game. DHMPIP Contract FG-1230.

United States Fish and Wildlife Service (USFWS). 2007. Recovery plan for the Sierra Nevada bighorn sheep. United States Fish and Wildlife Service, Sacramento, California.

Waetjen, D. P. and F. M. Shilling. 2017. Large extent volunteer roadkill and wildlife observation systems as sources of reliable data. Frontiers in Ecology and Evolution 5:1-10. doi:10.3389/fevo.2017.00089.

Wehausen, J. D. 1996. Effects of mountain lion predation on bighorn sheep in the Sierra Nevada and Granite Mountains of California. Wildlife Society Bulletin 24:471-479.

White, G. C., A. F. Reeve, F. G. Lindzey, and K. P. Burnham. 1996. Estimation of mule deer winter mortality from age ratios. The Journal of Wildlife Management 60:37-44.

White, G. C. and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46:(Supplement) 120-139.

White, G. C., K. P. Burnham, and D. R. Anderson. 2001. Advanced features of program Mark. Pages 368-377 in R. Field, R. J. Warren, H. Okarma, and P. R. Sievert, editors. Land and people: Priorities for the 21st century: Proceedings from the 2nd international wildlife management congress. The Wildlife Society, Bethesda, Maryland, USA.

White, G. C., and B. C. Lubow. 2002. Fitting population models to multiple sources of data. Journal of Wildlife Management 66:300-309.

Literature Citation Should Read as Follows:

J. S. McKeever, C. P. Massing, D. W. German, M. M. Conner, D. P. Taylor, and T. R. Stephenson. 2023. Long-term mule deer population monitoring in the eastern Sierra 2014-2022. California Department of Fish and Wildlife, Bishop, CA.

Appendix 1: Study Area

The East Sierra Deer Conservation Unit (ESDCU) encompasses approximately 12,033 km^2 (4,646 mi^2), of which 94% is public land and 6% is private land. The primary public landowners are the US Forest Service and the US Bureau of Land Management (BLM). The ESDCU contains two national forests, the Inyo National Forest and the Humboldt-Toiyabe National Forest. The Inyo National Forest covers 1,903,381 acres on the Mt. Whitney, White Mountain, Mammoth Lakes, and Mono Lake Ranger Districts. Approximately 1,000,000 acres of the Inyo National Forest is included within designated wilderness. The Bridgeport District of Humboldt-Toiyabe National Forest comprises 375,721 acres in northern Mono County of which 99,538 acres is designated wilderness. The BLM Bishop field office manages approximately 750,000 acres of federal public lands in the ESDCU. In addition, CDFW manages 21,955 acres of state lands, of which 13,783 acres were established as wildlife areas for the primary purpose of protecting mule deer winter and transition range. A detailed description can be found in California's Wildlife Action Plan (CDFW 2015).

Within the ESDCU, there are three deer hunt zones (Figure 1; X12, X9a, and X9b); each hunt zone has an area-specific archery hunt (A20, A16, and A17, respectively); additionally, there are three late-season hunts (G39 and J12 in X9a, and G3 in X9b). The ESDCU has been managed not only at the hunt zone level but also monitored by individual deer herds, which are the following: WWR, EWR, and MLK in hunt zone X12, CDB and RVD in hunt zone X9a, and GDL in hunt zone X9b. Hunt periods begin in mid-August with the area-specific archery hunts. General season hunts begin in October and late-season hunts begin in December. During the fall, some WWR, EWR, MLK, and CDB mule deer migrate into Nevada and occupy Deer Management Areas 201, 202, 204, and 206 within Nevada.

Detailed descriptions of each deer herd follow, beginning from south to north.

Goodale Deer Herd

The Goodale deer herd (GDL) occupies areas within Fresno, Inyo, and Tulare Counties. This area is bounded by Bishop Creek to the north, Cottonwood Creek to the south, and US Highway 395 to the east. The western boundary is not well defined but is generally between the 2,100 to 2,400 m level on the western slope of the Sierra Nevada. There is a gradient of annual precipitation in the Owens Valley resulting in drier conditions to the south. Precipitation occurs primarily between October and February as rain and snow in the valley, and as snow in the mountains. The average annual precipitation is 14.33 cm at the Bishop Airport in the north, and 7.57 cm along the shore of Owens Lake in the south. Precipitation generally increases with elevation and averages between 38 and 51 cm at 2,740 to 3,050 m, respectively. The Goodale winter range exists primarily between 1,370 and 2,440 m in elevation and supports Great Basin-type vegetation. The winter range contains the sagebrush scrub and pinyon-juniper plant communities described by Munz (1968). This includes sagebrush (*Artemisia* spp.), bitterbrush (*Purshia tridentata*), rabbitbrush (*Chrysothamnus nauseosus*), buckwheat (*Eriogonum* spp.), Mormon tea (*Ephedra nevadensis*), and bunch grasses (*Stipa* spp., *Oryzopsis* spp., *Elymus* spp.). Pinyon pine (*Pinus monophyla*) occurs at the higher winter range elevations. Summer ranges east of the Sierra crest are limited, although some areas, such as Bishop Creek, Coyote Flat, and Birch and Kidd mountains, provide significant summer range. Summer ranges on the western slope include high sub-alpine basins and lower timbered areas and small meadows. Major plant communities on the summer range are subalpine forest, alpine fell-fields, and sagebrush scrub (Munz 1968).

For management purposes, the Goodale herd has been divided into northern and southern sub-herds. The northern portion extends from Bishop Creek to Taboose Creek for about 22 miles. The southern portion extends from Taboose Creek to Cottonwood Creek for about 38 miles. Perhaps the greatest difference between the two sub-herds is that most deer that winter in the southern portion summer over the crest of the Sierra Nevada Mountains, within the Sequoia and Kings Canyon National Parks. These deer are not available to hunters during the X9b hunt season, resulting in higher buck:doe ratios in the southern sub-herd than in the northern sub-herd, where a larger percentage of the population is exposed to hunting pressure.

Round Valley Deer Herd

Round Valley (37.41722N, -118.59630W) is located on the east side of the Sierra Nevada in California in Inyo and Mono Counties. Round Valley is bounded by US Highway 395 to the east, the prominent features of Mt. Tom and Wheeler Ridge to the west, and to the south by the Buttermilk Boulder area. Approximately 18.3 km^2 of Round Valley is open pasture, and 3.2 km^2 is low density residential housing (Monteith et al. 2011). Annual precipitation in Round Valley is variable and seasonal, ranging from 5.3 to 25.2 cm with most occurring in winter (Pierce et al. 2012). Vegetation in Round Valley is dominated by big sagebrush, bitterbrush, rabbitbrush, blackbrush (*Coleogyne ramosissima*), desert peach (*Prunus andersonii*), and Mormon tea, typical of sagebrush steppe (Pierce et al. 2004). Riparian areas also support willow (*Salix* spp.), rose (*Rosa* spp.), and water birch (*Betula occidentalis*; Pierce et al. 2004). Many mule deer inhabiting Round Valley during winter migrate to high elevations (>2,200 m) on the west side of the Sierra Nevada for the summer months (Monteith et al. 2011). Deer graze in high mountain meadows during summer and migrate back down to Round Valley in fall (Monteith et al. 2011).

In 1991, the Round Valley deer herd (RVD) population wintering in Round Valley hit a low of 939, down from 5,978 animals in 1985 (Kucera 1988, Pierce et al. 2012). By 1999 the deer population had risen to 2,165 (Pierce et al. 2012). The population decline was coincident with a severe drought that occurred from 1987-1990, when water content of winter snowpack was 27% of the long-term average (Pierce et al. 2012).

Casa Diablo Deer Herd

The Casa Diablo deer herd (CDB) winter range encompasses approximately 480 km^2 in eastern Mono County, CA and western Esmeralda County, NV (37.7646N, -118.4833W) on land administered by the BLM and the Inyo National Forest (Taylor 1988). The winter range is bounded by the Pizona Range to the north, the Owens River gorge to the south, the White Mountains to the east, and the Glass Mountains to the west. The landscape is characterized by several small, rugged mountain ranges interspersed with undulating valleys and plateaus dissected by shallow canyons and arroyos. Prominent land features include Antelope Peak, Marble Creek, Blind Springs Hill, Banner Ridge, the Benton Range, Yellow Jacket Valley, Benton Valley, Hammil Valley, Chidago Flat, Casa Diablo Mountain, and the Volcanic Tablelands. US Highway 6 bisects the eastern portion of the winter range in a north to south direction. Elevations range from 1,600 m along the US Highway 6 corridor in Hammil Valley to over 2,600 m on Banner Ridge. Climate in nearby Benton, CA (1,642 m) is characterized by hot, dry summers and cold, dry winters. Temperatures average a low of -16˚ C in January and a high of 34.1˚ C in August. Annual precipitation in Benton, CA averages 19.07 cm and water is limited to valley bottoms and widely dispersed mountain springs. Major plant communities on the winter range include sagebrush steppe and pinyon-juniper (*Juniperus occidentalis*) woodland. Common plants of the sagebrush steppe include mountain big sagebrush, bitterbrush, rabbitbrush, desert peach, and buckwheat. At some locations, such as the Marble Creek alluvial fan, Chidago Flat, and the Yellow Jacket Valley, shrub stands are dominated almost entirely by bitterbrush. Pinyon-juniper woodland occurs primarily on the steeper, rocky slopes of Casa Diablo Mountain, Banner Ridge, and the Benton Range. The winter range encompasses one federal Horse Management Area (HMA), the Montgomery Pass HMA, located along the CA-NV boarder. Deer leave the winter range in March and April and migrate to high elevation summer range located in Mono and Tuolumne counties on east and west slopes of the Sierra Nevada, including Yosemite National Park.

Mono Lake Deer Herd

The Mono Lake deer herd (MLK) is an interstate deer herd that occupies summer range in California and winter and spring range in both California and Nevada. The winter range encompasses some 230 km² in Mineral County, NV and is located between approximately 20 km and 55 km south of Hawthorne, NV, in the Excelsior and Wassuk mountain ranges. Land is largely public and administered by the BLM and Humboldt-Toiyabe National Forest. The Excelsior and Wassuk mountains are adjacent ranges that originate from the Anchorite Hills approximately 30 km north of Mono Lake. The two ranges are oriented in a north-south direction and are divided by a large, sandy flat, Whiskey Flat, which extends from Anchorite Pass, north toward Hawthorne and Walker Lake. Nevada Highway 359 traverses the west side of Whiskey Flat and is the main transportation corridor in the area. Elevations range from 1,875 m on Whiskey Flat to 2,900 m on Powell Mountain in the Wassuk Range. Topography is variable, ranging from steep and rugged in the Wassuk and Excelsior mountains, to gently rolling on Whiskey Flat. Annual precipitation in nearby Hawthorne, NV averages 11.5 cm and water is limited to widely dispersed mountain springs located in the Wassuk Range and Excelsior Mountains. Vegetation on the winter range is typical of a cool, arid climate and is comprised of sagebrush-steppe, desert scrub, and pinyon-juniper woodland (Taylor 1991). Dominant shrubs of the sagebrush steppe include big sagebrush, Wyoming big sagebrush (*Artemisia tridentata wyomingensis*), and bitterbrush. The desert scrub community, on Whiskey Flat and in the Garfield Hills is dominated by shadscale (*Atriplex* spp.), greasewood (*Sarcobatus* spp.), and rubber rabbitbrush (*Ericameria nauseosa*). Pinyon-juniper woodland occurs primarily on steep, rocky slopes in the Wassuk and Excelsior ranges. Two BLM HMAs occur on the winter range, including the Wassuk HMA and the Garfield Flat HMA. Deer leave the winter range in March and April and migrate to high elevation summer range located on both the east and west slopes of the Sierra Nevada in Mono, Alpine, and Tuolumne counties, including Yosemite National Park and the Bodie Hills.

East Walker Deer Herd

The East Walker deer herd (EWR) is an interstate deer herd that occupies summer range in California and winter and spring range in both California and Nevada (Taylor 1995). The winter range encompasses approximately 350 km² in Lyon and Mineral counties, NV, on land administered by the BLM and the Humboldt-Toiyabe National Forest. The winter range is bounded by the Bodie Hills to the south, the Pine Grove Hills and Bald Mountain to the north, and the Sweetwater Mountains to the west. Topography to the east of the winter range is not well defined and is characterized by steep, rugged, uplifted ridges capped by rock outcroppings (Taylor 1991). Elevations range from 1,800 m along the East Walker River corridor to 2,970 m on Bald Mountain in the Pine Grove Hills. Annual precipitation in nearby Yerington, NV, averages 13 cm. Several tributary streams drain north from the Bodie Hills and east from the Sweetwater Mountains into the East Walker River, which flows north through the center of the winter range from the Sierra Nevada. Major plant communities include sagebrush steppe, desert scrub and pinyon-juniper woodland. Dominant plants of the sagebrush-steppe community include big sagebrush, Wyoming big sagebrush, low sagebrush, and bitterbrush. The desert scrub community occurs on the ridges and flats adjacent to the East Walker River and is dominated by four-wing saltbush (*Atriplex canescens*), Mormon tea, greasewood, and rubber rabbitbrush. Pinyon-juniper woodland occurs primarily on steep, rocky slopes located to the north, south, and west of the winter range in the Pine Grove Mountains, Bodie Hills, and Sweetwater Mountains (Taylor 1991). Deer leave the winter range in March and April and migrate to high elevation summer range located in the Bodie Hills, Sweetwater Mountains, and on the east and west slopes of the Sierra Nevada, including Yosemite National Park and the Emigrant Wilderness, CA.

West Walker Deer Herd

The West Walker deer herd (WWR) is an interstate deer herd that occupies summer range in California and winter and spring range in both California and Nevada. The winter range encompasses approximately 600 km² in Mono County, CA and Douglas County, NV, and is bounded by the Pine Nut Mountains to the north, the Sweetwater Mountains to the south, Slinkard Valley to the west and Smith Valley, NV to the east. Public land on the winter range is administered by the BLM, the Humboldt-Toiyabe National Forest, and CDFW. Topography is characterized by three large, gently rolling valleys surrounded by steep, rocky, mountainous terrain dissected by deep canyons. Antelope Valley, the largest of the three valleys, comprises approximately 312 km² at an average elevation of 1,517 m. Annual precipitation in Antelope Valley averages 40.1 cm. Agriculture is the primary land use and includes cattle and sheep ranching and alfalfa hay cropping. The major geographical feature in Antelope Valley is the West Walker River, which flows north from the Sierra Nevada to Topaz Lake, a reservoir situated on the CA-NV boarder that provides water for Yerington, NV. Several small communities, including the towns of Walker, Coleville, and Topaz, are located along the US Highway 395 corridor, which traverses the western edge of the valley in a north to south direction. West of Antelope Valley and the US Highway 395 corridor are the CDFW Slinkard Valley and Little Antelope Valley Wildlife Areas, which were created in the early 1980s for the protection of mule deer winter range habitat. The two wildlife areas encompass approximately 47 km² at elevations ranging from 1,765-1,920 m. Sagebrush steppe is the dominant plant community in the wildlife areas. Common plants include big sagebrush, bitterbrush, rabbitbrush, and desert peach. Other plant communities include pinyon-juniper woodland, willow riparian, mixed conifer forest, annual (invasive) grassland (*Bromus tectorum*), and irrigated pasture. Other major geographical features on the winter range include Wild Oat Mountain, located north of Topaz Lake, the Gray Hills situated east of Topaz Lake, and the Wellington Hills, a small north-to south-oriented mountain range situated between Antelope Valley and Smith Valley, NV. Deer migrate from the winter range in March and April and migrate to high elevation summer range located in the Sweetwater Mountains and on both the east and west slopes of the Sierra Nevada, in Mono and Alpine counties, CA, on the Humboldt-Toiyabe and Stanislaus National Forests.

Appendix 2: Model-Averaged Survival

Initially, to estimate survival for the Integrated Population Model (IPM), we used a model averaging approach using Program MARK, in which we constructed all possible combinations of models with herd, season, and year effects and then used model-averaged estimates of survival. This powerful approach smoothed the estimates and was not fully capturing the yearly fluctuations of survival. We felt in the beginning stage (few years) of the IPM it was important to model the IPM with yearly fluctuations, thus we chose to use Kaplan Meier. Here, we detail methods for estimating survival from known-fate models in Program MARK (White and Burnham 1999, 2001), which is an extension of the Kaplan Meier model (Kaplan and Meier 1958) and accommodates staggered entry and exit of marked animals (Pollock et al. 1989).

For survival, the goal was to have robust and reasonably precise estimates, as detection of small changes in survival that can lead to large declines in population size require prohibitively large numbers of collared deer. We designed this study to detect changes in population size and have survival estimates with a coefficient of variation (CV) of approximately 0.10. Sample size calculations were based on observed low survival rates (Pierce et al. 2012, Monteith et al. 2013). At an average survival as low as 0.77, 30 marks in the population provided a CV of 0.10 (Table A1). However, survival is only one component of the IPM, and we determined the number of collars in each herd based on the highest number required for the different data sources collected (e.g., composition and recruitment, survival, and population size), and mark-resight sample size simulation determined we needed ≥60 deer collared in each herd.

Table A1. Optimal allocation when adult female survival is 0.80 (a) and 0.77 (b). Grey row indicates between 25 (a) and 30 (b) collars will give a CV of 0.10.

a

No. of Collars	Survival	SE	CV
20	0.800	0.089	0.112
21	0.800	0.087	0.109
22	0.800	0.085	0.107
23	0.800	0.083	0.104
24	0.800	0.082	0.102
25	0.800	0.080	0.100
26	0.800	0.078	0.098

b

No. of Collars	Survival	SE	CV
20	0.770	0.094	0.122
25	0.770	0.084	0.109
30	0.770	0.077	0.100
31	0.770	0.076	0.098
32	0.770	0.074	0.097
33	0.770	0.073	0.095
34	0.770	0.072	0.094
35	0.770	0.071	0.092
36	0.770	0.070	0.091

There were 3 seasonal study periods per year: January – mid-April (winter), mid-April – July (spring), and August – December (fall). These periods also coincided with the timing of CDFW management needs. The seasonal intervals were of slightly unequal length from year-to-year; we standardized survival (S) estimates to a 4-month period (e.g., S = 0.9 is the probability an animal survived for 4 months) using unequal time intervals in Program MARK (White et al. 2001). We conducted survival analyses separately for herds in the southern (CDB, RVD, and GDL) and northern (WWR, MLK, and EWR) areas.

Because we were primarily interested in robust estimates of annual survival for use in IPM models, we used the all-combinations approach (Doherty et al. 2012). Using this approach, we constructed all possible combinations of models with herd, season, and year effects and then used model-averaged estimates of survival. Specifically, we constructed a series of known-fate models in which survival was constant by herd, season and/or year, and in which survival varied by herd, and categorically by season and/or year in all possible additive and multiplicative combinations (Table A2). For the top model(s) (models within 2 ΔAICc of the model with the lowest AICc), we also replaced categorical year (or added if there was no year effect) as a linear trend in survival by year (Table A2). We used Akaike's Information Criterion adjusted for small sample sizes (AICc) and normalized AICc weights (w_i) to rank models (Burnham and Anderson 2002) and for model averaging. All reported annual and seasonal survival estimates were model-averaged. Annual survival was for a calendar year, 01 January-31 December, and was calculated by multiplying the 3 seasonal period estimates. Variance of the annual survival estimate was calculated using the Delta method (Seber 1982).

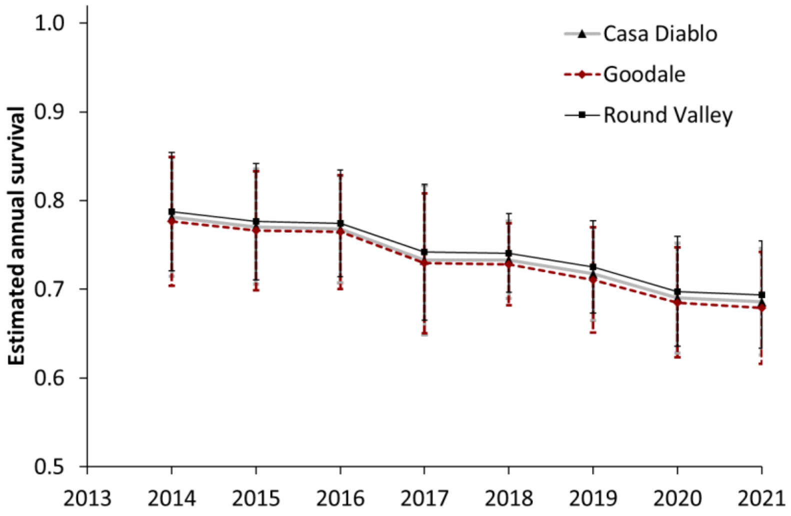
Top models for survival included season for herds in the southern and northern areas (Table A2), although the seasonal effect was much less pronounced in the southern herds (Figure A2). The southern herds showed little difference in survival by herd and there was a significant negative trend in annual survival during the study (Figure A1). The top model for the southern herds had a significant negative trend on annual survival (slope = -0.032, 95% CI -0.054,-0.011, $p = 0.002$). Based on model averaged estimates, survival decreased approximately 12% from 2014 through 2021, starting at 0.79 and decreasing to 0.69 for the 3 herds.

There was no trend in annual survival for the northern herds; survival was stable or slightly (non-significantly) increasing (Figure A1). While annual survival was constant, the seasonal pattern of survival was variable; survival was higher for August-December, and survival was similar and lower for January-April and May-July (Figure A2). Survival was also lower for the MLK herd compared to the EWR and WWR herds (Figures A1 and A2). Average annual survival was approximately 0.58 for the MLK herd, which was 14 to 19% lower than average survival for the EWR (0.71) and WWR (0.67) herds respectively.

Table A2. Top-ranked models for known-fate survival analysis of mule deer in southern herds, 2014-2021, and northern herds, 2017-2021, eastern slope of the Sierra Nevada, Inyo and Mono Counties, California. Only models with weights (w_i) ≥ 0.01 are shown.

Model[a]	*K*	ΔAIC_c	w_i	AICc	*Deviance*
Southern					
S(season + yrlintrend)	4	0.00	0.33	2331.71	76.66
S(year)	8	0.46	0.26	2332.17	69.09
S(herd + season + yrlintrend)	6	2.20	0.11	2333.91	74.85
S(herd + year)	10	2.56	0.09	2334.27	67.17
S(season × yrlintrend)	6	3.41	0.06	2335.12	76.06
S(season + year)	10	3.57	0.06	2335.28	68.19
S(.)	1	4.15	0.04	2335.86	86.83
S(herd)	3	6.38	0.01	2338.09	85.05
S(season)	3	7.33	0.01	2339.04	86.00
Northern					
S(herd + season)	5	0.00	0.50	1068.39	30.83
S(herd + season + yrlintrend)	6	1.38	0.25	1069.77	30.19
S(herd)	3	4.20	0.06	1072.59	39.06
S(herd + season + year)	9	4.28	0.06	1072.67	27.03
S(season)	3	5.04	0.04	1073.43	39.90
S(herd + (season × yrlintrend)	8	5.28	0.04	1073.67	30.06
S(herd × season)	9	5.90	0.03	1074.29	28.65
S(herd + year)	7	8.92	0.01	1077.31	35.72
S(season + year)	7	9.13	0.01	1077.52	35.93

[a] Season and year were modeled as categorical variables, and yrlintrend was a slope to model an annual linear trend on survival.



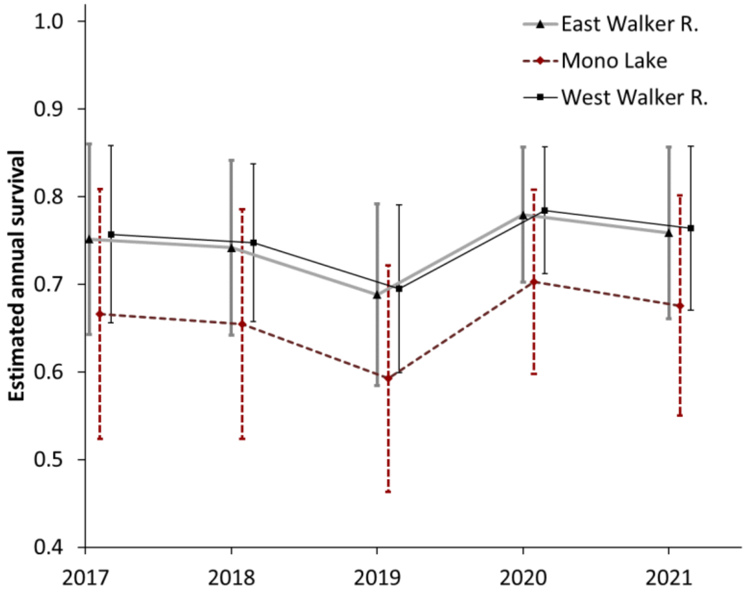
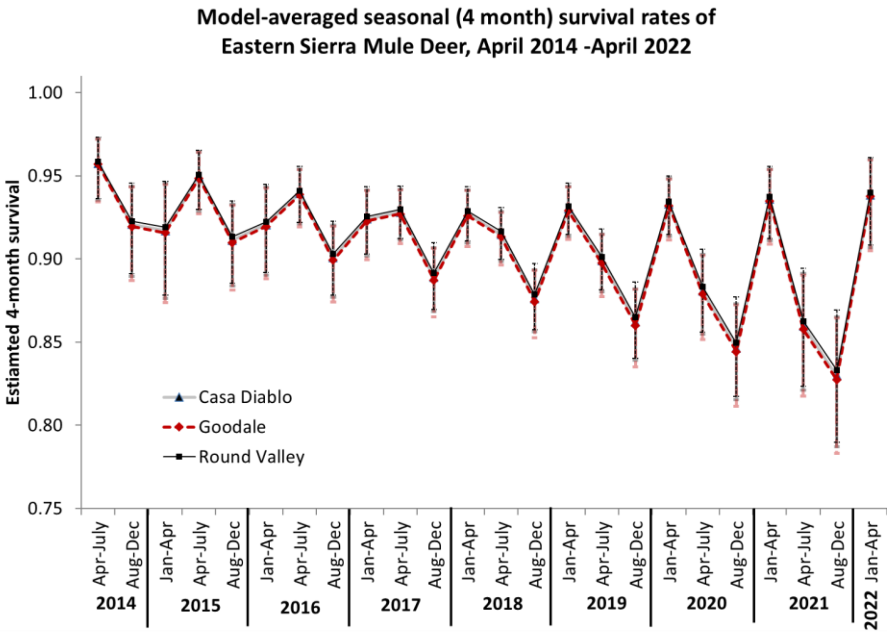


Figure A1. Model-averaged annual (January-December) survival rates (±95% CI) for collared female mule deer in the southern herds 2014-2021 (top) and the northern herds 2017-2021 (bottom) in the eastern Sierra, California.



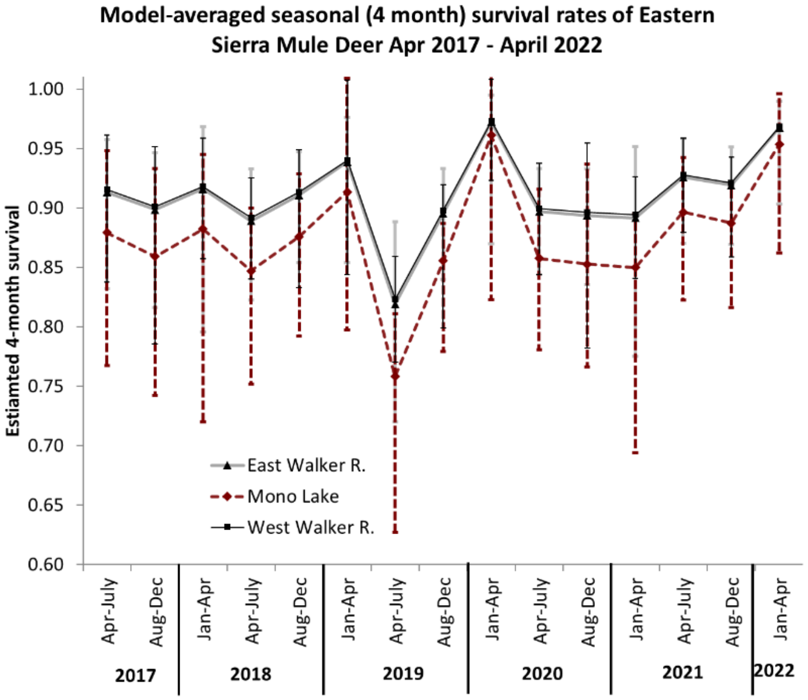


Figure A2. Model-averaged seasonal (4 month) survival estimates for mule deer in the eastern Sierra, California in the southern herds 2014-2022 (top) and the northern herds 2017-2022 (bottom).

Appendix 3: Integrated Population Model (IPM)

The IPM was a discrete time stage-based population model with 2 stages: fawns and adults. Data included annual estimates of recruitment (i.e., January fawn:adult ratios), adult and fawn survival, and harvest, which were used in the projection part of the IPM model. The model also integrated male:female ratios and mark-resight estimates of abundance, which were collected annually for RVD, but only every 4-5 years for the remaining herds. We estimated adult survival using a Kaplan Meier staggered-entry estimator (Kaplan and Meier 1958, Pollock et al. 1989), comparing the number of known live deer to known dead deer on monthly iterations.

We did not collect field data on adult male survival or fawn survival. For adult survival, we assumed adult male survival was equal to adult female (field-based) survival. Fawn survival was estimated using January and March composition survey data for fawn:adult ratios following the methods of White et al. (1996). In the RVD IPM, predicted fawn survival was constrained to be lower than adult survival (fawn survival ≤ 95% of adult survival) and above 0.02.

Mule deer population dynamics are much more complex than the model. However, collection of additional data (e.g., survival by sex, survival of yearlings, etc.) is required for a more complicated model. Thus, the model is a reasonable trade-off between data that can be feasibly collected and what is needed to predict mule deer populations for management purposes.

We modeled the population in yearly time steps, 01 January-31 December. This time step is referenced to annual composition surveys and mark-resight surveys and follows after the end of harvest (Figure A3). We assumed a 50:50 sex ratio at birth and until 6 months of age (r_{sex}); fawns are not differentiated from birth (in approximately early June) through January, when composition surveys are conducted and fawns are recruited into the population. Consequently, the model has 3 population segments: fawns (age 6-12 months; labeled as J or juveniles), adult females (≥1 year old, labeled as AF), and adult males (≥1 year old, labeled as AM). Population sizes (N) were projected forward from 01 January of year *t* to 01 January of year *t*+1 using equations:

$$N_{J,t+1} = N_{AF,t+1} \times R_{t+1} - H_{J,t}$$
$$N_{AF,t+1} = N_{AF,t} \times S_{A,t} + N_{J,t} \times r_{sex} \times S_{J,t} - H_{AF,t}$$
$$N_{AM,t+1} = N_{AM,t} \times S_{A,t} + N_{J,t} \times (1-r_{sex}) \times S_{J,t} - H_{AM,t}$$

Where:
R = January recruitment of juveniles into the population, estimated by the fawn:doe ratio (juvenile:adult female ratio)
H = Number of deer harvested in fall hunts
S_A = Survival of adults from year t to year t+1 (January to the following January)
$S_J = S_{6\text{-}12mo,t} \times S_{A,t}^{0.5}$ and $S_{6\text{-}12mo,t}$ is survival from January-June for fawns, and $S_{A,t}^{0.5}$ is adult survival for a 6-month period (July-December).

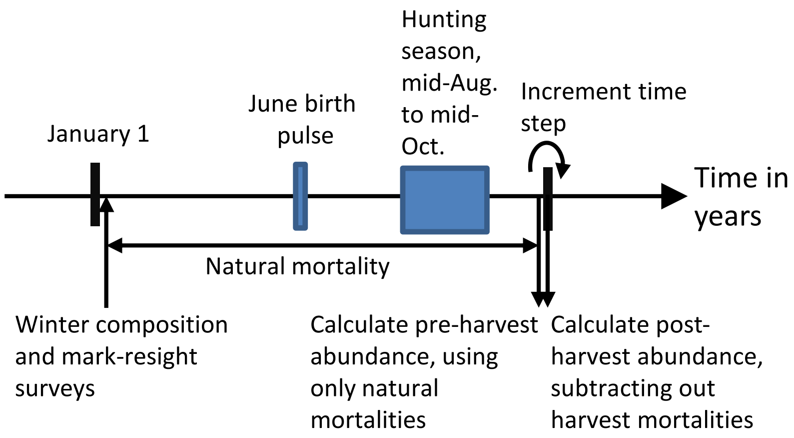


Figure A3. A visual depiction of the timeline used for population models for eastern Sierra mule deer herds.

Appendix 4: Survey Effort

When deer are at lower elevations, they are more concentrated on winter and spring ranges and the comparative ease of access enables more complete and accurate counts, classifications, and successful capture events. During March-April, mule deer migrate to and concentrate on areas with spring forage green-up before they migrate to higher elevation summer range (Monteith et al. 2011, Taylor 2023). For surveys reported here, we define winter range as the range mule deer occupy during the period of December through early February, and spring range as the range mule deer occupy late February through early April. See Monteith et al. (2011) for detailed analysis of the timing of migration for RVD and Taylor (2023) for information on the other five deer herds.

Table A3. Summarization of all survey effort conducted by method, season, and deer herd from 2014-2022. In some seasons and years, both helicopter and ground surveys were conducted, shown as 2 separate surveys.

Method	Deer Herd	Total Surveys (Winter)	Average Survey Hours (Winter)	Total Surveys (Spring)	Average Survey Hours (Spring)
Ground Survey	WWR	0	--	8	17.5
	EWR	0	--	7	4.7
	MLK	0	--	5	4.4
	CDB	9	17.0	9	15.1
	RVD	9	37.4	9	36.9
	GDL	9	36.4	9	32.2
	Totals/Averages	27	30.3	47	18.5
Helicopter Survey	WWR	4*	3.5**	1	9.9
	EWR	2		1	8.8
	MLK	2		1	16
	CDB	0	---	2	8.0
	RVD	1	1.7	2	6.1
	GDL	1	13.6	2	11.2
	Totals/Averages	10	6.3	9	10

*Primary objective of NDOW helicopter surveys was deer classification within WWR winter range, although some surveys included EWR and MLK winter range.

** Average hours is calculated from two surveys; for all three deer herds, only two surveys had survey hours recorded.

Appendix 5: An Overview of Historical Mule Deer Monitoring in the Eastern Sierra

Mule deer population monitoring in the East Sierra Deer Conservation Unit (ESDCU) has been extensive and long-term (Jones 1954; Kucera 1988; Taylor 1988, 1991, 1996; Bleich and Taylor 1998; Bleich et al. 2006; Monteith et al. 2011; Pierce et al. 2012; Monteith et al. 2014). The California Department of Fish and Game (CDFG) began ongoing winter deer herd composition counts in 1948, in conjunction with annual winter range deer censuses by the US Forest Service which began in 1936 (Jones 1954). To develop management plans for the Buttermilk (RVD) and GDL deer herds, during 1951-1954 Jones (1954) estimated abundance and vital rates, mortality and predation, forage utilization, and migration corridors.

During 1984-1988 and 1993-1994, Kucera (1988, 1992, and 1997) investigated population parameters, including abundance, reproductive parameters, movement, habitat use, forage availability, and diet of the RVD herd. During 1984-1986, 238 mule deer (93 males and 145 females) were captured, radio-collared (44 deer), or uniquely marked and released. In addition, 98 adult females were collected for determination of reproductive parameters and body condition (using kidney-fat index and carcass weight). Kucera (1992) determined migration timing and patterns based on sex of animal and weather. Deer were in poor condition, the population was in steep decline, and it was hypothesized that this was due to drought (Kucera 1988).

During 1986-1987, CDFG captured, marked, radio-collared (28 deer), and released 117 mule deer (86 females and 31 males) from the CDB herd, which winter in eastern Mono County and western NV (Taylor 1988). The study determined the timing and pattern of seasonal migrations and delineated the locations of migration routes and seasonal ranges. Taylor (1988) also identified critical habitats and limiting factors, one of which was water availability on lower elevation winter and spring ranges.

Farther north, during 1984-1987, Taylor (1991) studied the EWR and MLK interstate deer herds, which summer primarily in Mono County and winter in western NV. A total of 162 deer were captured and marked, of which 61 were fitted with radio-collars. The study delineated herd migration routes and seasonal home range use, ascertained diet composition and quality, evaluated female mule deer reproductive parameters in relation to body condition, and determined cause-specific mortality factors. Taylor (1991) concluded that an increased demand for multiple commercial, residential, and recreational uses of public and private lands threatened to fragment critical winter range and reduce habitat connectivity along traditional migration routes.

During 1992-1995, 133 WWR deer were captured, uniquely marked, radio-collared (57 deer), and released by CDFG (Taylor 1997). The study delineated migration routes and seasonal home ranges, evaluated diet composition and quality, and determined cause-specific mortality factors (Taylor 1997). In addition, 58 deer were collected to determine reproductive performance (pregnancy and fetal rates) and physical condition (kidney-fat index and carcass weights). The WWR deer herd was found to be in nutritionally stressed condition and the low herd productivity was hypothesized to be in response to drought-induced changes to habitat quality (Taylor 1996). Taylor (1991, 1997) provided knowledge that serves as the foundation for current WWR, EWR, and MLK mule deer conservation and management.

Beginning in 1954, cause-specific mortality was reported in numerous studies within the ESDCU, and it has been investigated and documented continuously since 1991. Bleich and Taylor (1998) compared cause-specific mortality and survivorship of five mule deer herds in the eastern Sierra during 1986-1994 and found predation to be the leading cause of mortality. Mountain lions (*Puma concolor*) were the primary predator in 90% of the predation mortalities. Pierce et al. (2004) documented that mountain lion movement patterns coincided with the migration of the RVD herd. Further, Pierce et al. (2012) determined the RVD herd was at or near carrying capacity during 1985, and that forage availability and predation were affecting the performance and recovery of the population.

The Round Valley Deer Herd Study began in 1991 and progressed through three project phases. Phase 1 focused on winter range and population performance. Phase 2 (1999-2004) focused on habitat quality, body condition, fawn production, and recruitment costs of reproduction, including biochemical and condition correlates of body condition on mule deer. Phase 3 (2002-2009) focused on population dynamics and the assessment of impacts associated with anthropogenic development.

In Phase 1, population dynamics, survival (adults and fawns from birth to 6 months), habitat selection, cause-specific mortality, and predation were investigated (Pierce et al. 2004, Bleich et al. 2006, Monteith et al. 2014). Winter range conditions, rather than predation, were important factors that determined deer numbers in Round Valley (Pierce et al. 2004).

Phase 2 measured summer range conditions and determined the differential recruitment of fawns by female deer that winter in Round Valley and summer either on the eastside (nonmigratory) or westside (migratory) of the Sierra Nevada, and how habitat affects diet quality, survival, and productivity of adult females, as well as fawn recruitment (Monteith et al. 2014). In 2001, GPS collars were incorporated into the Round Valley project when 10 GPS collars were deployed to determine summer range habitat quality, and birth site transmitters were placed in 20 pregnant females. The intensity of capture and collaring of the RVD herd increased and continued through 2010. Female deer that were non-migratory had a significantly higher rate of successful reproduction and fawn recruitment (Monteith et al. 2014).

With emphasis on timing and cause of mortality for fawns born from migratory or non-migratory females, Phase 3 included vaginal implant transmitters and the collaring of fawns and brought together long-term vital rates in the RVD herd, including body condition and nutrition (measured by ingesta-free body fat, IFBFat), and how they relate to life-history traits, adaptive behavioral strategies, and population performance (Monteith et al. 2011, 2013, 2014). Although vital rates provide critical information regarding the component of the population that is largely responsible for observed trends in population size, the underlying mechanism (e.g., predation, weather, nutrition) that determines the direction of change in vital rates may only be characterized with data on nutritional condition (Bowyer et al. 2005, Parker et al. 2009). Data collected on the population dynamics of mule deer in the eastern Sierra indicated that the survival of adults and recruitment of young was largely determined by bottom-up limitation, and therefore, data on nutritional condition was essential for interpreting population dynamics (Monteith et al. 2009). Body fat of adult females following winter provided an encompassing measure of population health and held predictive value for adult female survival, reproduction, recruitment of young, an index to abundance of males, and overall population trajectory (λ) during the following year (Monteith et al. 2009). Moreover, data on nutritional condition likely holds insight into determining the nutritional carrying capacity of a particular range and thus, realistic objectives for population management (Piasecke and Bender 2009).