

# **CORRELATES OF RECRUITMENT IN MONTANA BIGHORN SHEEP POPULATIONS**



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## EXECUTIVE SUMMARY

Bighorn sheep are undoubtedly one of the most iconic and revered wildlife species in Montana, yet in comparison to most big game animals, relatively little is known about their population dynamics across the state. This lack of knowledge is not due to a lack of care or effort, but more likely results from the fact that this species exists at low population levels, occupies rugged and inhospitable habitat, and is plagued by a complex disease system. Bighorn populations in Montana and across the western United States are threatened by continuing disease epizootics that, despite intense ecological and molecular research effort, are still not well understood. Montana lost 20% of its bighorn population as a result of a series of pneumonia outbreaks from 2008-2011, and many of the affected populations still fail to recruit enough lambs for population recovery to occur. We are at a point in bighorn conservation where a better understanding of population dynamics across Montana is much needed. This initiative is a step towards improving our understanding, laying groundwork that future research can be built upon.

We summarized demographic data from 48 bighorn populations in five ecological regions (eco-regions) across Montana, and used PRISM and NRCS Snotel climate data to summarize climatic conditions for 43 bighorn populations. We used multiple linear regression to test for relationships of recruitment rates (indexed by lamb:ewe ratios) in 22 populations with annual variation in weather conditions and all-age disease die-off events. We found that long-term average lamb:ewe ratios of populations and average precipitation experienced by populations varied substantially within most eco-regions. Annual precipitation amounts varied across eco-regions, but the variation appeared to be mostly explained by October-April precipitation, while all eco-regions received similar amounts of May-September precipitation. After accounting for all-age disease die-off events, average lamb:ewe ratios in the Northwest Montane, Mountain Foothills, and Prairie Mountain Foothills eco-regions were very similar, lamb:ewe ratios in the Southern Mountains eco-region were lower than all others, and lamb:ewe ratios in the Prairie Breaks eco-region were not comparable to others because they were collected in a different season than ratios in the other regions. Average lamb:ewe ratios of individual populations were related to the average number of animals counted in a population, with small populations having lower average lamb:ewe ratios than large populations.

All-age disease die-off events were associated with severely reduced lamb:ewe ratios for at least two years in all populations that experienced die-off events. Recruitment rates in many populations are still affected by recent die-off events, making it impossible to fully assess the recovery pattern of recruitment following die-off events. On average, lamb:ewe ratios of individual populations were predicted to decline by 76% for 2-3 years following all-age disease die-off events, but estimated decline ranged from 44% to over 90%. Strong correlations were detected between lamb:ewe ratios and variation in annual weather conditions in multiple populations. However the nature of the correlations and the weather covariates that lamb:ewe ratios were associated with varied substantially, with no obvious patterns to explain the variation. Findings suggest that bighorn populations within eco-regions and across the state have different factors limiting their recruitment. We suspect that the small population size of many bighorn populations in Montana limits biological insight that can be gained, as accurate demographic data are difficult to collect from small populations and small populations can be largely influenced by unpredictable, chance events.

## INTRODUCTION

Bighorn sheep (*Ovis canadensis*) were historically common across much of North America, occupying rugged habitats from Mexico to the Canadian Rockies (Geist 1971, Shackleton 1999). As the western half of the continent became settled in the 19<sup>th</sup> and 20<sup>th</sup> centuries, many bighorn populations were drastically reduced or extirpated as a result of disease, habitat loss and exploitation (Montana Department of Fish Wildlife and Parks 2010). The current bighorn sheep population (including all subspecies) in North America is likely 50,000-70,000 individuals (Toweill and Geist 1999)

Bighorn sheep in Montana historically occupied a wide array of habitats across much of the state, ranging from alpine expanses to low elevation river breaks (Montana Department of Fish, Wildlife and Parks 2010). Historic numbers are unknown, but likely numbered in the tens of thousands. Bighorn populations in Montana experienced the same struggles throughout the 19<sup>th</sup> and 20<sup>th</sup> centuries as other ungulate populations across North America, and most local populations became extinct. By 1950, an estimated 1,100 bighorns remained in Montana (Montana Department of Fish, Wildlife and Parks 2010). There has been a strong effort to restore bighorn populations in Montana with over 120 translocations in the state between 1940 and 2008 (Picton and Lonner 2008). As a result of these efforts, the bighorn population in Montana increased five-fold to 5000-6000 in 2009, and range has increased to occupy a variety of historic habitat (Picton and Lonner 2008). However, widespread pneumonia epizootics between 2008 and 2011 have likely reduced the current population to between 4000 and 5000 individuals. In comparison with other big game animals in Montana, the restoration of bighorn sheep has been less successful, with many small local populations that are isolated and marginally viable without management intervention. Since 1990 there have been over 40 translocations to augment struggling bighorn populations in Montana, requiring considerable effort and expense. The factors that limit struggling bighorn populations across the state are largely unknown.

Ungulate population dynamics are primarily a function of adult female survival, birth rate, juvenile survival, and immigration/emigration. Population growth is most sensitive to survival of adult females; however, survival rates of adult females are generally consistently high (Gaillard et al. 2000). Bighorn sheep are somewhat of an exception because adult survival can be severely affected by sporadic and unpredictable disease outbreaks. Conversely, birth rates and juvenile survival in ungulates vary significantly on an annual basis and therefore, these vital rates play an important role in population dynamics (Gaillard et al. 2000). Together, birth rate and juvenile survival constitute recruitment. Recruitment in ungulates can be driven by many factors such as disease (Douglas 2001, Monello et al. 2001, Cassirer and Sinclair 2007, Cassirer et al. 2013), habitat quality (Langvatn et al. 1996), density dependence (Douglas and Leslie Jr. 1986, Portier et al. 1998, Forchhammer et al. 1998), predation (Festa-Bianchet et al. 1994, Wehausen 1996,

White and Garrott 2005), and climate (Owen-Smith 1990, Langvatn et al. 1996, Garrott et al. 2003, Brown 2011).

Though many factors can affect ungulate recruitment, climatic variation is the most ubiquitous (Sæther 1997). Climatic variation can affect recruitment rates in many different ways and can be partitioned by their seasonal timing. Weather conditions during the growing season are thought to primarily influence ungulates through their effect on forage quality and quantity, though extreme conditions can have direct effects (Gaillard et al. 2000). Forage quality and quantity affect body size and condition (Albon and Langvatn 1992, Van Soest 1994, White 1983, Cook et al. 1996, Cook et al. 2001), which in turn has been shown to affect fecundity rates and juvenile survival through winter (Sæther 1997, Singer et al. 1997, Cook et al. 2001, Cook et al. 2004). Though both forage quantity and quality almost certainly can impact ungulate body condition, there is evidence that access to high quality forage during the growing season is especially important for weight gain in northern ungulates (White 1983, Albon and Langvatn 1992, Van Soest 1994, Langvatn et al. 1996). A multiplier effect of forage quality has been identified, where high quality forage not only contains more nutritional value, but is also digested more rapidly, resulting in a dramatic increase in rate of nutrition uptake with increasing forage quality (White 1983). Thus, in areas where forage production is consistently sufficient in quantity to sustain ungulate populations, prolonged access to high quality pre-senescent forage may result in greater rates of energy intake than increased production of forage (Langvatn et al. 1996). This may be especially important for migrating animals, such as many bighorn sheep populations, that follow green-up along an elevational gradient (Albon and Langvatn 1992, Mysterud et al. 2001a). Weather conditions outside the growing season (cold season), generally indicative of winter severity, can affect ungulate populations via two distinct mechanisms. In the traditional view, winter severity affects energy loss of animals through winter by influencing forage accessibility, metabolic costs, energetic expenditure for locomotion and accessing forage, as well as length of time before high quality forage emerges (See Figure 1 for conceptual diagram). However, winter severity can also influence ungulate populations as moisture from melting snowpack affects forage, quality, quantity and phenology (Mysterud et al. 2001b). Climatic factors can also be partitioned by their timing in relation to the reproductive cycle. Pre-birth climatic conditions primarily influence maternal condition and investment, which in turn influence conception rate, birth rate, body weight of newborns, and lactation (Gaillard et al. 2000). Post-birth climatic conditions influence juvenile body condition as well as maternal condition and thus lactation.

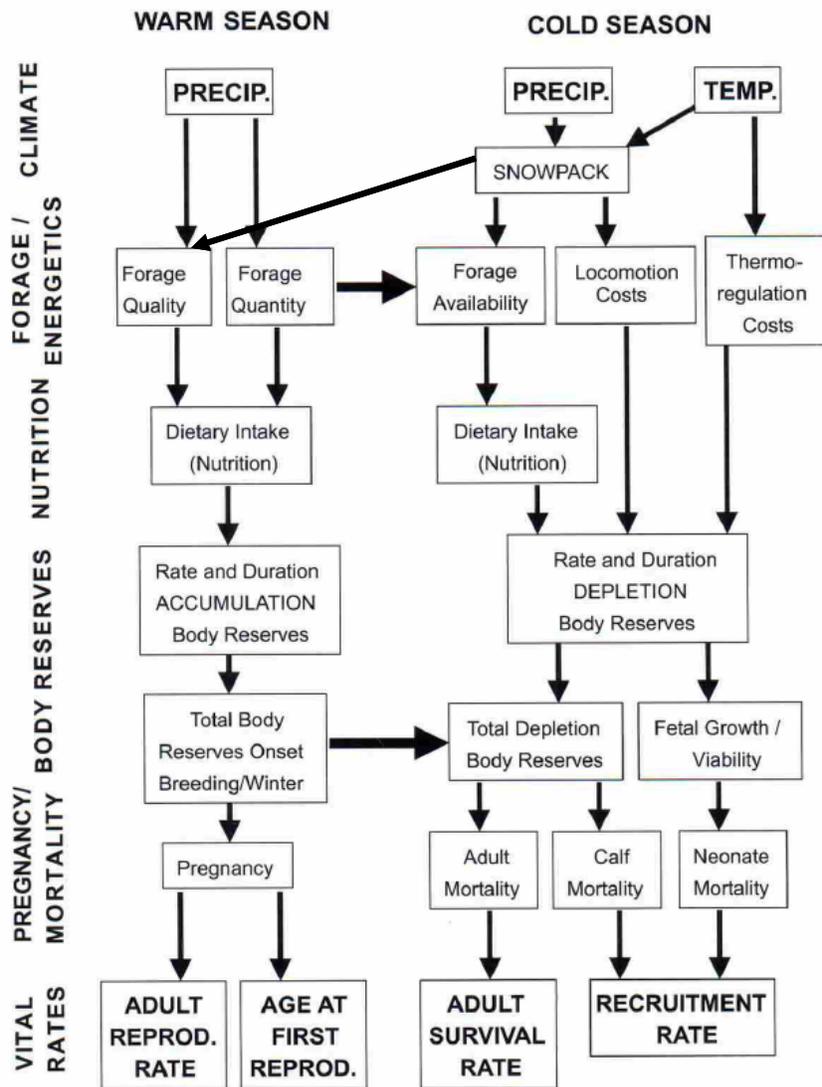


Figure 1. A conceptual model of the linkage between cold and warm season climate variation and vital rates for ungulates occupying northern latitudes. Slightly modified from Garrott et al. 2003.

Additionally, regional variation in long-term climate conditions can influence the effects of variation in annual climate on ungulate recruitment, such that populations of the same species living in different regions are impacted by a different set of climatic factors or are impacted in different ways by the same climatic factors. This phenomenon has been described in fish (Mueter et al. 2002, Crozier and Zabel 2006), birds (Sæther et al 2003, Sæther et al. 2008), as well as in ungulates (Sæther 1985, Grøtan et al. 2008, Grøtan et al. 2009). These findings highlight an advantage of conducting research over a broad geographic range, in that a better understanding of how species are affected by different environmental factors can be attained, as opposed to how individual populations are affected. Further, uncovering how populations

respond to environmental factors across different climate regimes may prove important for conservation measures as climate change alters the long-term conditions experienced by individual bighorn populations.

Disease, particularly pneumonia, plays an important role in bighorn sheep population dynamics and recruitment in the western United States (Monello et al. 2001, Cassirer and Sinclair 2007, George et al. 2008, Edwards et al. 2010, Cassirer et al. 2013). In Montana, over 1,500 bighorn sheep died between 2008 and 2011 as a result of all-age pneumonia die-off events. There is evidence that contact with domestic sheep (*Ovis aries*) introduces pneumonic pathogens to bighorn populations, leading to pneumonia epizootics (Monello et al 2001, George et al. 2008), however not all epizootics appear to be linked to contact with domestic sheep, as some bighorn populations (i.e., Sun River metapopulation west of Choteau, MT) have experienced pneumonia die-offs and are not in close proximity to any known domestic sheep (B. Lonner, MTFWP, personal communication). Pneumonia epizootics are commonly associated with bacterial infection by *Mannheimia haemolytica* and/or *Mycoplasma ovipneumonia*, (Besser et al. 2008, Lawrence et al. 2010, Besser et al. 2012a, Besser et al. 2012b), however the precise factors that result in pneumonia die-off events are unknown and the severity and persistence of epizootics are not uniform across cases (Besser et al. 2012b, Cassirer et al. 2013). Additionally, the effect of pneumonia epizootics on demographics and vital rates of infected populations in Montana has not been quantified and contrasted among populations.

Montana Department and Fish, Wildlife and Parks (MTFWP) conducts population surveys of many bighorn sheep populations in Montana on a regular basis, which has resulted in a large volume of available and useful information. Here we summarize and describe bighorn sheep recruitment data that has been collected by MFWP since 1980, then investigate the factors that are associated with bighorn recruitment across Montana. Specific objectives were to:

1. Characterize variability in climatic conditions experienced by bighorn sheep populations throughout Montana.
2. Determine average and variability of recruitment rates of populations throughout Montana.
3. Determine the relative associations of annual variation in cold and warm season weather conditions with recruitment rates.
4. Determine the relative associations of annual variation in weather conditions experienced by adult females prior to conception, pregnant females, and directly by juveniles.
5. Determine the relationship between bighorn sheep recruitment and variation in annual weather conditions in different climatic settings across Montana
6. Determine the association of all-age disease die-off events with bighorn recruitment rates.
7. Investigate relationships of population size and long-term climatic conditions with variability in recruitment rates.

## METHODS

### STUDY AREA

Bighorn sheep occupy a wide variety of rugged habitat types across much of Montana. Habitat includes desert and Prairie Breaks habitat, lush mountain ranges, dry mountain ranges, and high elevation alpine environments. The regions that bighorns occupy in Montana have been classified into five eco-regions with differing climatic and geographical characteristics (Montana Department of Fish, Wildlife and Parks 2010). These eco-regions are Northwest Montane, Mountain Foothills, Southern Mountains, Prairie Mountain Foothills, and Prairie-Breaks. Occupied bighorn sheep habitat ranges in elevation from less than 700 meters along the lower Clark Fork and Kootenai Rivers to over 3,500 meters in the Beartooth Mountains. Annual precipitation ranges from approximately 25 cm to 140 cm. Additionally, bighorn populations occupy habitats experiencing a range of human influence, from wilderness areas to areas adjacent to major highways to suburban areas.

### COLLECTING AND CENSORING DATA

Recruitment data used in this analysis were provided by MTFWP. The data were collected during regular bighorn sheep classification counts, typically conducted by MTFWP area biologists between 1980 and 2012. The index of recruitment that was calculated from these data was the number of young:100 adult females (lamb:ewe ratio). The majority of classification counts were conducted from an aerial platform, though the classification counts for several populations were conducted from the ground. Given that the data were collected using a variety of techniques across a variety of conditions, and that the data were not collected with the specific intention for this type of analysis, we censored the recruitment data in order to assure we had the best indices of recruitment rates as possible, even if it resulted in using less of the data. The first level of data censoring occurred at the population level. Populations that were favored for inclusion in the analysis were those that have been surveyed often and consistently surveyed in the same season. Additionally, an effort was made to include herds from different eco-regions of Montana (defined in Montana Department of Fish Wildlife and Parks 2010) in order to capture the range of environments bighorn sheep in Montana occupy and, thus, making this effort broadly applicable. For analysis, data from the Yankee Jim-Corwin Springs population were included with data from the Cinnabar population (they are small neighboring populations within the Southern Mountains eco-region) in order to increase representation from that region. Most populations across Montana whose data were used for analysis were consistently surveyed in late winter to early spring. However, most survey data from the Prairie Breaks eco-region that were analyzed came from summer classification surveys, making comparison of recruitment data from this ecologically distinct area with other areas difficult. The 22 populations whose recruitment data were analyzed are shown in Figure 2. After populations were chosen for analysis, the data were censored at the level of individual survey records. In an effort to reduce variability in lamb:ewe ratios due to small sample size we only included surveys where a minimum sample of

18 adult females were observed. This minimum sample size was chosen as a trade-off between maintaining sufficient records in the analysis and generating the most representative lamb:ewe ratios possible (Samuel et al. 1992). Survey data were also censored for each population so that the data used in analysis were collected during the same time of year. Additionally, professional judgment from area biologists was used to eliminate records from surveys that may not have provided an accurate index of recruitment.

Most climate covariates used in the analysis were derived from the PRISM climate mapping system (PRISM Climate Group, Oregon State University, <http://prism.oregonstate.edu>). The PRISM climate model extrapolates data from weather stations to surrounding areas using digital elevation models to provide estimates of weather conditions experienced in 4 km raster grid cells on a monthly and annual basis. Natural Resource Conservation Service (NRCS) Snotel data (<http://www.wcc.nrcs.usda.gov/snow/>) were used to calculate an additional climate covariate, cumulative snow water equivalent (SWE). We did not have Snotel data available for all populations that we analyzed and SWE was not considered in those cases.

### CLIMATE COVARIATES

For each bighorn population used in analysis, the PRISM data were extracted using ESRI Spatial Analyst software (ESRI 2012). We used the “zonal statistics” tool to overlay PRISM data with general ranges of 43 bighorn populations to index the weather conditions experienced by each population. General herd ranges were created using online GIS data from MTFWP as well as expert opinion from area biologists. PRISM data were used to index annual May and June precipitation (SpP), May and June average temperature (SpT), July-September precipitation (SuP), and October – April precipitation (WP) for each population. Average annual precipitation (AnP) experienced by each population was available from PRISM (PRISM used 1981-2010 data to calculate average annual precipitation). The annual covariates (SpP, SpT, SuP, WP) were centered and standardized to index the departure, in standard deviations, from the mean value since 1980. The annual climate covariates then became indices of the extremeness of a season’s weather compared to the annual normal. Winter snow pack conditions experienced annually by each population were indexed by summing daily snow water equivalent (SWE) values from October 1 to April 30 from the nearest Snotel site to each population. SWE values were centered and standardized in the same fashion as the other annual covariates. The mean, standard deviation, and coefficient of variation was calculated for each of the covariates across the population ranges. Table 1 shows all climate covariates that were considered for analysis.

### Climate Covariate Hypotheses

*Spring Precipitation (SpP)*- Precipitation in May and June (SpP) may be important for recruitment in bighorn sheep as lambing in most Rocky Mountain populations falls in this time period, and weather during the neonatal period may directly impact juvenile survival (Geist 1971, Thompson and Turner 1982). May and June precipitation can also impact forage

production during the neonatal period, which may be an important time in determining later juvenile survival. Positive associations have been found between spring precipitation and juvenile survival in bighorn sheep in Montana (Enk et al. 2001) and Alberta (Portier et al. 1998) as well as in elk in Yellowstone National Park (Taper and Gogan 2002). In a recent meta-analysis of bighorn sheep recruitment in the Greater Yellowstone Area of Wyoming, spring precipitation was found to be strongly correlated with lamb:ewe ratios (Butler and Garrott 2012). Although severe weather during the neonatal period can impact juvenile survival, direct effects of severe weather are exceptional (Gaillard et al. 2000). Therefore, we hypothesized a generally positive association between SpP and bighorn sheep recruitment as indexed by lamb:ewe ratios but anticipated the strength and direction of the association between SpP and recruitment to vary with average annual precipitation.

*Spring Temperature (SpT)*-Average temperature in May and June (SpT) is thought to influence forage growth in complex ways. Lower temperatures during this period delay forage growth, resulting in less overall forage production (Langvatn et al. 1996). However, the trade-off of delayed forage growth is that plant senescence may be delayed, resulting in a longer period of time in which high quality forage is available, which may be more important for ungulate body condition than forage quantity (White 1983, Van Soest 1994). Lower temperatures early in the growing season may slow the rate of green-up, providing pregnant and lactating females a better opportunity to access high quality newly emergent forage (Langvatn et al. 1996, Pettoirelli et al. 2007). Portier et al. 1998 also found a negative association between spring temperatures and bighorn lamb survival in southwest Alberta. As such, we hypothesized a negative association between spring temperature and recruitment of bighorn sheep.

*Summer Precipitation (SuP)*-Total precipitation during summer months (July-September) may impact bighorn sheep recruitment in several ways. Total forage production is thought to increase as precipitation during the growing season increases (Lauenroth et al. 1992, Nippert et al. 2006), and precipitation later in the growing season may delay senescence, prolonging access to high quality forage. Late summer nutrition has important implications for ungulate body condition entering the winter, which may affect conception/birth rates and juvenile survival through the winter (Cook et al. 1996, Cook et al. 2004). Enk et al. (2001) found bighorn lamb production in a semi-arid region of central Montana to be correlated with summer precipitation. Conversely, late summer precipitation has been found to be negatively correlated with fecundity of young adult female red deer on the Island Rum, Scotland, which experiences a maritime climate (Langvatn et al. 1996). Butler and Garrott (2012) found that bighorn lamb:ewe ratios in the Greater Yellowstone Area of Wyoming were correlated with summer precipitation and that the relationship varied with the average amount of moisture experienced by different populations. Given these previous findings, we hypothesized that lamb:ewe ratios in Montana bighorn sheep populations are correlated with SuP (or  $SuP_{t-1}$ ) and that the strength of the relationship varies with long-term climatic conditions experienced by different populations.

*Cumulative Snow Water Equivalent (SWE)*-Cumulative Snow Water Equivalent (SWE) is a metric of winter severity that incorporates total snowfall, snow depth, and length of time snow cover is present into a single covariate that indexes snow pack severity over an entire winter. SWE in a given year may affect winter survival of juveniles as well as development of the next cohort *in utero*. Most studies of ungulate populations have found generally negative effects of winter severity indices on performance of populations (Adams and Bailey 1982, Picton 1984, Sæther 1985, Singer et al. 1997, Loison et al. 1999, Garrott et al 2003, Grøtan et al. 2008, Hamel et al. 2009), though others have found positive effects (Solberg et al. 1999). Further, other studies have found both negative and positive effects of winter severity indices on ungulate populations in different areas (Post and Stenseth 1999, Butler and Garrott 2012) or in the same areas in different years (Mysterud et al. 2001b, Butler and Garrott 2012), suggesting that under certain conditions, the moisture provided by winter precipitation may be more beneficial to ungulate populations than the hardships of winter itself are detrimental. We hypothesized that SWE (or  $SWE_{t-1}$ ) is correlated with bighorn lamb:ewe ratios, and that the strength and direction would vary with average annual precipitation experienced by different populations.

*Winter Precipitation (WP)*-WP is an alternative index of winter severity to SWE. The WP covariate is similar to SWE in that it indexes precipitation outside the growing season, but different in that it does not index the actual snow conditions. However, we expect most precipitation that falls in Montana during this time period to be snow, and WP to generally index total snow fall, which is supported by a strong correlation with SWE ( $P=0.69$ ). Thus, we expect WP to be associated with bighorn recruitment in similar ways as SWE. We hypothesized that WP (or  $WP_{t-1}$ ) is correlated with bighorn lamb:ewe ratios, and that the strength and direction would vary with average annual precipitation experienced by different populations.

*Average Annual Precipitation (AnP)*-The amount of average annual precipitation (AnP) an area receives is an important determinant of many characteristics of the biological community, leading to different species composition, habitat characteristics, and limiting factors for the local biota (Holdridge 1947). Picton (1984) found that mule deer recruitment in Montana was negatively correlated with average regional precipitation, suggesting that ungulate populations have different average recruitment rates in different climates. Further, there are multiple studies that have found ungulate population dynamics to have different relationships with annual climatic conditions in different areas (Sæther 1985, Post and Stenseth 1999, Mysterud et al. 2000, Grøtan et al. 2008, Grøtan et al. 2009, Butler and Garrott 2012) and we suspected that AnP is one factor that explains these differences. Thus, we anticipated variability in the associations of the annual climate covariates with lamb:ewe ratios to be explained by average annual precipitation.

### DISEASE COVARIATES

Disease, particularly pneumonia, outbreaks play an important role in bighorn sheep populations (Douglas 2001, Monello 2001, Cassirer and Sinclair 2006, Besser et al. 2008, George et al. 2008,

Edwards et al. 2010, Besser et al. 2012a, Besser et al. 2012b, Cassirer et al. 2013). Not only do disease outbreaks result in significant all-age mortality events, recruitment in following years is often severely reduced (Edwards et al. 2010, Besser et al. 2012b, Cassirer et al. 2013). Years of disease outbreaks for each population were determined through herd-specific management records (MTFWP 2010; Sarah Sells, University of Montana, personal communication) and querying area biologists. . See Table 2 for years of all-age disease die-off events that were in the analysis dataset. Six covariates to index the potential influence of the occurrence of all-age disease die-off event on post-event recruitment were created.

Five indicator variables (D1, D2, D3, D4, and D5) were created to test the lingering effects of disease outbreaks on bighorn recruitment, where year specific data from each bighorn population in the analyses were assigned as having or not having experienced an all-age disease die-off within a time frame of one to five years. An additional variable (Dc) was created from the negative exponent of years since disease die-off, where lamb:ewe ratios were a function of  $\frac{1}{\text{Years Since Dieoff}}$ , allowing the covariate to predict a gradual increase in lamb:ewe ratios for five years following a die-off. Given the high amount of cost and effort required to sample bighorn populations for disease pathogens, adequate data were not available to provide indices of disease presence that were collected in a consistent manner for all populations in the datasets. Table 1 shows all disease covariates that were considered for analysis.

### STATISTICAL ANALYSIS

The climate covariates assigned to recruitment data used in the climate recruitment analyses were tested for collinearity using Pearson's correlation coefficients. First order autocorrelation was also assessed using Pearson's correlation coefficients between current and time-lagged versions of each covariate in the spring recruitment dataset. The recruitment analyses were conducted using the linear model function in program R (R Development Core Team 2012). Twenty-five time-series datasets from 22 bighorn populations were analyzed independently (three populations in Sun River area were consistently surveyed multiple times each year, resulting in more datasets than populations). Model suites consisting of models with all possible combinations of the covariates were assembled and Akaike's Information Criterion adjusted for small sample sizes ( $AIC_c$ ) was used to determine the most parsimonious models for describing variation in lamb:ewe ratios in each dataset (Doherty et al. 2012). Model averaged results and relative variable importance values were also calculated for each model using the MuMIn package (Barton 2013) in program R, though model averaged results are not presented. The winter weather covariates ( $WP/WP_{t-1}$  and  $SWE/SWE_{t-1}$ ) and the disease covariates (D1, D2, D3, D4, D5, Dc) were collinear and only one from each category (winter weather or disease) was included in any given model with in the model suite that was evaluated for each dataset (including time-lagged version of winter weather covariates). The appropriate winter weather and disease covariates were selected by comparing relative variable importance values calculated from precursory model averaging procedures. In several datasets, missing data and recentness of

Table 1. Descriptions of each of the covariates used in the 25 recruitment analyses.

<b>Covariate</b>	
<b>Abbreviation</b>	<b>Description</b>
SWE <sub>t-1</sub>	Standardized cumulative snow water equivalent from the winter (October-April) experienced by pregnant mothers of the cohort classified as lambs during annual surveys
SWE	Standardized cumulative snow water equivalent from the winter (October-April) experienced by the cohort classified as lambs during annual surveys (only applicable to the spring recruitment dataset)
SuP <sub>t-1</sub>	Standardized cumulative precipitation from the summer (July-September) prior to the conception of the cohort classified as lambs during annual surveys
SuP	Standardized cumulative precipitation from the first summer (July-September) experienced by the cohort classified as lambs during annual surveys (only applicable to spring recruitment dataset)
SpP <sub>t-1</sub>	Standardized cumulative spring precipitation (May-June) experienced by adult females prior to conception of cohort classified as lambs during annual surveys
SpP	Standardized cumulative spring precipitation (May-June) during the birthing season for the cohort classified as lambs during annual surveys
SpT <sub>t-1</sub>	Standardized average spring temperature (May-June) experienced by adult females prior to conception of cohort classified as lambs during annual surveys
SpT	Standardized average spring temperature (May-June) during the birthing season for the cohort classified as “young” during annual surveys
D1	Variable indicating if population had experienced all-age disease die-off event within 1 year of the time survey data were collected
D2	Variable indicating if population had experienced all-age disease die-off event within 2 years of the time survey data were collected
D3	Variable indicating if population had experienced all-age disease die-off event within 3 years of the time survey data were collected
D4	Variable indicating if population had experienced all-age disease die-off event within 4 years of the time survey data were collected
D5	Variable indicating if population had experienced all-age disease die-off event within 5 years of the time survey data were collected
Dc	Variable indicating number of years prior to collection of survey data that population experienced all-age disease die-off event. Variable was analyzed in form of
	<b>1</b>
	<b>“Years Since Dieoff”</b>

Table 2. Years of known all-age disease die-of events in bighorn sheep populations whose data were formally analyzed.

<b>Eco-Region-Population</b>	<b>All-Age Disease Die-off Events in Dataset</b>
<b>Northwest Montane</b>	
100-Kootenai Falls	None
121-North Clark Fork	None
122-Clark Fork Cutoff	None
123-Cabinet Mountains	None
124-Paradise	None
203-Grave Creek Range	None
<b>Mountain Foothills</b>	
210-Lower Rock Creek	2009-2010
213-Lost Creek	1991, 2010
216-Upper Rock Creek	2009-2010
270-East Fork Bitterroot	2009-2010
340-Highlands	1995
<b>Prairie Mountain Foothills</b>	
421-Deep Creek	1984, 2010
422-Castle Reef	1984,2010
423-Gibson Lake North	1984,2010
424-Ford Creek	1984,2010
<b>Southern Mountains</b>	
Cinnabar	None
Mt Everts	None
500a-Stillwater	None
501-West Rosebud	None
<b>Prairie Breaks</b>	
622-Middle Missouri Breaks	None
482-Fergus	None
680-North Missouri Breaks	None

disease die-offs led to multiple disease covariates having the same relative variable importance value; in this scenario the supported disease covariate reflecting the minimum time since a disease die-off was used in the analysis (ie if D2, D3, and D4 had equal support, D2 would be used). Disease covariates were only considered in populations that have experienced all-age disease die-off events within the data time-series. All climate covariates were considered for analysis of datasets where lamb:ewe ratios were collected during the spring. SWE/WP were not considered for analysis of datasets where lamb:ewe ratios were collected during the winter, and neither SWE/WP nor SuP were considered for analysis of datasets where lamb:ewe ratios were collected during the summer, as these covariates index weather conditions after the lamb:ewe ratios were collected. The estimated intercept values (which approximate average

recruitment rate for a population) from the top models for each of the populations with spring recruitment data were tested for correlations with long-term average values of the annual climate covariates (including annual precipitation) and for correlations with average number of animals counted in the population (an index of population size). We were unable to assess if there were relationships between the estimated beta coefficients of the annual climate covariates and average annual precipitation because none of the annual climate covariates were in the top model for more than 4 populations. Thus, we were unable to assess our hypotheses regarding how the relationship of the annual climate covariates with recruitment varies with average annual precipitation. When models predicted lamb:ewe ratios less than zero, we reported zero as the predicted value, as real lamb:ewe ratios cannot be less than zero.

## RESULTS

The results section consists of three subsections. The first subsection summarizes the covariate and recruitment data that were used in the analyses, illustrating variability of these data within and between the bighorn populations whose data were incorporated in the analyses. The second subsection consists of narratives and graphics describing the results of the statistical analyses that were performed for individual populations. The first narrative describing the results of the statistical analysis for a single population (100-Kootenai Falls) contains additional narrative explaining how to interpret the results. This additional narrative will be informative for interpreting results for other populations. For the several populations for which statistical models explained a large proportion of the variation in lamb:ewe ratios, summary graphics that display predicted lamb:ewe ratios for different covariate conditions based on the best-supported models are also shown. The third subsection summarizes the results of the individual population analyses across covariates and across populations.

### SUMMARIZATION OF RECRUITMENT AND CLIMATE DATA

#### Recruitment Data

The initial dataset contained recruitment data from 889 classification surveys of 49 bighorn sheep populations in Montana. After censoring, we analyzed data from 559 classification surveys of 22 populations, representing each eco-region (Northwest Montane: 6 populations, Mountain Foothills: 5 populations, Prairie Mountain Foothills: 4 populations, Southern Mountains: 4 populations, Prairie Breaks: 3 populations; Figure 2). Recruitment data for 13 populations were collected during spring, recruitment data for 4 populations were collected during winter, recruitment data for 2 populations were collected during summer, and 3 populations had recruitment data collected during winter and spring each year. Mean lamb:ewe ratios of bighorn populations whose recruitment data were collected during spring ranged from 22 lambs:100 ewes (Mt Everts) to 42 lambs:100 ewes (203-Grave Creek Range) (Figure 2, Table 3). Coefficient of variation values (CV) for lamb:ewe ratios of individual populations ranged

from 20% (121-North Clark Fork) to 63% (421-Deep Creek). Figure 3 depicts how lamb:ewe ratios of the populations varied through time

Average lamb:ewe ratios of populations in the Northwest Montane eco-region varied from 26 (100-Kootenai Falls) to 42 lambs:100 ewes (203-Grave Creek Range); average lamb:ewe ratios of populations in the Mountain Foothills eco-region varied from 28 (270-East Fork Bitterroot) to 41 lambs:100 ewes (213-Lost Creek); average lamb:ewe ratios of populations in the Prairie Mountain Foothills eco-region varied from 27 (421-Deep Creek) to 38 lambs:100 ewes (422-Castle Reef); average spring lamb:ewe ratios of populations in the Southern Mountains eco-region varied from 22 (Mt Everts) to 27 lambs:100 ewes (Cinnabar); average summer lamb:ewe ratios of populations in the Prairie Breaks eco-region varied from 45 (680-North Missouri Breaks) to 55 lambs:100 ewes (482-Fergus). See Table 3 for demographic summaries of all populations whose data were analyzed. The mean lamb:ewe ratio was 38 lambs:100 ewes for populations in the Northwest Montane eco-region, 34 lambs:100 ewes for populations in the Mountain Foothills eco-region, 33 lambs:100 ewes for populations in the Prairie Mountain Foothills, 28 lambs:100 ewes in the Southern Mountains eco-region, and 48 lambs:100 ewes for populations in the Prairie Breaks eco-region. Collectively, lamb:ewe ratios from the Prairie Breaks eco-region were most representative of summer recruitment, while lamb:ewe ratios from other eco-regions were representative of spring recruitment.

#### Climate Covariate Data

Bighorn populations whose data were used in the climate analyses occupied habitats that received annual precipitation ranging from 33.2 cm (622-Middle Missouri Breaks) to 141.0 cm (123-Cabinet Mountains). An illustration of herd ranges and annual precipitation received in each range is shown in Figure 4. Mean spring precipitation values ranged from 12.6 cm (124-Paradise) to 21.6 cm (123-Cabinet Mountains) (Figure 5), mean summer precipitation values ranged from 8.9 cm (124-Paradise) to 15.5 cm (123-Cabinet Mountains) (Figure 6), mean winter precipitation ranged from 10.9 cm (622-Middle Missouri Breaks) to 104.9 cm (123-Cabinet Mountains) (Figure 7), and mean spring temperature ranged from 7.5 °C (Cinnabar) to 15.0 °C (622-Middle Missouri Breaks) (Figure 8). SWE values were not always indicative of relative snow accumulation experienced by different bighorn sheep populations because some populations were assigned data from Snotel sites that experienced different amounts of snow accumulation than the bighorn range. SWE data suggested some populations experienced significantly less or significantly more snow accumulation on average than the population truly experienced, and thus, it was not fruitful to compare average SWE conditions experienced between different populations. However, the SWE data still appear to index annual fluctuations in weather conditions experienced by the bighorn populations, as evidenced by the strong correlation with WP ( $P=0.69$ ). SWE data are shown in Table 8 of Appendix A. The most variable climate covariate across all populations was summer precipitation ( $CV=43.9\%$ ) and the least variable climate covariate across all populations was spring temperature ( $CV = 11.7\%$ ) (Table 2 of Appendix A). There was little evidence for 1<sup>st</sup> order autocorrelation or collinearity

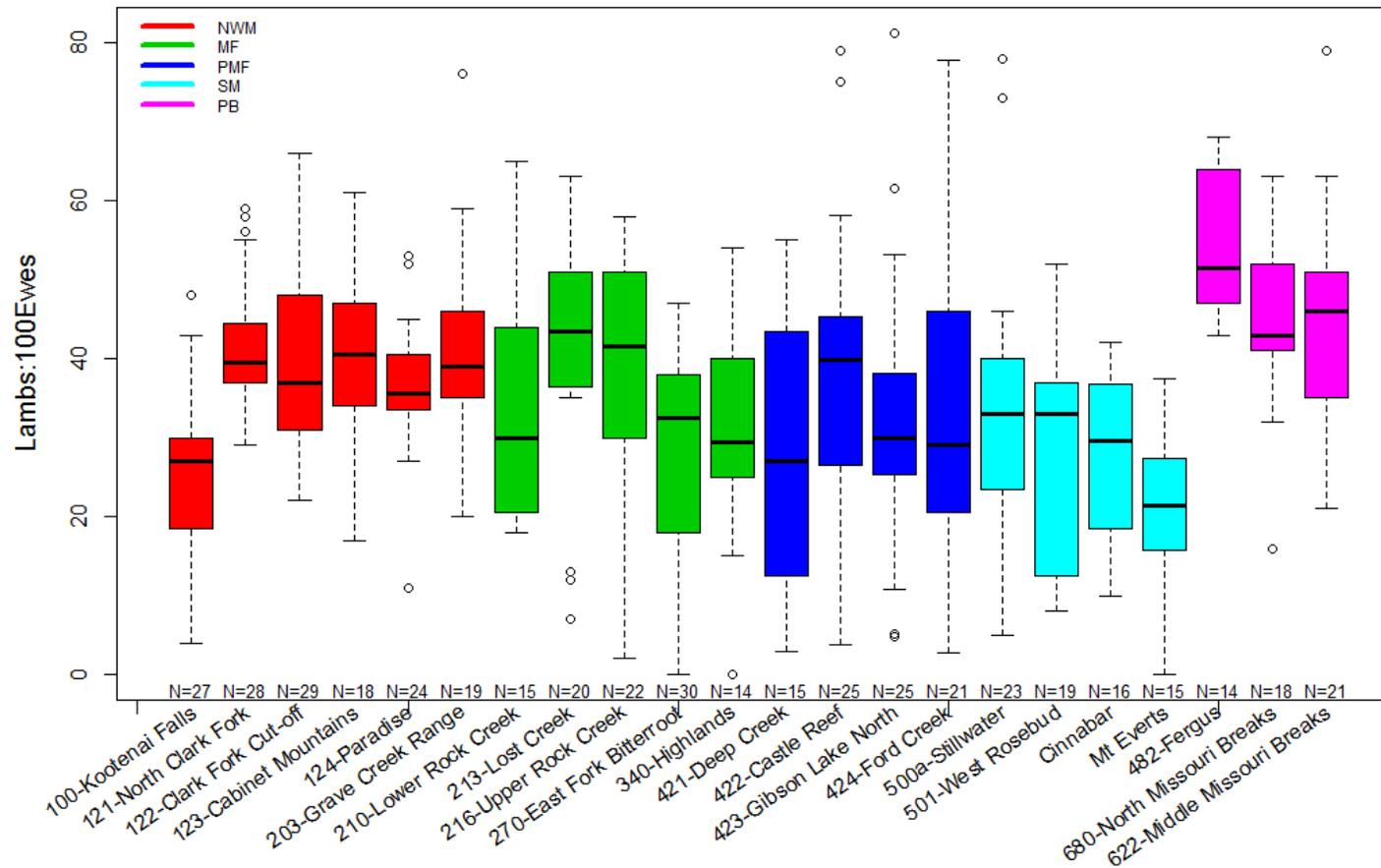


Figure 2. Variability of lamb:ewe ratios during 1980-2012 in each of the bighorn populations whose data were analyzed. Box outlines represent the inter-quartile range, whiskers represent values within 1.5 times the interquartile range from the upper or lower quartiles. Open circles represent outliers outside the range of the whiskers. Horizontal center lines represent median values. The plots are color coded by ecoregion, which are, from left to right, Northwest Montane (NWM) in red, Mountain Foothills (MF) in green, Prairie Mountain Foothills (PMF) in blue, Southern Mountains (SM) in light blue and Prairie Breaks (PB) in magenta. Lamb:ewe ratios of 500a-Stillwater, 501-West Rosebud, and 622-Middle Missouri Breaks are from winter classification surveys and lamb:ewe ratios of 482-Fergus and 680-North Missouri Breaks are from summer classification surveys. Lamb:ewe ratios from all other populations are from spring classification surveys.

Table 3. Summary of Montana bighorn sheep classification surveys from the 22 populations whose data were analyzed. Populations marked with a single asterisk (\*) were surveyed primarily winter months, datasets marked with two asterisks (\*\*) were surveyed primarily in summer months, and unmarked populations were surveyed primarily collected in spring months, prior to the birth pulse. Table continued on next page.

<b>Ecoregon-Herd</b>	<b>Number Classification Surveys</b>	<b>Range Years</b>	<b>Mean Animals Counted</b>	<b>Coefficient Variation Animals Counted (%)</b>	<b>Range Animals Counted</b>	<b>Current Population Estimate<sub>1</sub></b>	<b>Mean Lamb: Ewe Ratio</b>	<b>Coefficient Variation Lamb: Ewe Ratios (%)</b>	<b>Range Lamb: Ewe Ratios</b>
<b>NW MONTAINE</b>									
100-Kootenai Falls	27	1982-2012	70	43	34-130	75	26	37	4-48
121-North Clark Fork	28	1983-2012	216	34	49-426	200	41	20	29-59
122-Clark Fork Cutoff	29	1982-2012	93	21	61-141	150	40	30	22-66
123-Cabinet Mountains	18	1986-2012	84	27	43-120	100	41	28	17-61
124-Paradise	24	1988-2011	303	34	93-501	375	37	23	11-53
203-Grave Creek Range	19	1984-2012	113	23	63-152	175	42	29	20-76
<b>MOUNTAIN FOOTHILLS</b>									
210-Lower Rock Creek	15	1989-2012	151	33	57-245	100	33	44	18-65
213-Lost Creek	20	1982-2012	200	44	90-361	100	41	37	7-63
216-Upper Rock Creek	22	1990-2012	212	32	116-347	125	38	41	2-58
270-East Fork Bitterroot	30	1982-2012	115	42	47-246	100	28	47	0-47
340-Highlands	14	1983-1997	168	55	18-320	75	31	49	0-54
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>									
421-Deep Creek*	15	1982-2012	86	31	42-139	125	27	63	3-55
422-Castle Reef	25	1982-2012	202	35	61-323	175	38	47	4-79
423-Gibson Lake North	25	1982-2012	150	41	45-315	175	33	51	5-81
424-Ford Creek	21	1982-2012	168	48	55-389	150	32	56	3-78

<sub>1</sub>Footnote explained on next page

Table 3 (continued)

<b>Ecoregon-Herd</b>	<b>Number Classification Surveys</b>	<b>Range Years</b>	<b>Mean Animals Counted</b>	<b>Coefficient Variation Animals Counted (%)</b>	<b>Range Animals Counted</b>	<b>Current Population Estimate<sub>1</sub></b>	<b>Mean Lamb: Ewe Ratio</b>	<b>Coefficient Variation Lamb: Ewe Ratios (%)</b>	<b>Range Lamb: Ewe Ratios</b>
<b>SOUTHERN MTNS</b>									
500a-Stillwater*	23	1982-2012	42	22	27-62	50	33	52	5-78
501-West Rosebud*	19	1982-2012	60	34	28-100	100	28	53	8-52
Cinnabar	16	1992-2011	54	38	30-107	75	27	37	10-42
Mt Everts	15	1992-2011	61	33	41-110	100	22	45	0-38
<b>PRAIRIE BREAKS</b>									
622-Middle Missouri Breaks*	21	1988-2012	130	34	78-217	225	43	34	21-79
482-Fergus**	14	1995-2012	350	20	235-498	400	55	17	43-68
680-North Missouri Breaks**	18	1992-2012	300	43	73-532	500	45	24	16-63

<sup>1</sup>. For populations that seem to be relatively stable since 2008 and have had high quality surveys since 2008, the recent population estimate was calculated using the average number of animals counted in the surveys since 2008 divided by a herd-specific sighting probability that biologists indicated to UM Master's student Sarah Sells. Populations marked with a single asterisk were exceptions to the above criteria. For various reasons, the above methods were not thought to provide accurate population estimates, so these populations were estimated using the 2010 bighorn conservation strategy or the best available information. Population estimates marked with 2 asterisks are for populations that have experienced all-age disease die-offs and recent population estimates were taken from research proposal by Tom Carlsen and Neil Anderson. However for 261-Skalkaho and the Sun River populations more recent data were available that reflected different population sizes than estimated by Carlsen and Anderson, so estimates were made based on the more recent data and sighting probabilities.

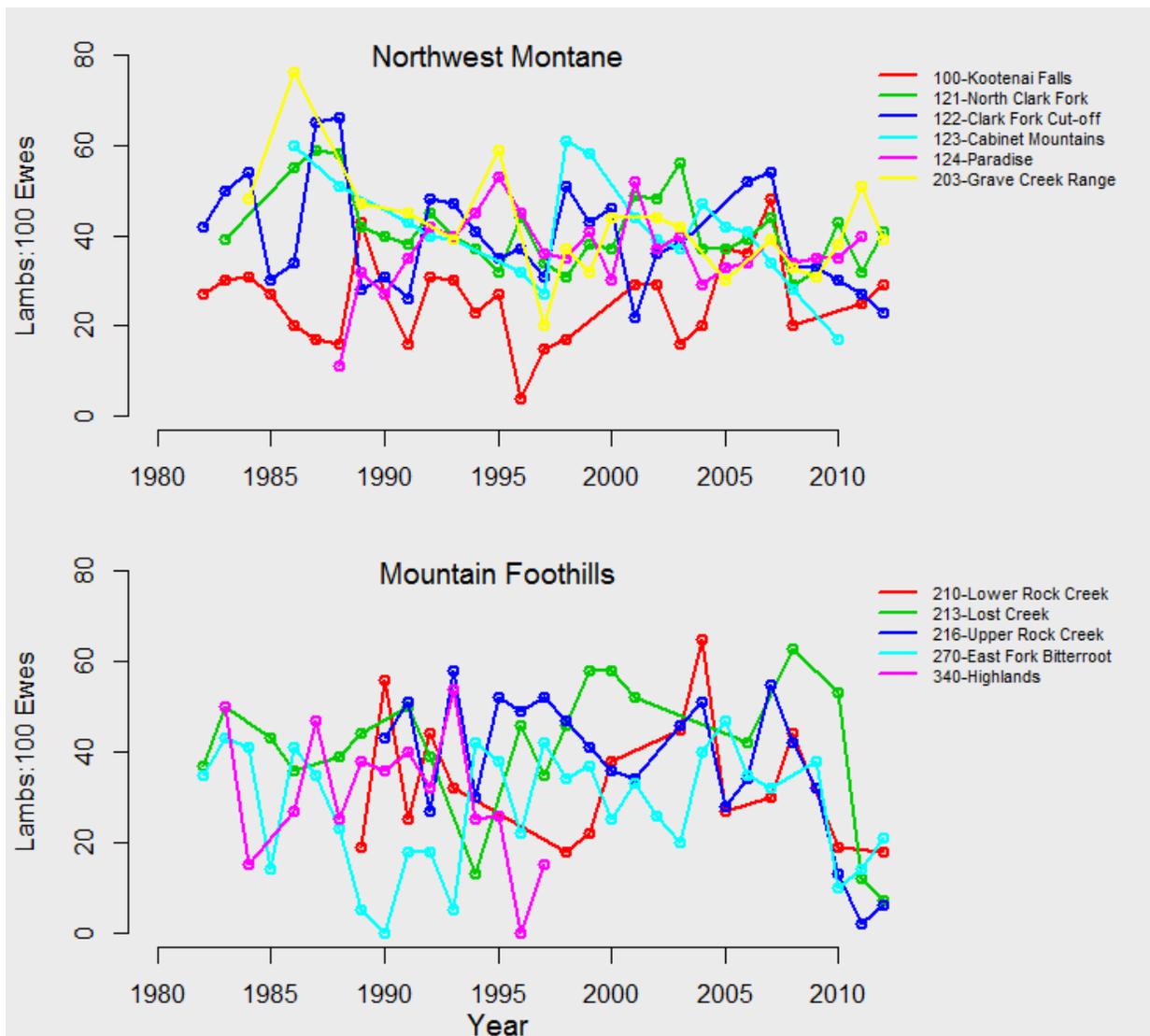
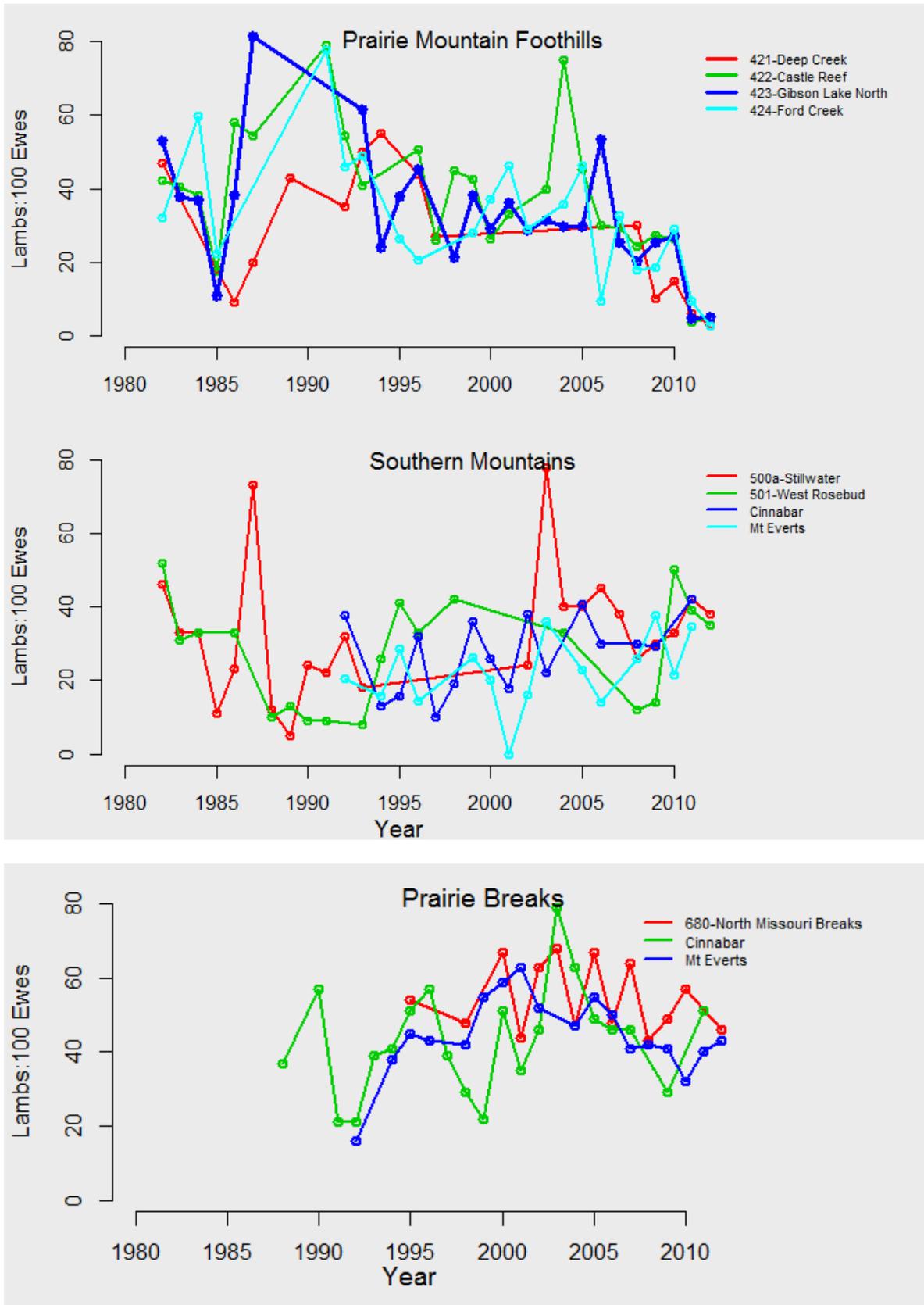


Figure 3. Time-series of observed lamb:ewe ratios for each population in the climate recruitment analyses. Lamb:ewe ratios of 421-Deep Creek, 500a-Stillwater, 501-West Rosebud, and 622-Middle Missouri Breaks are from winter classification surveys and lamb:ewe ratios of 482-Fergus and 680-North Missouri Breaks are from summer classification surveys. Lamb:ewe ratios from all other populations are from spring classification surveys.

Figure 3 continued



between the other climate covariates (Figure 7 of Appendix A). Weather conditions experienced by bighorn populations in the same eco-region showed very similar patterns of fluctuation from year to year (Figures 1-5 of Appendix A), yet populations in the same region often experienced different amounts of long-term average precipitation and spring temperatures (Figures 3-6; Tables 1-6 of Appendix A).

## INDIVIDUAL POPULATION ANALYSES

### Northwest Montane Eco-region

#### *100-Kootenai Falls*

The top model describing variation in spring lamb:ewe ratios for the 100-Kootenai Falls bighorn sheep population included a positive association of spring precipitation prior to conception of females (estimated  $\beta_{\text{SP}(t-1)} = 4.4$ , 95% CI = 0.0 to 8.7), a negative association of cumulative snow water equivalent experienced by pregnant females (estimated  $\beta_{\text{SWE}(t-1)} = -5.0$ , 95% CI = -8.8 to -1.2), and a negative association of cumulative snow water equivalent experienced by lambs (estimated  $\beta_{\text{SWE}} = -3.8$ , 95% CI = -7.5 to -0.1). There was not conclusive evidence that this population experienced an all-age die-off event due to *disease*, and as such, no disease covariates were explored. The intercept value of the top model was 25.5 (95% CI = 22.2 to 28.8), which, given the standardization of the covariates, represents the recruitment rate of this population (in terms of lambs:100 ewes) under average covariate conditions. The adjusted  $R^2$  of the top model was 0.21.

The population-specific climate-covariate values used in the analyses were standardized to have a mean of 0 and a standard deviation of 1, and as such, interpretation of the results requires brief explanation. The coefficients represent the estimated change in lambs:100 ewes that is expected to occur when the value for the specified climate covariate increases by 1 standard deviation. The size of the standard deviation for each climate covariate varied by population, and population-specific values are shown in Tables 4-8 of Appendix A. For example, SWE (cumulative snow water equivalent experienced by lambs) was in most top models and appears to be associated with recruitment in the 100-Kootenai Falls population. In the top-ranked model the SWE coefficient estimate was -3.8 and in Table 8 of Appendix A, we see that the standard deviation of SWE for the 100-Kootenai Falls population was 1466 cm, thus for every increase of 1466 cm in cumulative SWE, lambs:100 ewes is predicted to decline by 3.8 in this population. Approximately 95% of the standardized climate covariate values will fall between values of -2 and +2, therefore the influence we generally expect these covariates to have on lambs:100 ewes ranges from -2 to +2 times the estimated regression coefficient. If we apply this concept to the 100-Kootenai Falls population, changes in SWE can generally explain changes of up to 15.2 lambs:100 ewes.

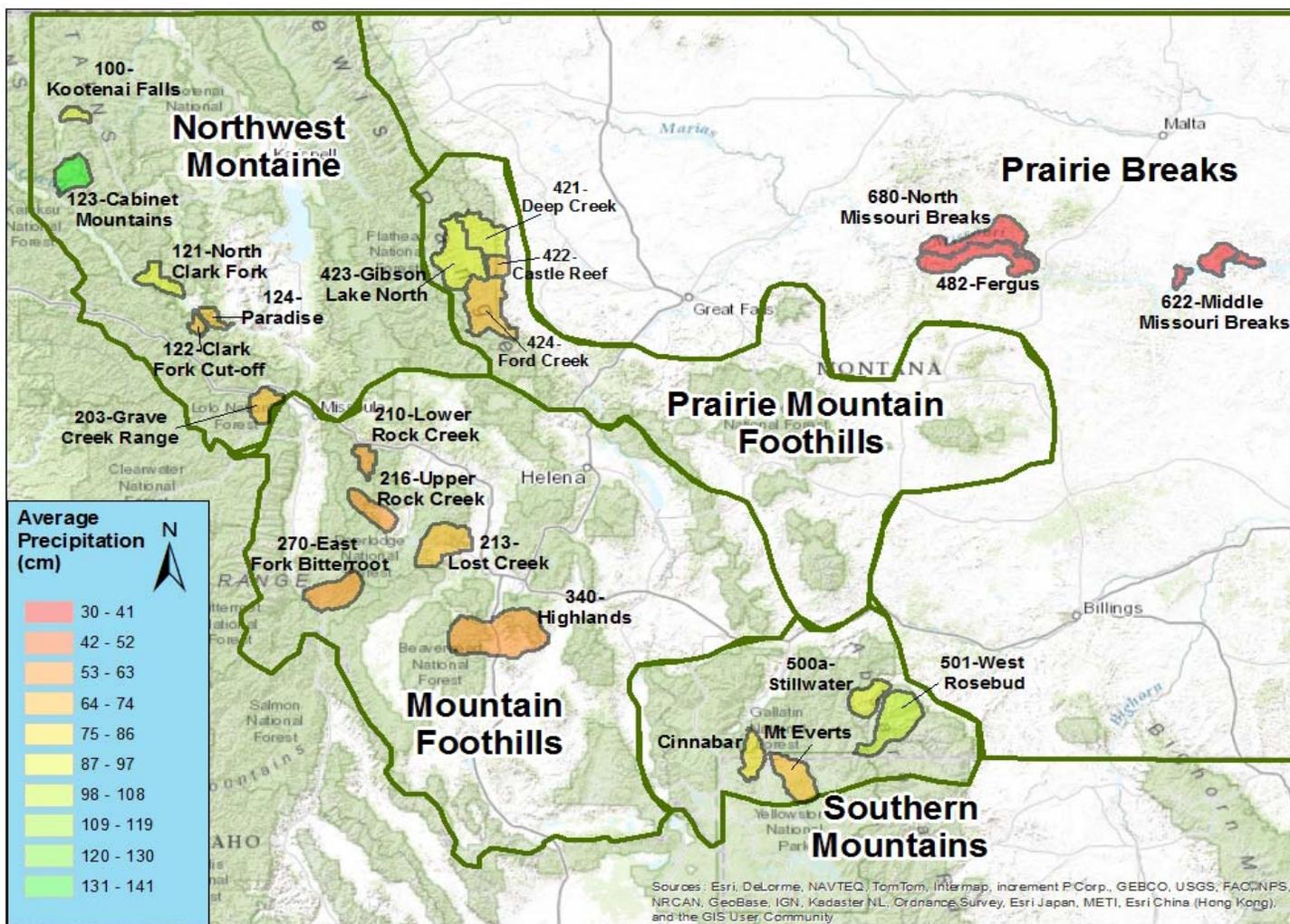


Figure 4. Map depicting the ranges of bighorn sheep populations used in the climate recruitment analyses. The individual range polygons are shaded along a gradient according to the amount of average annual precipitation the range receives. Areas receiving the least amount of annual precipitation are shaded red-orange and areas receiving the most are shaded green-yellow.

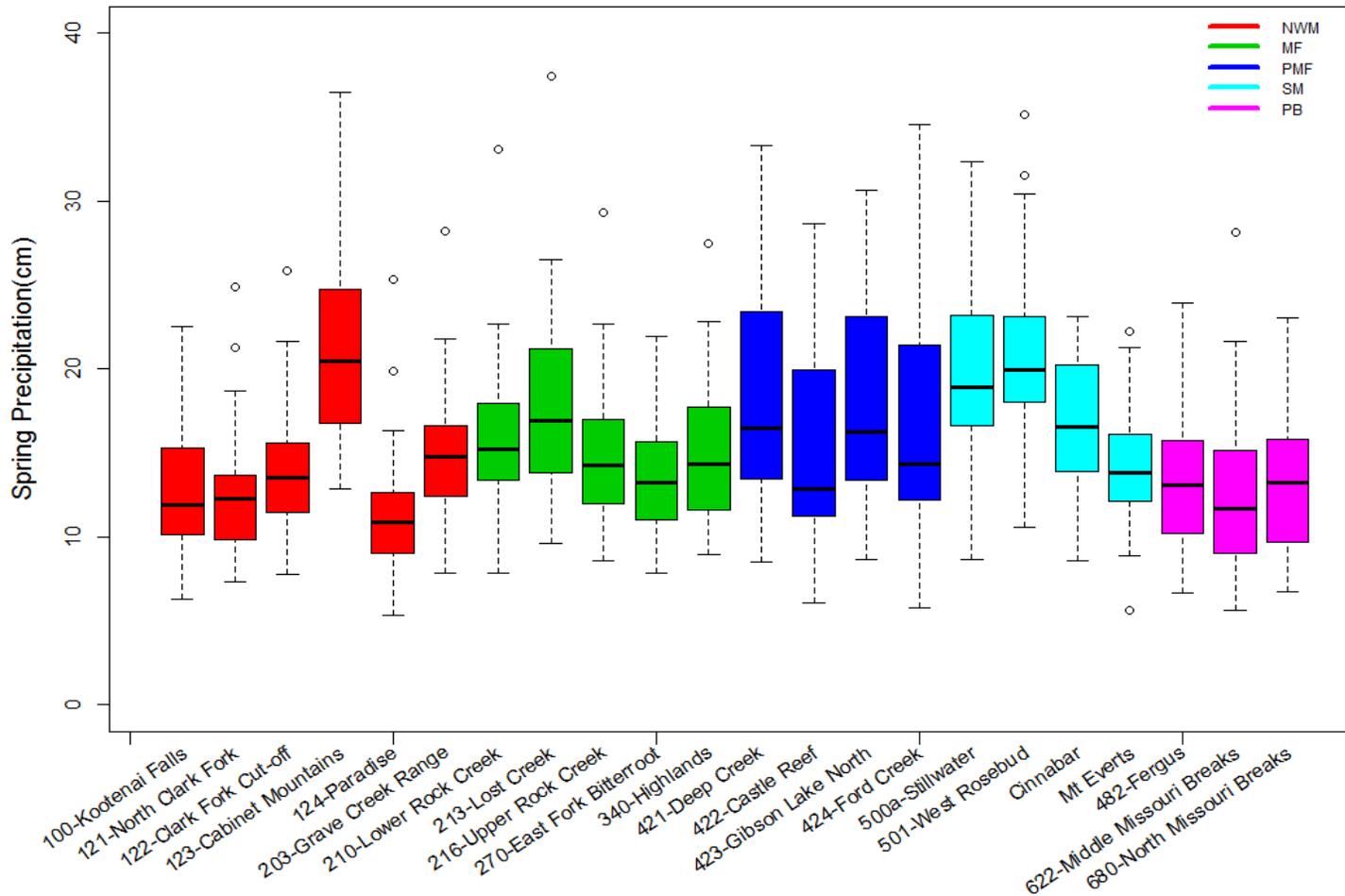


Figure 5. Boxplot illustrating variability of spring (May-June) precipitation experienced by each of the bighorn populations in the spring recruitment and summer-early winter analysis datasets 1980-2012. Box outlines represent the inter-quartile range, whiskers represent values within 1.5 times the interquartile range from the upper or lower quartiles. Open circles represent outliers outside the range of the whiskers. Horizontal center lines represent median values. The plots are color coded by eco-region, which are, from left to right, Northwest Montane (NWM) in red, Mountain Foothills (MF) in green, Prairie Mountain Foothills (PMF) in blue, Southern Mountains (SM) in light blue, and Prairie Breaks (PM) in magenta.

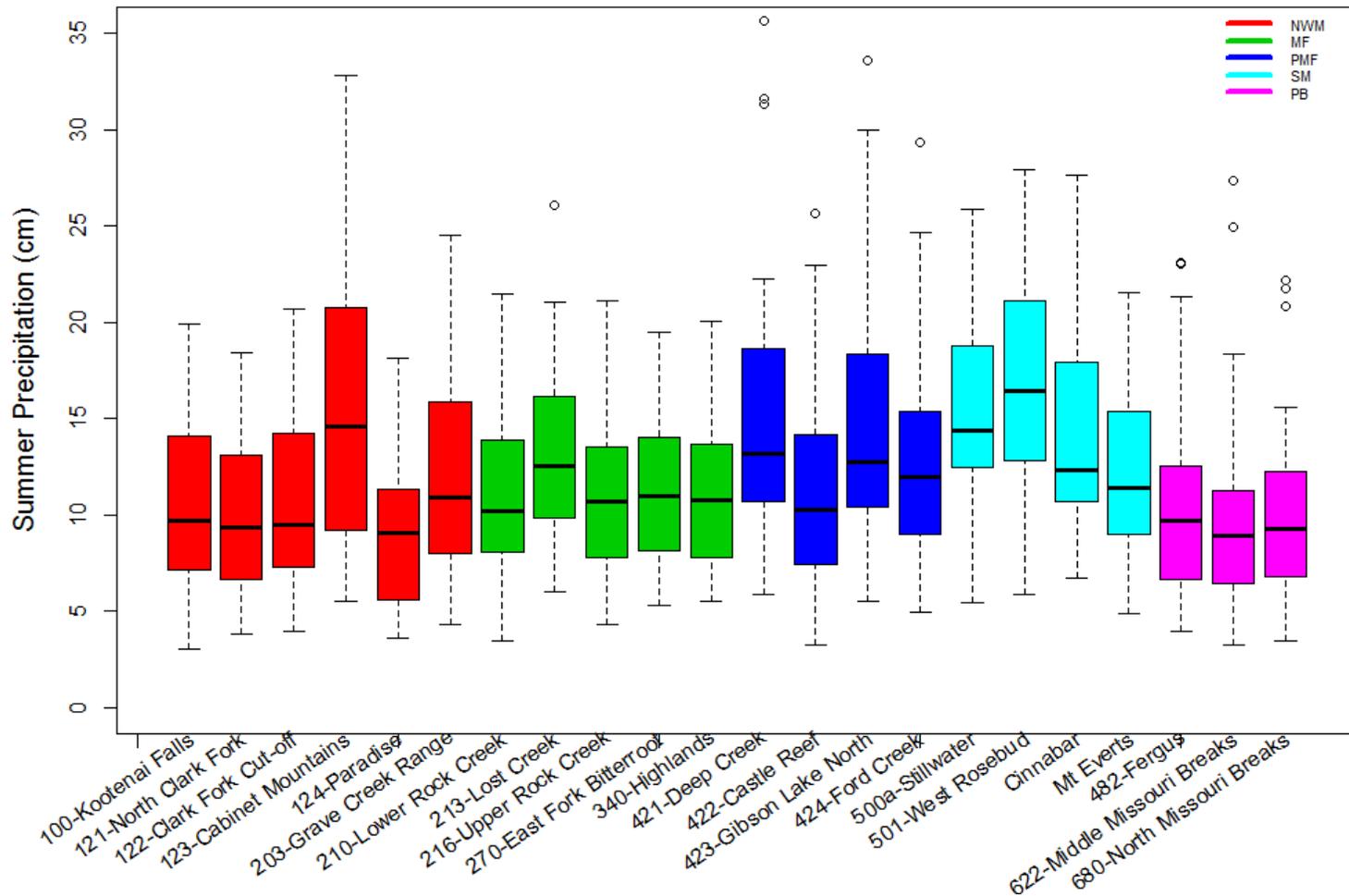


Figure 6. Boxplot illustrating variability of summer (July-September) precipitation (1980-2012) experienced by bighorn populations whose data were analyzed. Box outlines represent the inter-quartile range, whiskers represent values within 1.5 times the interquartile range from the upper or lower quartiles. Open circles represent outliers outside the range of the whiskers. Horizontal center lines represent median values. The plots are color coded by eco-region, which are, from left to right, Northwest Montane (NWM) in red, Mountain Foothills (MF) in green, Prairie Mountain Foothills (PMF) in blue, Southern Mountains (SM) in light blue, and Prairie Breaks (PB) in magenta.

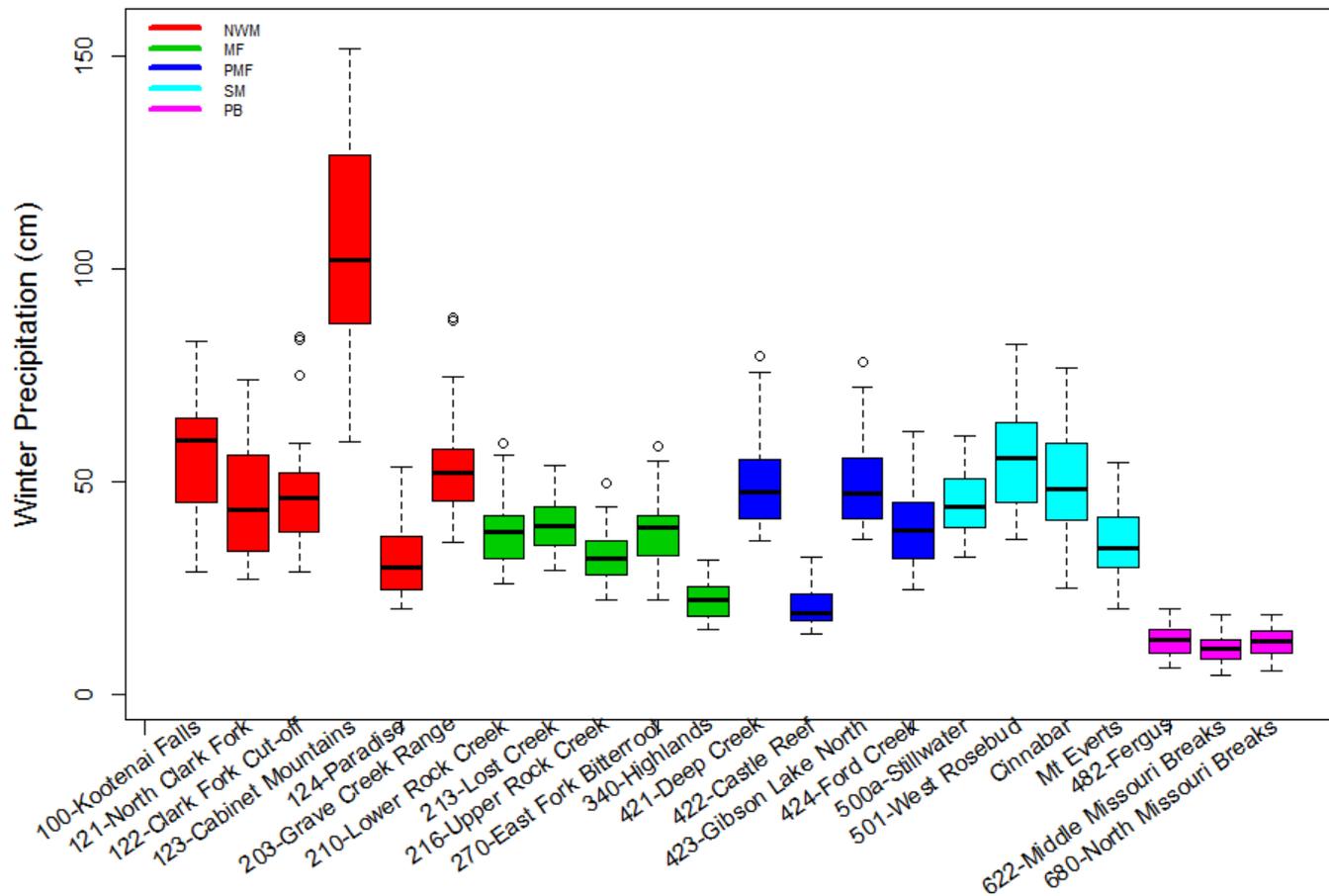


Figure 7. Boxplot illustrating variability of winter (October-April) precipitation (1980-2012) experienced by bighorn populations whose data were analyzed. Box outlines represent the inter-quartile range, whiskers represent values within 1.5 times the interquartile range from the upper or lower quartiles. Open circles represent outliers outside the range of the whiskers. Horizontal center lines represent median values. The plots are color coded by eco-region, which are, from left to right, Northwest Montane (NWM) in red, Mountain Foothills (MF) in green, Prairie Mountain Foothills (PMF) in blue, Southern Mountains (SM) in light blue, and Prairie Breaks (PB) in magenta.

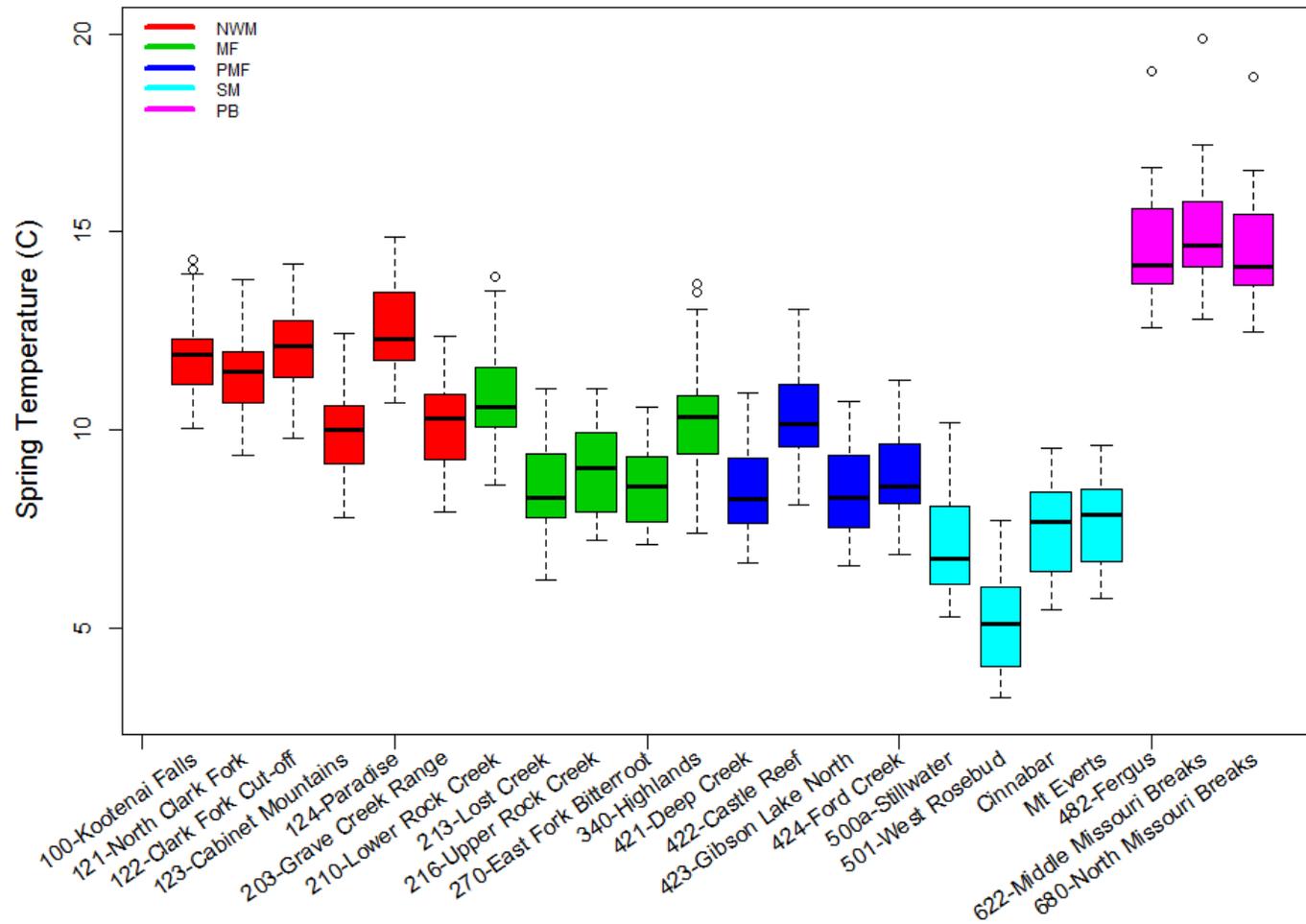


Figure 8. Boxplot illustrating variability of average spring (May-June) temperature (1980-2012) experienced by bighorn populations whose data were analyzed. Box outlines represent the inter-quartile range, whiskers represent values within 1.5 times the interquartile range from the upper or lower quartiles. Open circles represent outliers outside the range of the whiskers. Horizontal center lines represent median values. The plots are color coded by eco-region, which are, from left to right, Northwest Montane (NWM) in red, Mountain Foothills (MF) in green, Prairie Mountain Foothills (PMF) in blue, Southern Mountains (SM) in light blue, and Prairie Breaks (PB) in magenta.

There was a large amount of model-selection uncertainty in the results for this population: 26 models were within 4  $AIC_c$  units of the top model, and the  $\Delta AIC_c$  of the intercept-only model was 1.42. Estimated regression coefficients for two of the covariates (SWE & SWE<sub>t-1</sub>) that occurred in the better-supported models were quite consistent across all models that were within 4  $AIC_c$  units of the top model (range of estimated  $\beta_{SWE} = -4.8$  to  $-2.3$ , range of estimated  $\beta_{SWE(t-1)} = -2.7$  to  $-5.0$ ), while estimated regression coefficients for the other well supported coefficient was less consistent (range of estimated  $\beta_{SP(t-1)} = 0.9$  to  $4.6$ ). Although SWE<sub>t-1</sub> was present in 15 of the 26 models that were within 4  $AIC_c$  units of the top model, model structure was inconsistent across top models (Table 1 of Appendix D).

### *121-North Clark Fork*

The top model describing variation in spring lamb:ewe ratios for the 121-North Clark Fork population only included a negative association of winter precipitation experienced by lambs (estimated  $\beta_{WP} = -2.9$ , 95% CI =  $-6.0$  to  $0.2$ ). This population has not experienced an all-age disease die-off event, and as such, no disease covariates were explored. The recruitment rate under average conditions estimated by the intercept value of the top model was 41.4 lambs:100 ewes (95% CI = 38.4 to 44.4). The adjusted  $R^2$  of the top model was 0.09.

There was much model-selection uncertainty in the results for this population: 25 models were within 4  $AIC_c$  units of the top model and the  $\Delta AIC_c$  of the intercept-only model was 1.25. WP was included in 11 of the 25 models that were within 4  $AIC_c$  units of the top model, and the estimated regression coefficient for WP was consistent across these models (range of estimated  $\beta_{WP} = -2.4$  to  $-2.9$ ). Model structure was inconsistent across top models (Table 2 of Appendix D).

### *122-Clark Fork Cutoff*

The top model describing variation in spring lamb:ewe ratios for the 122-Clark Fork Cutoff population included a positive association of summer precipitation prior to conception of females (estimated  $\beta_{SuP(t-1)} = 4.9$ , 95% CI = 1.4 to 8.5), a positive association of cumulative snow water equivalent experienced by pregnant females (estimated  $\beta_{SWE(t-1)} = 4.1$ , 95% CI = 0.9 to 7.3), a positive association of spring precipitation experienced by neonates (estimated  $\beta_{SP} = 3.7$ , 95% CI =  $-0.3$  to 7.6), and a positive association of average spring temperature experienced by neonates (estimated  $\beta_{SpT} = 6.7$ , 95% CI = 3.6 to 9.9). This population has not experienced an all-age disease die-off event, and as such, no disease covariates were explored. The recruitment rate under average conditions estimated by the intercept value of the top model was 39.1 lambs:100 ewes (95% CI = 36.0 to 42.3). The adjusted  $R^2$  of the top model was 0.53. Figure 9 shows predicted lamb:ewe ratios from this model under varying covariate conditions.

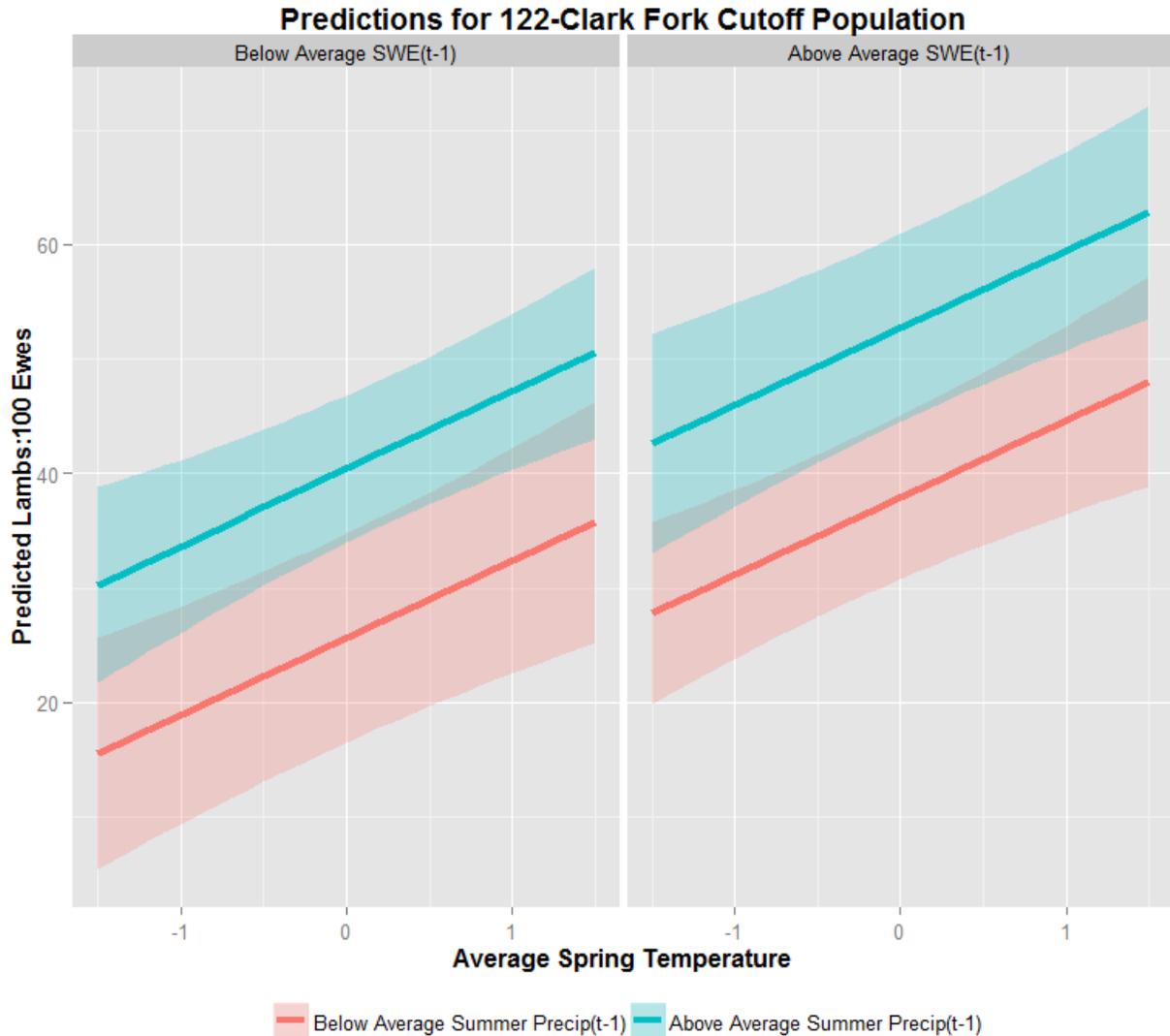


Figure 9. Prediction plots from the top model describing variation in lamb:ewe ratios in the 122-Clark Fork Cutoff bighorn sheep population. The plots show the predicted relationship between average spring temperature (based on standardized values with a mean of 0) experienced by neonates ( $SpT$ ) and lamb:ewe ratios under different weather conditions. The blue line shows predicted lamb:ewe ratios when summer precipitation prior to conception of females ( $SuP_{t-1}$ ) is 1.5 standard deviations above average, the red line shows predicted lamb:ewe ratios when  $SuP_{t-1}$  is 1.5 standard deviations below average. Shaded areas represent 95% confidence bands. The left panel shows predicted lamb:ewe ratios when cumulative snow water equivalent experienced by pregnant females ( $SWE_{t-1}$ ) is 1.5 standard deviations below average and the right panel shows predicted lamb:ewe ratios when  $SWE_{t-1}$  is 1.5 standard deviations above average. Predicted lamb:ewe ratios were calculated assuming spring precipitation experienced by neonates ( $SpP$ ) was at average.

There was little model-selection uncertainty in the results for this population: 8 models were within 4  $AIC_c$  units of the top model and the  $\Delta AIC_c$  of the intercept-only model was 14.9. Estimated regression coefficients for each of the covariates that occurred in the better supported models were consistent across all models that were within 4  $AIC_c$  units of the top model (range of estimated  $\beta_{SuP(t-1)} = 4.4$  to 5.6, range of estimated  $\beta_{SWE(t-1)} = 3.5$  to 4.6, range estimated  $\beta_{SpP} = 3.4$  to 42, range estimated  $\beta_{SpT} = 6.0$  to 7.5. All models that were within 4  $AIC_c$  units of the top model contained SpT, SuP<sub>t-1</sub>, and SWE<sub>t-1</sub>, and 5 of the 8 models that were within 4  $AIC_c$  units of the top model also included SpP (Table 3 of Appendix D).

### *123-Cabinet Mountains*

The intercept-only model was the top-ranked model describing variation in spring lamb:ewe ratios for the 123-Cabinet Mountains population. The population has not experienced an all-age disease die-off event, and as such, no disease covariates were explored. The average recruitment rate estimated by the intercept value of the top model was 41.1 lambs:100 ewes (95% CI= 35.3 to 46.9). The adjusted  $R^2$  of the top model (intercept-only model) was 0.00.

There was much model-selection uncertainty in the results for this population: 16 models were within 4  $AIC_c$  units of the top model and the intercept-only model was the most supported. Model structure was not consistent across top models (Table 4 of Appendix D).

### *124-Paradise*

The intercept-only model was the top-ranked model describing variation in spring lamb:ewe ratios for the 124-Paradise population. The population has not experienced an all-age disease die-off event, and as such, no disease covariates were explored. The average recruitment rate under average conditions, as estimated by the intercept value of the top model, was 36.7 lambs:100 ewes (95% CI= 33.1 to 40.2). The adjusted  $R^2$  of the top model (intercept-only model) was 0.00.

There was much model-selection uncertainty in the results for this population: 19 models were within 4  $AIC_c$  units of the top model and the intercept-only model was the most supported. Model structure was not consistent across top models (Table 5 of Appendix D).

### *203-Grave Creek Range*

The top model describing variation in spring lamb:ewe ratios for the 203-Grave Creek Range population included a negative association of average spring temperature prior to conception of females (estimated  $\beta_{SpT(t-1)} = -6.0$ , 95% CI = -10.4 to -1.7) and a negative association of winter precipitation experienced by pregnant females (estimated  $\beta_{WP(t-1)} = -8.1$ , 95% CI = -12.2 to -4.1). This population has not experienced an all-age disease die-off event, and as such, no disease covariates were explored. The recruitment rate under average conditions estimated by the

intercept value of the top model was 42.4 lambs:100 ewes (95% CI = 38.2 to 46.5). The adjusted  $R^2$  of the top model was 0.50. Figure 10 shows predicted lamb:ewe ratios from this model under varying covariate conditions.

There was little model-selection uncertainty in the results for this population: 8 models were within 4  $AIC_c$  units of the top model and the  $\Delta AIC_c$  of the intercept-only model was 9.2. Estimated regression coefficients for both of the covariates that occurred in the top model were consistent across all models that were within 4  $AIC_c$  units of the top model (range of estimated  $\beta_{SpT(t-1)} = -6.2$  to  $-4.6$ , range of estimated  $\beta_{WP(t-1)} = -8.4$  to  $-7.2$ ).  $WP_{t-1}$  was included in all models that were within 4  $AIC_c$  units of the top model,  $SpT_{t-1}$  was included in 7 of the 8 models that were within 4  $AIC_c$  units of the top model, and 6 of the 8 models included both  $WP_{t-1}$  and  $SpT_{t-1}$  combined with a single uninformative covariate (Table 6 of Appendix D).

### Mountain Foothills Eco-region

#### *210-Lower Rock Creek*

The top model describing variation in spring lamb:ewe ratios for the 210-Lower Rock Creek population only included a negative association of summer precipitation prior to conception of females (estimated  $\beta_{SuP(t-1)} = -10.4$ , 95% CI =  $-22.0$  to  $1.3$ ). This population experienced an all-age disease die-off event in 2009-2010, but a disease covariate was not supported in the top model. The recruitment rate under average conditions and not accounting for the die-off event, as estimated by the intercept value of the top model, was 30.6 lambs:100 ewes (95% CI =  $22.5$  to  $38.8$ ). The adjusted  $R^2$  of the top model was 0.16.

There was much model-selection uncertainty in the results for this population: 19 models were within 4  $AIC_c$  units of the top model and the  $\Delta AIC_c$  of the intercept-only model was 0.6. The estimated regression coefficient for  $SuP_{t-1}$  was consistent across all 9 of the 19 models that were within 4  $AIC_c$  units in which it was present (range of  $\beta_{SuP(t-1)} = -13.5$  to  $-9.2$ ). Model structure was inconsistent across models that were within 4  $AIC_c$  units of the top model (Table 7 of Appendix D).

#### *213-Lost Creek*

The top model describing variation in spring lamb:ewe ratios for the 213-Lost Creek population included a negative association of summer precipitation prior to conception of females (estimated  $\beta_{SuP(t-1)} = -5.0$ , 95% CI =  $-10.5$  to  $0.6$ ) and a negative association of winter precipitation experienced by lambs (estimated  $\beta_{WP} = -3.9$ , 95% CI =  $-7.8$  to  $0.0$ ) for climate covariates. This population experienced all-age disease die-off events in 1991 and 2010 and the top model included D3 (estimated  $\beta_{D3} = -32.3$ , 95% CI =  $-42.3$  to  $-22.2$ ) as the disease covariate

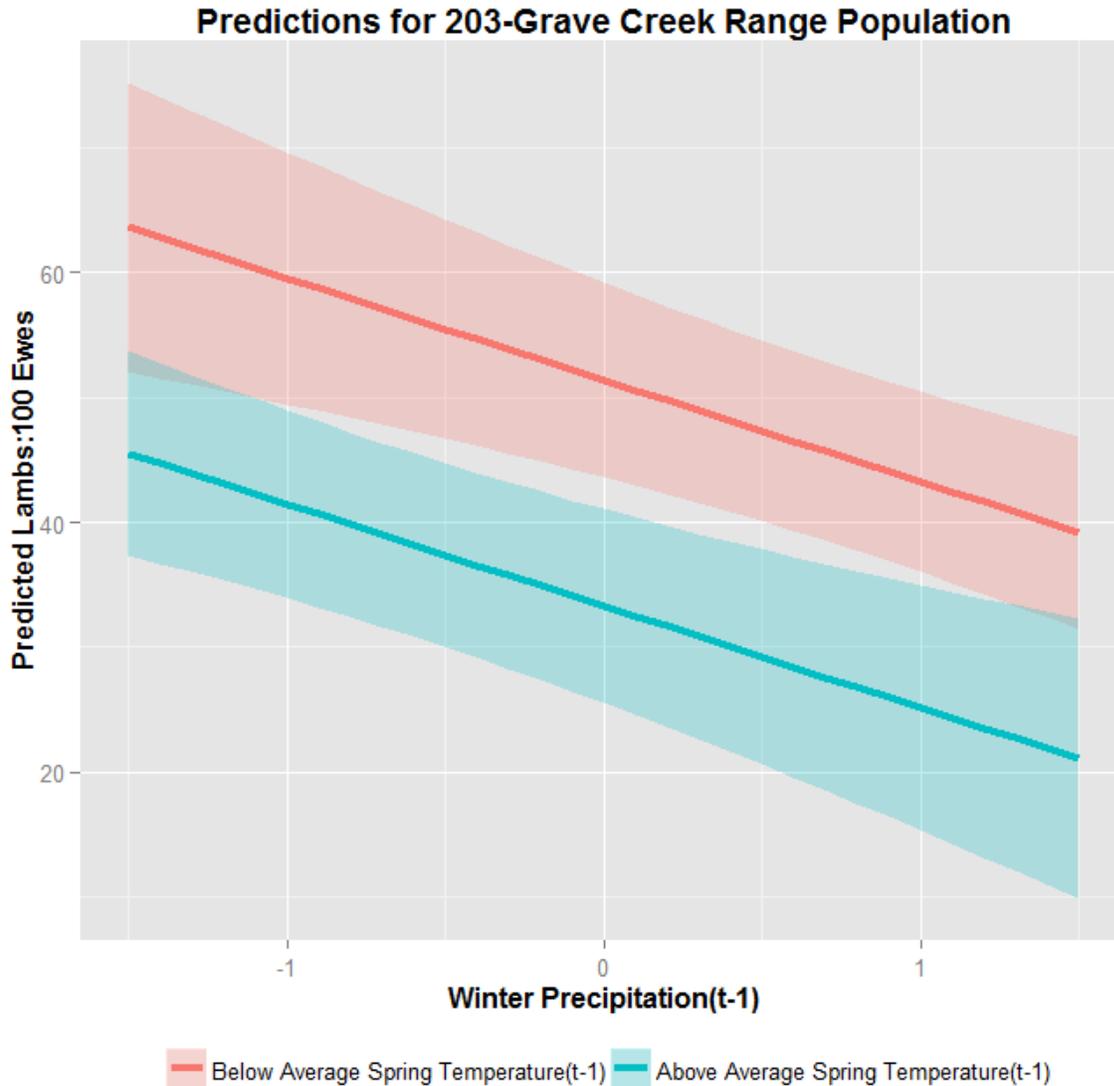


Figure 10. Prediction plot from the top model describing variation in lamb:ewe ratios in the 203-Grave Creek Range bighorn sheep population. The plot shows the predicted relationship between winter precipitation (based on standardized values with a mean of 0) experienced by pregnant females ( $WP_{t-1}$ ) and lamb:ewe ratios under different weather conditions. The blue line shows predicted lamb:ewe ratios when average spring temperature prior to conception of females ( $SpT_{t-1}$ ) is 1.5 standard deviations above average, the red line shows predicted lamb:ewe ratios when  $SpT_{t-1}$  is 1.5 standard deviations below average. Shaded areas represent 95% confidence bands

that best describes the association of all-age disease die-off events with lamb:ewe ratios. This regression coefficient can be interpreted as the average reduction in lambs:100 ewes in this population for the 3 years following an all age disease die-off event. The inclusion of D3 as a disease covariate suggests that the die-off events in this population were negatively associated with recruitment for at least 3 years after the die-off, though data availability made it impossible to determine whether D3 or D4 best described the association of the all-age disease die-off events with recruitment. The recruitment rate under average conditions after accounting for die-off events, as estimated by the intercept value of the top model, was 48.8 lambs:100 ewes (95% CI = 44.2 to 53.3). The predicted recruitment rate under average conditions but within 3 years of an all-age disease die-off event was 16.5 lambs:100 ewes (95% CI = 7.6 to 25.4). The adjusted  $R^2$  of the top model was 0.71. Figure 11 shows predicted lamb:ewe ratios from this model under varying covariate conditions

There was a moderate amount of model-selection uncertainty in the results for this population: 16 models were within 4  $AIC_c$  units of the top model and the  $\Delta AIC_c$  of the intercept-only model was 18.6. D3 was included in all models that were within 4  $AIC_c$  units of the top model and the estimates of the regression coefficient were consistent across these models (range of estimated  $\beta_{D3} = -34.2$  to  $-29.1$ ). WP was included in 12 of the 16 models that were that were within 4  $AIC_c$  units of the top model, and the estimated regression coefficient was consistent across these models (range of estimated  $\beta_{WP} = -4.5$  to  $-3.7$ ).  $SuP_{t-1}$  was included in 9 of the 16 models that were within 4  $AIC_c$  units of the top model and the estimated regression coefficient was consistent across the models (range of estimated  $\beta_{SuP(t-1)} = -5.7$  to  $-4.6$ ). Fifteen of the 16 models that were within 4  $AIC_c$  units of the top model included at least two of the three covariates in the top model (Table 8 of Appendix D).

### *216-Upper Rock Creek*

The top model describing variation in winter/spring lamb:ewe ratios for the 216-Upper Rock Creek population included a positive association of winter precipitation experienced by pregnant females (estimated  $\beta_{WP(t-1)} = 4.4$ , 95% CI = 0.8 to 7.9) and a positive association of average spring temperature experienced by neonates (estimated  $\beta_{SpT} = 3.5$ , 95% CI = -0.5 to 7.6). This population experienced an all-age disease die-off event in 2009-2010 and the top model included D3 (estimated  $\beta_{D3} = -32.6$ , 95% CI = -43.5 to -21.8) as the disease covariate that best describes the association of the die-off events with lamb:ewe ratios. This regression coefficient can be interpreted as the average reduction in lambs:100 ewes in this population for the 3 years following an all-age disease die-off event. The inclusion of D3 as a disease covariate suggests that the die-off event in this population was negatively associated with recruitment for at least 3

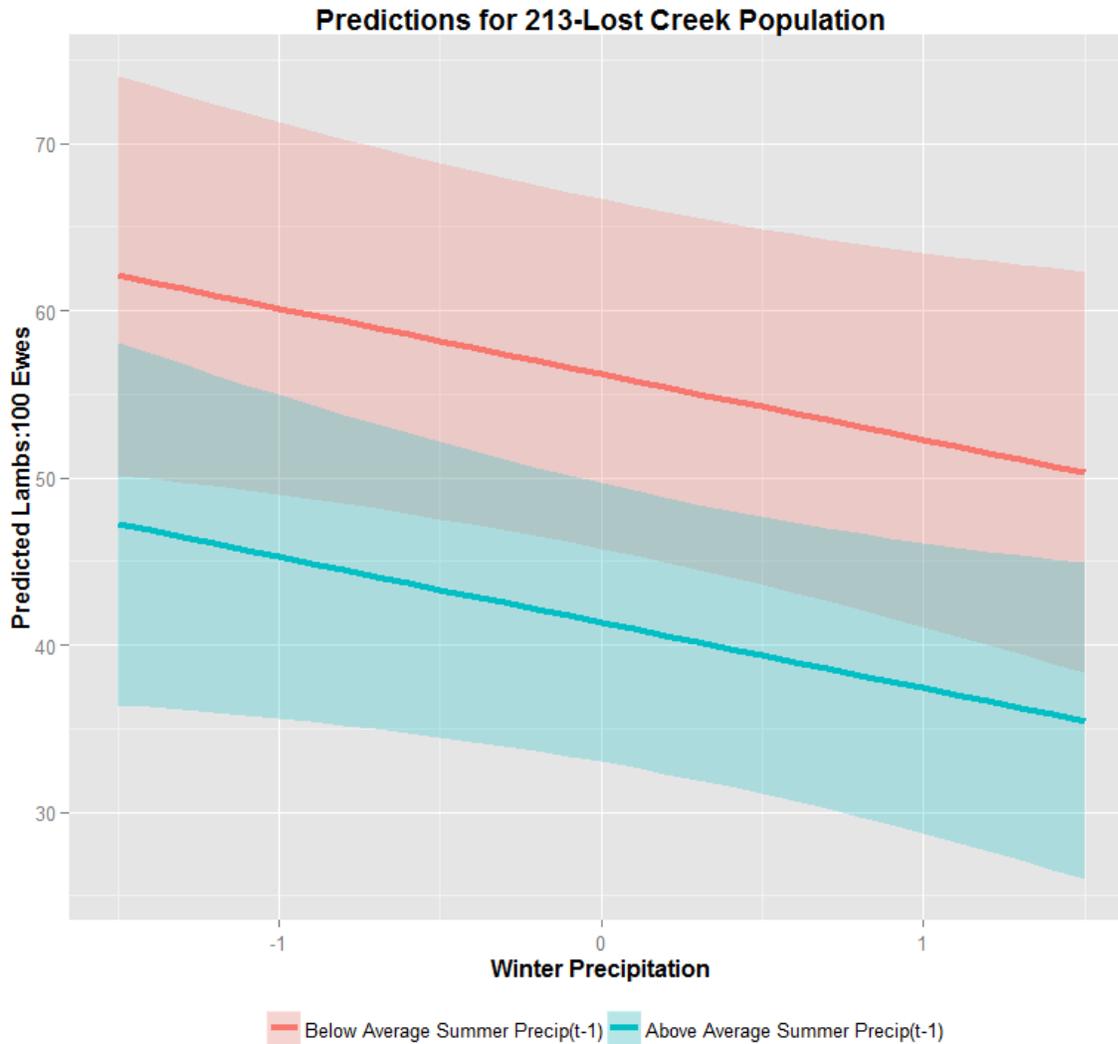


Figure 11. Prediction plot from the top model describing variation in lamb:ewe ratios in the 213-Lost Creek bighorn sheep population, in years when recruitment is not associated with all-age disease die-offs. The plot shows the predicted relationship between winter precipitation (based on standardized values with a mean of 0) experienced by lambs (WP) and lamb:ewe ratios under different weather conditions. The blue line shows predicted lamb:ewe ratios when summer precipitation prior to conception of females ( $SuP_{t-1}$ ) is 1.5 standard deviations above average, the red line shows predicted lamb:ewe ratios when  $SuP_{t-1}$  is 1.5 standard deviations below average. Shaded areas represent 95% confidence bands

years after the die-offs, though data availability (due to how recently the disease die-off event occurred) made it impossible to determine whether D3, D4, or D5 best describes the association of the die-off event with recruitment. The recruitment rate under average conditions after accounting for all-age disease die-off events, as estimated by the intercept value of the top model, was 42.1 lambs:100 ewes (95% CI = 38.3 to 46.0). The predicted recruitment rate under average conditions but within 3 years of a disease die-off event was 9.5 lambs:100 ewes (95% CI = 0 to 19.6). The adjusted  $R^2$  of the top model was 0.74. Figure 12 shows predicted lamb:ewe ratios from this model under varying covariate conditions

There was a moderate amount of model-selection uncertainty in the results of this population: 29 models were within 4  $AIC_c$  units of the top model and the  $\Delta AIC_c$  of the intercept-only model was 23.5. D3 was included in all models that were within 4  $AIC_c$  units of the top model and the estimates of the regression coefficient were consistent across these models (range of estimated  $\beta_{D3} = -37.4$  to  $-31.8$ ).  $WP_{t-1}$  was included in 17 of the 29 models that were within 4  $AIC_c$  units of the top model and the estimates of the regression coefficient were consistent across these models (range of estimated  $\beta_{WP(t-1)} = 2.7$  to 4.4). SpT was included in 11 of the 29 models that were within 4  $AIC_c$  units of the top model and the estimates of the regression coefficient were consistent across these models (range of estimated  $\beta_{SpT} = 1.8$  to 4.2). Although spring precipitation experienced by neonates (SpP) was not included in the top model, it received some support. SpP was included in 13 of the 29 models that were within 4  $AIC_c$  units of the top model and the estimates of the regression coefficient were consistent across these models (range of estimated  $\beta_{SpP} = -5.5$  to  $-2.8$ ). Model structure was consistent across models that were within 4  $AIC_c$  units of the top model with regard to the disease covariate, as D3 was included in all of the models, but model structure across these models was inconsistent with regard to the climate covariates (Table 9 of Appendix D).

### *270-East Fork Bitterroot*

The top model describing variation in spring lamb:ewe ratios for the 270-East Fork Bitterroot population included no climate covariates. This population experienced an all-age disease die-off event 2009-2010 and the top model included Dc (estimated  $\beta_{Dc} = -21.6$ , 95% CI =  $-44.4$  to 1.2) as the disease covariate that best describes the association of the disease outbreak with lamb:ewe ratios. This regression coefficient can be interpreted by multiplying the estimated beta

$$\frac{1}{\text{Years since die-off event}}$$

coefficient by  $\frac{1}{\text{Years since die-off event}}$ , which predicts a gradual recovery in lamb:ewe ratios following a disease outbreak. The model predicts the lamb:ewe ratio the year following an all-age disease die-off event to be 7.5 (95% CI = 0 to 29.4), the lamb:ewe ratio 2 years following a die-off event to be 18.3 lambs:100 ewes (95% CI = 7.3 to 29.4), and the lamb:ewe ratio 3 years following a die-off event to be 21.9 lambs:100 ewes (95% CI = 14.2 to 29.7). The recruitment rate under average conditions after accounting for the all-age disease die-off events, as estimated by the intercept value of the top model, was 29.1 lambs:100 ewes (95% CI = 24.3 to 34.0).

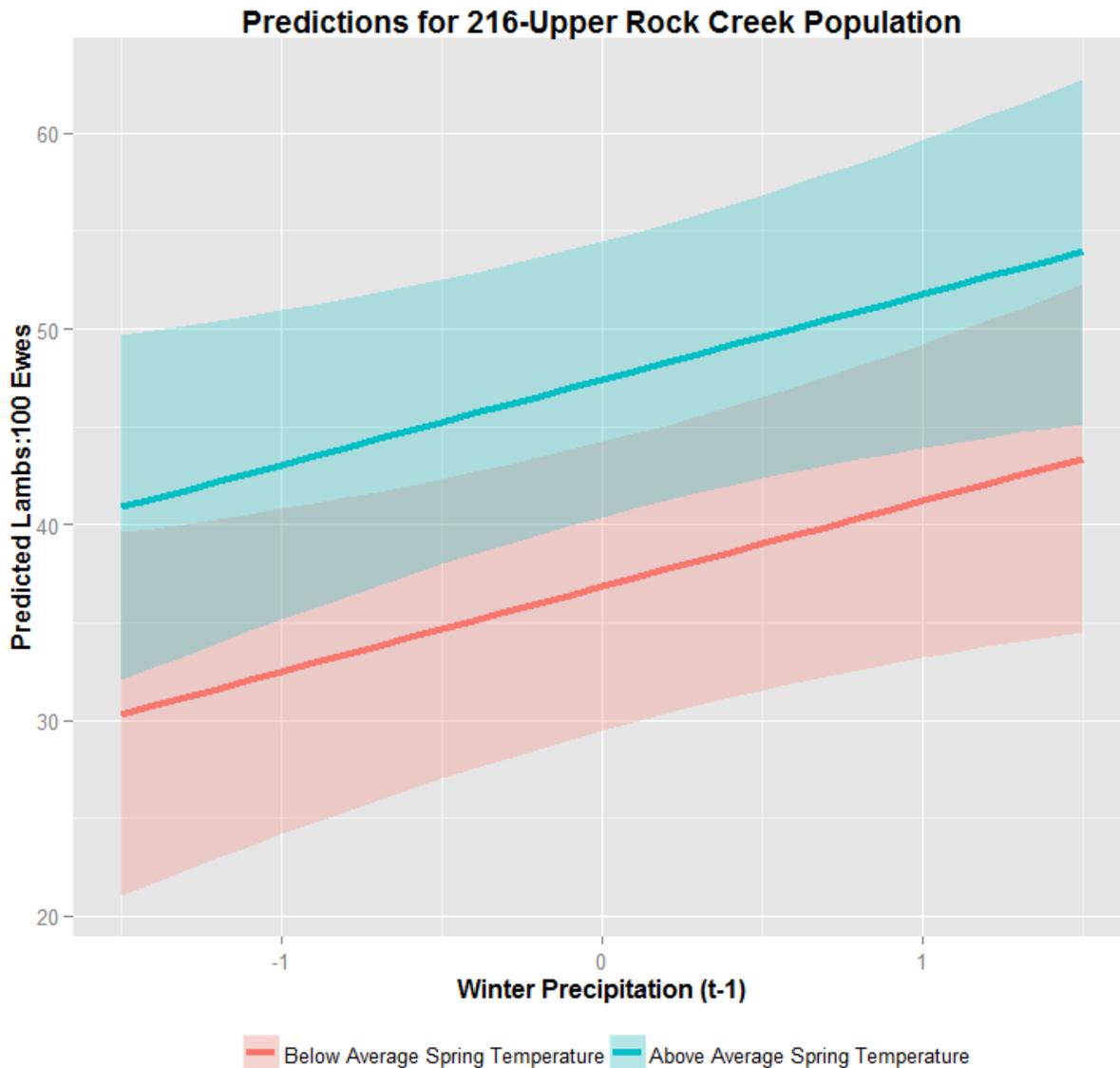


Figure 12. Prediction plot from the top model describing variation in lamb:ewe ratios in the 213-Lost Creek bighorn sheep population, in years when recruitment is not associated with all-age disease die-offs. The plot shows the predicted relationship between winter precipitation experienced by pregnant females ( $WP_{t-1}$ ) and lamb:ewe ratios under different weather conditions. The blue line shows predicted lamb:ewe ratios when average spring temperature (based on standardized values with a mean of 0) experienced by neonates (SpT) is 1.5 standard deviations above average, the red line shows predicted lamb:ewe ratios when SpT is 1.5 standard deviations below average. Shaded areas represent 95% confidence bands

There was much model-selection uncertainty in the results for this population: 35 models were within 4  $AIC_c$  units of the top model and the  $\Delta AIC_c$  of the intercept-only model was 1.3. Dc was included in 19 of the 35 models that were within 4  $AIC_c$  units of the top model, and the estimates of the regression coefficient were consistent across these models (range estimated  $\beta_{Dc} = -22.0$  to  $-16.3$ ). Model structure was inconsistent across models that were within 4  $AIC_c$  units of the top model (Table 10 of Appendix D).

### *340-Highlands*

The top model describing variation in spring lamb:ewe ratios for the 340-Highlands population included a positive association of cumulative snow water equivalent experienced by lambs (estimated  $\beta_{SWE} = 7.3$ , 95% CI =  $-0.5$  to  $15.1$ ). This population experienced an all-age disease die-off event in 1995 and the top model included D3 (estimated  $\beta_{D3} = -36.0$ , 95% CI =  $-57.7$  to  $-14.2$ ) as the disease covariate that best describes the association of the die-off event with lamb:ewe ratios. This regression coefficient can be interpreted as the average reduction in lambs:100 ewes in this population for the 3 years following the all-age disease die-off event. The inclusion of D3 as a disease covariate suggests that the die-off event in this population was negatively associated with recruitment for at least 3 years after the die-off, though data availability made it impossible to determine whether D3, D4, or D5 best described the association of disease with recruitment. The recruitment rate under average conditions after accounting for the all-age disease die-off event, as estimated by the intercept value of the top model, was 38.0 lambs:100 ewes (95% CI =  $30.3$  to  $45.7$ ). The predicted recruitment rate under average conditions but within 3 years of the die-off event was 2.0 lambs:100 ewes (95% CI =  $0$  to  $20.6$ ). The adjusted  $R^2$  of the top model was 0.47.

There was a moderate amount of model-selection uncertainty: 10 models were within 4  $AIC_c$  units of the top model and the  $\Delta AIC_c$  of the intercept-only model was 4.0. D3 was included in 9 of the 10 models that were within 4  $AIC_c$  units of the top model, and the estimates of the regression coefficients were not consistent across these models (range estimated  $\beta_{D3} = -36$  to  $-19.3$ ). SWE was included in 3 of the 10 models that were within 4  $AIC_c$  units of the top model and the estimates of the regression coefficients were similar across these models (range of estimated  $\beta_{SWE} = 6.3$  to  $7.6$ ). Model structure was consistent across models that were within 4  $AIC_c$  units of the top model with regard to the disease covariate, as D3 was included in 9 of the 10 models, but model structure was inconsistent with regard to the climate covariates (Table 11 of Appendix D).

## Prairie Mountain Foothills Eco-region

### *421-Deep Creek-Winter Recruitment Data*

The intercept-only model was the top-ranked model describing variation in winter lamb:ewe ratios for the 421-Deep Creek population. This population experienced all-age disease die-off events in 1984 and 2010, but a disease covariate was not supported in the top model. The recruitment rate under average conditions and not accounting for die-off events, as estimated by the intercept value of the top model, was 27.5 lambs:100 ewes (95% CI = 17.8 to 37.1). The adjusted  $R^2$  of the top model (intercept-only model) was 0.00.

There was much model-selection uncertainty in the results for this population: 19 models were within 4  $AIC_c$  units of the top model and the intercept-only model was the most supported. Model structure was not consistent across models that were within 4  $AIC_c$  units of the top model, with top models including different combinations of one or two uninformative parameters (Table 12 of Appendix D).

### *422-Castle Reef-Winter Recruitment Data*

The top model describing variation in winter lamb:ewe ratios for the 422-Castle Reef population included a negative association of spring precipitation prior to conception of females (estimated  $\beta_{SpP(t-1)} = -4.4$ , 95% CI = -9.9 to 1.1). This population experienced all-age disease die-off events in 1984 and 2010 and the top model included D2 (estimated  $\beta_{D2} = -35.3$ , 95% CI = -52.5 to -18.2) as the disease covariate that best describes the association of the die-off events with lamb:ewe ratios. This regression coefficient can be interpreted as the average reduction in lambs:100 ewes in this population for the 2 years following an all age disease die-off event. The inclusion of D2 as a disease covariate suggests that the die-off events in this population were negatively associated with recruitment for at least 2 years after the die-off. The recruitment rate under average conditions after accounting for all-age disease die-off events, as estimated by the intercept value of the top model, was 44.1 lambs:100 ewes (95% CI = 38.4 to 49.7). The predicted recruitment rate under average conditions but within 2 years of an all-age disease die-off event was 8.8 lambs:100 ewes (95% CI = 0 to 25.0). The adjusted  $R^2$  of the top model was 0.40.

There was a moderate amount of model-selection uncertainty: 16 models were within 4  $AIC_c$  units of the top model and the  $\Delta AIC_c$  of the intercept-only model was 10.6. D2 was included in all models that were within 4  $AIC_c$  units of the top model, and the estimates of the regression coefficient were consistent across these models (range of estimated  $\beta_{D2} = -36.5$  to -29.9).  $SpP_{t-1}$  was included in 7 of the 16 models that were within 4  $AIC_c$  units of the top model and the estimates of the regression coefficient were consistent across these models (range of estimated  $\beta_{SpP(t-1)} = -4.4$  to -3.9). Model structure was consistent across models that were within 4  $AIC_c$

units of the top model with regard to the disease covariate, as D2 was included in all models, but model structure was inconsistent with regard to the climate covariates (Table 13 of Appendix D)

#### *422-Castle Reef-Spring Recruitment Data*

The top model describing variation in spring lamb:ewe ratios for the 422-Castle Reef population included a negative association of spring precipitation prior to conception of females (estimated  $\beta_{SpP(t-1)} = -4.8$ , 95% CI = -10.9 to 1.3). This population experienced all-age disease die-off events in 1984 and 2010 and the top model included D2 (estimated  $\beta_{D2} = -29.7$ , 95% CI = -47.2 to -12.2) as the disease covariate that best describes the association of the die-off events with lamb:ewe ratios. This regression coefficient can be interpreted as the average reduction in lambs:100 ewes in this population for the 2 years following an all age disease die-off event. The inclusion of D2 as a disease covariate suggests that the die-off events in this population were negatively associated with recruitment for at least 2 years after the die-off. The recruitment rate under average conditions after accounting for all-age disease die-off events, as estimated by the intercept value of the top model, was 43.2 lambs:100 ewes (95% CI = 36.4 to 50.1). The predicted recruitment rate under average conditions but within 2 years of a die-off event was 13.5 lambs:100 ewes (95% CI = 0 to 29.4). The adjusted  $R^2$  of the top model was 0.32.

There was a moderate amount of model-selection uncertainty: 20 models were within 4  $AIC_c$  units of the top model and the  $\Delta AIC_c$  of the intercept-only model was 6.2. D2 was included in all models that were within 4  $AIC_c$  units of the top model, and the estimates of the regression coefficient were relatively consistent across these models (range of estimated  $\beta_{D2} = -22.0$  to -31.1).  $SpP_{t-1}$  was included in 8 of the 20 models that were within 4  $AIC_c$  units of the top model and the estimates of the regression coefficient were consistent across these models (range of estimated  $\beta_{SpP(t-1)} = -5.1$  to -4.0). Model structure was consistent across models that were within 4  $AIC_c$  units of the top model with regard to the disease covariate, as D2 was included in all models, but model structure was inconsistent with regard to the climate covariates (Table 14 of Appendix D).

#### *423-Gibson Lake North-Winter Recruitment Data*

The top model describing variation in winter lamb:ewe ratios for the 423-Gibson Lake North population included no climate covariates. This population experienced all-age disease die-off events in 1984 and 2010 and the top model included Dc (estimated  $\beta_{Dc} = -34.6$ , 95% CI = -57.0 to -12.2) as the disease covariate that best describes the association of the disease outbreak with lamb:ewe ratios. This regression coefficient can be interpreted by multiplying the estimated beta coefficient by  $\frac{1}{\text{Years since die-off event}}$ , which predicts a gradual recovery in lamb:ewe ratios following

a disease outbreak. The model predicts the lamb:ewe ratio the year following a disease outbreak to be 12.4 (95% CI = 0 to 32.6), the lamb:ewe ratio 2 years following a disease outbreak to be 29.7 lambs:100 ewes (95% CI = 19.5 to 40.0), and the lamb:ewe ratio 3 years following a disease

outbreak to be 35.5 lambs:100 ewes (95% CI = 27.8 to 43.2). The recruitment rate under average conditions after accounting for all-age disease die-off events, as estimated by the intercept value of the top model, was 47.0 lambs:100 ewes (95% CI = 39.8 to 54.3). The adjusted  $R^2$  of the top model was 0.27.

There was much model-selection uncertainty in the results for this population: 25 models were within 4  $AIC_c$  units of the top model and the  $\Delta AIC_c$  of the intercept-only model was 6.6. Dc was included in all models that were within 4  $AIC_c$  units of the top model, though the estimates of the regression coefficient varied across these models (range estimated  $\beta_{Dc} = -29.0$  to  $-49.6$ ). Model structure was consistent across models that were within 4  $AIC_c$  units of the top model with regard to the disease covariate, as Dc was included in all models, but model structure was inconsistent with regard to the climate covariates (Table 15 of Appendix D).

#### *423-Gibson Lake North-Spring Recruitment Data*

The top model describing variation in spring lamb:ewe ratios for the 423-Gibson Lake North population included a negative association of average spring temperature prior to conception of females (estimated  $\beta_{SpT(t-1)} = -10.2$ , 95% CI=  $-17.4$  to  $-3.1$ ), a positive association of summer precipitation prior to conception of females (estimated  $\beta_{SuP(t-1)} = 8.9$ , 95% CI=  $3.5$  to  $14.3$ ), a negative association of cumulative snow water equivalent experienced by pregnant females (estimated  $\beta_{SWE(t-1)} = -8.3$ , 95% CI=  $-13.4$  to  $-3.2$ ), a positive association of spring precipitation experienced by neonates (estimated  $\beta_{SpP} = 7.2$ , 95% CI=  $2.3$  to  $13.1$ ), and a negative association of cumulative snow water equivalent experienced by lambs (estimated  $\beta_{SWE} = -7.3$ , 95% CI=  $-14.0$  to  $-0.7$ ). This population experienced all-age disease die-off events in 1984 and 2010 and the top model included D2 (estimated  $\beta_{D2} = -39.3$ , 95% CI =  $-54.8$  to  $-23.7$ ) as the disease covariate that best describes the association of the disease outbreaks with lamb:ewe ratios. This regression coefficient can be interpreted as the average reduction in lambs:100 ewes in this population for the 2 years following an all age disease die-off event. The inclusion of D2 as a disease covariate suggests that the die-off events in this population were negatively associated with recruitment for at least 2 years after the die-off. The recruitment rate under average conditions after accounting for all-age disease die-off events, as estimated by the intercept value of the top model, was 36.9 lambs:100 ewes (95% CI = 31.7 to 42.1). The predicted recruitment rate under average conditions but within 2 years of a die-off event was 0 lambs:100 ewes (95% CI = 0 to 11.9). The adjusted  $R^2$  of the top model was 0.62. Figure 13 shows predicted lamb:ewe ratios from this model under varying covariate conditions.

There was little model-selection uncertainty in the results for this population: 10 models were within 4  $AIC_c$  units of the top model, and the  $\Delta AIC_c$  of the intercept-only model was 10.8. D2 was included in all models that were within 4  $AIC_c$  units of the top model, though the estimates of the regression coefficient varied across these models (range estimated  $\beta_{D2} = -27.6$  to  $-41.43$ ).

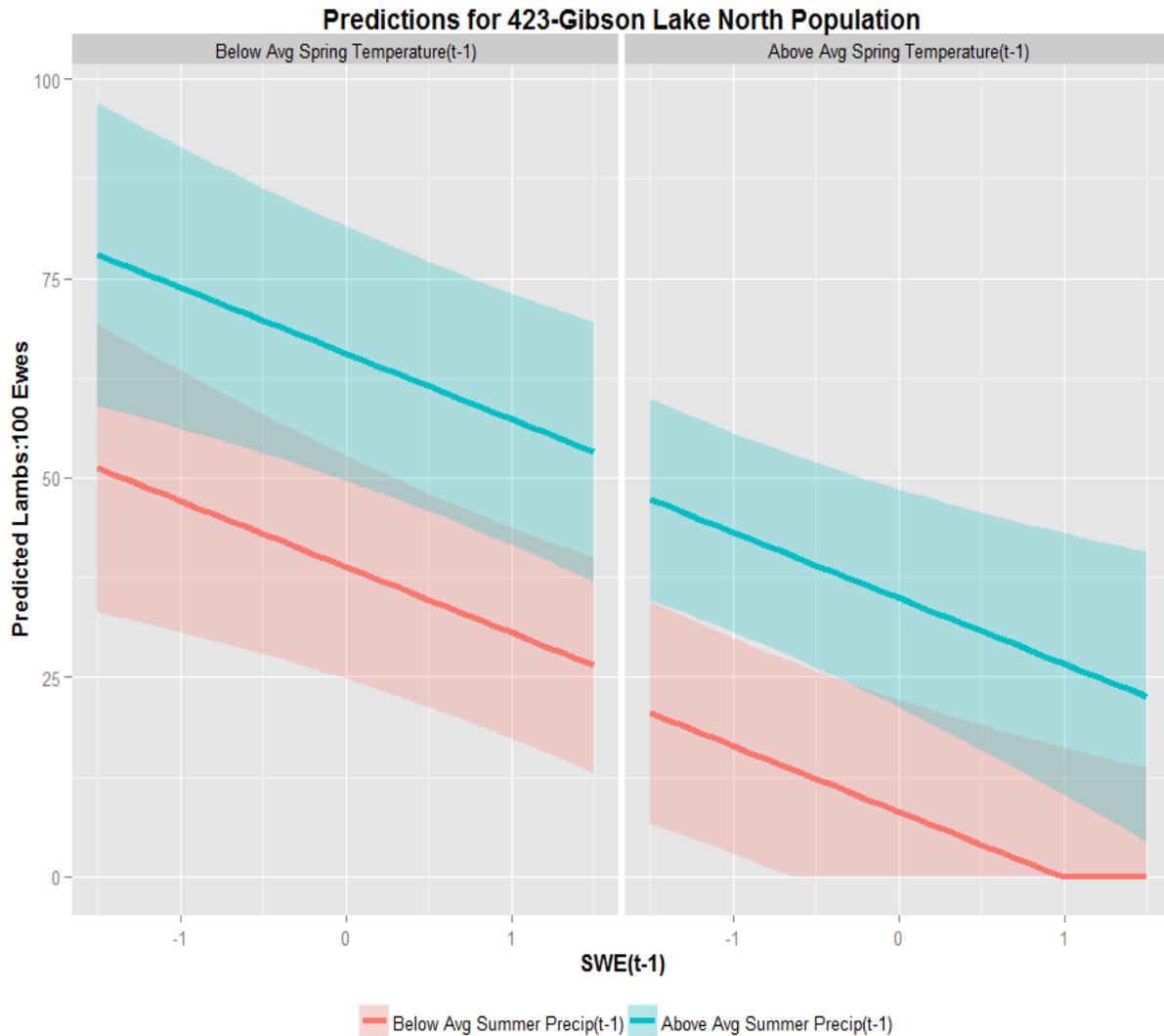


Figure 13. Prediction plots from the top model describing variation in lamb:ewe ratios in the 423-Gibson Lake North bighorn sheep population, in years when recruitment is not associated with all-age disease die-offs. The plots show the predicted relationship between average spring temperature (based on standardized values with a mean of 0) experienced by neonates ( $SWE_{t-1}$ ) and lamb:ewe ratios under different weather conditions. The blue line shows predicted lamb:ewe ratios when summer precipitation prior to conception of females ( $SuP_{t-1}$ ) is 1.5 standard deviations above average, the red line shows predicted lamb:ewe ratios when  $SuP_{t-1}$  is 1.5 standard deviations below average. Shaded areas represent 95% confidence bands. The left panel shows predicted lamb:ewe ratios when average spring temperature prior to conception of females ( $SpT_{t-1}$ ) is 1.5 standard deviations below average and the right panel shows predicted lamb:ewe ratios when  $SpT_{t-1}$  is 1.5 standard deviations above average. Predicted lamb:ewe ratios were calculated assuming spring precipitation experienced by neonates ( $SpP$ ), and cumulative snow water equivalent experienced by lambs ( $SWE$ ) were both at average.

SpT<sub>t-1</sub> was included in 9 of the 10 models that were within 4 AIC<sub>c</sub> units of the top model, and the estimates of the regression coefficient was consistent (range estimated  $\beta_{\text{SpT}(t-1)} = -7.6$  to  $-10.5$ ). SuP<sub>t-1</sub> was included in 9 of the 10 models that were within 4 AIC<sub>c</sub> units of the top model, and the estimates of the regression coefficient was consistent (range estimated  $\beta_{\text{SuP}(t-1)} = 6.2$  to  $8.9$ ). SWE<sub>t-1</sub> was included in all models that were within 4 AIC<sub>c</sub> units of the top model, and the estimates of the regression coefficient was consistent (range estimated  $\beta_{\text{SWE}(t-1)} = -7.6$  to  $-10.5$ ). SpP and SWE were each included in 4 of the 10 models, and estimated regression coefficients were somewhat consistent (range estimated  $\beta_{\text{SpP}} = 3.8$  to  $8.4$ , range estimated  $\beta_{\text{SWE}} = -7.3$  to  $-3.0$ ). Model structure was consistent across models that were within 4 AIC<sub>c</sub> units of the top model as 8 of the 10 models included D2, SpT<sub>t-1</sub>, SuP<sub>t-1</sub> and SWE<sub>t-1</sub>, with other climate covariates included, and the other 2 models included D2 and two of the three well-supported climate covariates (Table 16 of Appendix D).

#### *424-Ford Creek-Winter Recruitment Data*

The top model describing variation in winter lamb:ewe ratios for the 424-Ford Creek population included a negative association of spring precipitation experienced by neonates (estimated  $\beta_{\text{SpP}} = -5.8$ , 95% CI =  $-12.2 - 0.6$ ). This population experienced all-age disease die-off events in 1984 and 2010 and the top model included D2 (estimated  $\beta_{\text{D2}} = -18.7$ , 95% CI =  $-32.7$  to  $-4.6$ ) as the disease covariate that best describes the influence of die-off events on lamb:ewe ratios. This regression coefficient can be interpreted as the average reduction in lambs:100 ewes in this population for the 2 years following an all age disease die-off event. The inclusion of D2 as a disease covariate suggests that the die-off events in this population were negatively associated with recruitment for at least 2 years after the die-off, though missing data made it impossible to determine whether D2, D3, D4 or D5 best described the association of disease with recruitment. The recruitment rate under average conditions after accounting for all-age disease die-off events, as estimated by the intercept value of the top model, was 38.4 lambs:100 ewes (95% CI =  $32.8$  to  $43.9$ ). The predicted recruitment rate under average conditions but within 2 years of a die-off event was 19.7 lambs:100 ewes (95% CI =  $6.7$  to  $32.6$ ). The adjusted R<sup>2</sup> of the top model was 0.26.

There was much model-selection uncertainty in the results for this population: 28 models were within 4 AIC<sub>c</sub> units of the top model and the  $\Delta\text{AIC}_c$  of the intercept-only model was 4.7. D2 was included in 26 of the 28 models that were within 4 AIC<sub>c</sub> units of the top model, though the estimates of the regression coefficient varied across these models (range estimated  $\beta_{\text{D2}} = -23.1$  to  $-13.0$ ). SpP was included in 12 of the 28 models that were within 4 AIC<sub>c</sub> units of the top models, and estimates of the regression coefficient were consistent across these models (range estimated  $\beta_{\text{SpP}} = -5.9$  to  $-4.6$ ). Although summer precipitation experienced by lambs (SuP) was not included in the top model it received some support. SuP was included in 13 of the 28 models that were within 4 AIC<sub>c</sub> units of the top model, and estimates of regression coefficients were somewhat consistent (range estimated  $\beta_{\text{SuP}} = 3.7$  to  $7.9$ ). Model structure was consistent across models that were within 4 AIC<sub>c</sub> units of the top model with regard to the disease covariate, as D2

was included in all models, but model structure was inconsistent with regard to the climate covariates (Table 17 of Appendix D).

#### *424-Ford Creek-Spring Recruitment Data*

The top model describing variation in spring lamb:ewe ratios included a positive association of average spring temperature prior to conception of females (estimated  $\beta_{SpT(t-1)} = 11.2$ , 95% CI = 1.1 to 21.2) and a negative association of winter precipitation experienced by lambs (estimated  $\beta_{WP} = -9.3$ , 95% CI = -17.1 to -1.5). This population experienced all-age disease die-off events in 1984 and 2010, but a disease covariate was not supported in the top model. The recruitment rate under average conditions and not accounting for all-age disease die-off events estimated by the intercept value of the top model was 35.4 lambs:100 ewes (95% CI = 28.0 to 42.8). The adjusted  $R^2$  of the top model was 0.26.

There was little model-selection uncertainty in the results for this population: 13 models were within 4  $AIC_c$  units of the top model and the  $\Delta AIC_c$  of the intercept-only model was 2.6.  $SpT_{t-1}$  was included in 10 of the 13 models that were within 4  $AIC_c$  units of the top model and the estimates of the regression coefficient were relatively consistent (range estimated  $\beta_{SpT(t-1)} = 7.3$  to 11.2).  $WP$  was included in 9 of the 13 models that were within 4  $AIC_c$  units of the top model and the estimates of the regression coefficient were consistent (range estimated  $\beta_{WP} = -9.6$  to -6.6). Model structure was mostly consistent as 8 of the 13 models that were within 4  $AIC_c$  units of the top model included both  $SpT_{t-1}$  and  $WP$ , with a single uninformative covariate included in most of these models. 11 of the 13 models that were within 4  $AIC_c$  units of the top model included either  $SpT_{t-1}$  or  $WP$  (Table 18 of Appendix D).

#### *Southern Mountains Eco-region*

##### *Cinnabar*

The top model describing variation in spring lamb:ewe ratios for the Cinnabar population included a negative association of average spring precipitation prior to conception of females (estimated  $\beta_{SpP(t-1)} = -4.9$ , 95% CI = -10.2 to 0.4) and a negative association of winter precipitation experienced by pregnant females (estimated  $\beta_{WP(t-1)} = -5.9$ , 95% CI = -11.8 to 0.2). This population has not experienced an all-age disease die-off event during the time period data were available, and as such no disease covariates were explored. The recruitment rate under average conditions, as estimated by the intercept value of the top model, was 27.1 lambs:100 ewes (95% CI = 22.3 to 31.9). The adjusted  $R^2$  of the top model was 0.26.

There was much model-selection uncertainty in the results for this population: 28 models were within 4  $AIC_c$  units of the top model and the  $\Delta AIC_c$  of the intercept-only model was 0.4. Estimated regression coefficients for both of the covariates that occurred in the top model were

consistent across all models in which they were included that were within 4  $AIC_c$  units of the top model (range of estimated  $\beta_{SpP(t-1)} = -5.2$  to  $-2.5$ , range of estimated  $\beta_{WP(t-1)} = -7.0$  to  $-4.8$ ).  $WP_{t-1}$  was only included in 13 of the 28 models that were within 4  $AIC_c$  units of the top model and  $SpP_{t-1}$  was only included in 9 of the 28 models, and model structure was inconsistent (Table 19 of Appendix D).

#### *Mt. Everts*

The top model describing variation in spring lamb:ewe ratios for the Mt. Everts population included a positive association of winter precipitation experienced by lambs (estimated  $\beta_{WP} = 5.6$ , 95% CI = 0.6, 10.6). This population has not experienced an all-age disease die-off event during the time data were available, and as such no disease covariates were explored. The recruitment rate under average conditions, as estimated by the intercept value of the top model, was 22.6 lambs:100 ewes (95% CI = 16.8 to 26.4). The adjusted  $R^2$  of the top model was 0.26.

There was a moderate amount of model-selection uncertainty in the results for this population: 11 models were within 4  $AIC_c$  units of the top model and the  $\Delta AIC_c$  of the intercept-only model was 2.4. WP was included in 8 of the 11 models that were within 4  $AIC_c$  units of the top model and the estimates of the regression coefficient was consistent across these models (range of estimated  $\beta_{WP} = 4.7$  to 6.1). Model structure was fairly consistent and most models that were within 4  $AIC_c$  units of the top model included the top model with one additional covariate (Table 20 of Appendix D).

#### *500a-Stillwater*

The intercept-only model was the top-ranked model describing variation in winter lamb:ewe ratios for the 500a-Stillwater population. The population has not experienced an all-age disease die-off event, and as such no disease covariates were explored. Further, this population was typically surveyed during the winter, while WP was calculated based partially on weather conditions after the surveys are completed; thus WP was not considered as a covariate. The average recruitment rate estimated by the intercept value of the top model was 33.3 lambs:100 ewes (95% CI = 25.8 to 40.8). The adjusted  $R^2$  of the top model (intercept-only model) was 0.00.

There was little model-selection uncertainty in the results for this population, as there was very little support for any covariates. Six of the 7 models that were within 4  $AIC_c$  units of the top model included a single uninformative covariate (Table 21 of Appendix D).

#### *501-West Rosebud*

The top model describing variation in winter lamb:ewe ratios for the 501-West Rosebud population only included a negative association of average spring temperature experienced prior to conception of females (estimated  $\beta_{SpT(t-1)} = -6.7$ , 95% CI =  $-13.1$  to  $-0.3$ ). This population has

not experienced an all-age disease die-off event, and as such no disease covariates were explored. Further, this population was typically surveyed during the winter, while WP was calculated based partially on weather conditions after the surveys are completed; thus WP was not considered as a covariate. The recruitment rate under average conditions, as estimated by the intercept value of the top model, was 27.7 (95% CI = 21.3 to 34.1). The adjusted  $R^2$  of the top model was 0.18.

There was a moderate amount of model-selection uncertainty in the results for this population: 14 models were within 4  $AIC_c$  units of the top model and the  $\Delta AIC_c$  of the intercept-only model was 1.92.  $SpT_{t-1}$  was included in 7 of the 14 models that were within 4  $AIC_c$  units of the top model and the estimates of the regression coefficient were consistent across these models (range of estimated  $\beta_{SpT(t-1)} = -7.7$  to  $-4.6$ ). Spring precipitation experienced prior to conception of females ( $SpP_{t-1}$ ) also received some support, although it was not included in the top model.  $SpP_{t-1}$  was included in 7 of the 14 models that were within 4  $AIC_c$  units of the top model and the estimates of the regression coefficient were consistent across these models (range of estimated  $\beta_{SpP(t-1)} = 3.5$  to  $6.0$ ). Model structure was fairly consistent, as all models (except intercept-only model) that were within 4  $AIC_c$  units of the top model included either  $SpT_{t-1}$  or  $SpP_{t-1}$  individually or included with a single uninformative covariate (Table 22 of Appendix D).

### *Prairie-Breaks Eco-region*

#### *482-Fergus*

The intercept-only model was the top-ranked model describing variation in summer lamb:ewe ratios for the 482-Fergus population. The population has not experienced an all-age disease die-off event, and as such no disease covariates were explored. The average recruitment rate, as estimated by the intercept value of the top model, was 54.6 lambs:100 ewes (95% CI= 49.2 to 60.1). The adjusted  $R^2$  of the top model (intercept-only model) was 0.00.

There was little model-selection uncertainty in the results for this population, as there was very little support for any covariates. The 7 models that were within 4  $AIC_c$  units of the top model all included a single uninformative covariate (Table 23 of Appendix D).

#### *680-North Missouri Breaks*

The intercept-only model was the top-ranked model describing variation in summer lamb:ewe ratios for the 680-North Missouri Breaks population. The population has not experienced an all-age disease die-off event, and as such no disease covariates were explored. The average recruitment rate, as estimated by the intercept value of the top model, was 44.7 lambs:100 ewes (95% CI= 39.4 to 50.0). The adjusted  $R^2$  of the top model (intercept-only model) was 0.00.

There was little model-selection uncertainty in the results for this population, as there was very little support for any covariates. Seven of the 8 models that were within 4 AIC<sub>c</sub> units of the top model only included a single uninformative covariate (Table 24 of Appendix D).

### *622-Middle Missouri Breaks*

The intercept-only model was the top-ranked model describing summer/winter lamb:ewe ratios for the 622-Middle Missouri Breaks population. The population has not experienced an all-age disease die-off event, and as such no disease covariates were explored. The average recruitment rate estimated by the intercept value of the top model was 44.7 lambs:100 ewes (95% CI= 39.4 to 50.0). The adjusted R<sup>2</sup> of the top model (intercept-only model) was 0.00.

There was little model-selection uncertainty in the results for this population, as there was very little support for any covariates. Seven of the 8 models that were within 4 AIC<sub>c</sub> units of the top model only included a single uninformative covariate (Table 25 of Appendix D).

## ACROSS POPULATION COMPARISONS

### Intercept Estimates

There was a large amount of variation in baseline spring lamb:ewe ratios across the bighorn sheep populations that were analyzed, as estimated by the intercept values of the top models. The intercept estimate approximates baseline lamb:ewe ratios for each population because “normal” conditions for all covariates occur when the covariates, which were standardized to have a mean value of zero, equaled the mean ( i.e. equaled zero). Thus, the intercept for each population estimates lamb:ewe ratios under normal conditions in the absence of all-age disease die-off events. Intercept estimates ranged from 21.6 (Mt Everts) to 48.8 (Lost Creek) lambs:100 ewes (Figure 14). Average intercept estimates from populations in the Northwest Montane, Mountain Foothills, and Prairie Mountain Foothills eco-regions were very similar, 37.7, 37.7, and 38.5 lambs:100 ewes respectively, while the average intercept estimate from populations in the Southern Mountains eco-region was substantially lower, 27.4 lambs:100 ewes. Recruitment data for two populations (500a-Stillwater and 501-West Rosebud) in the Southern Mountains eco-region were collected during winter months before all winter lamb mortality occurs, therefore average spring lamb:ewe ratios for this eco-region are likely slightly lower than what the intercept values estimate. The average intercept estimate from populations in the Prairie Breaks eco-region was substantially higher than other eco-regions, 47.5 lambs:100 ewes, however recruitment data for populations in this eco-region were collected in either primarily summer (482-Fergus, 680-North Missouri Breaks) or primarily winter (622-Middle Missouri Breaks) and are not directly comparable to recruitment data for populations in the other eco-regions, as average spring lamb:ewe ratios in this eco-region may be much lower than the intercept values estimate.

Intercept estimates of baseline lamb:ewe ratios among populations within each eco-region varied substantially: Northwest Montane intercept estimates ranged from 25.5 (100-Kootenai Falls) to 42.4 (203-Grave Creek Range) lambs:100 ewes, Mountain Foothills ranged from 29.1 (270-East Fork Bitterroot) to 48.8 (Lost Creek) lambs:100 ewes, Prairie-Mountain Foothills range from 27.5 (421-Deep Creek) to 43.2 (422-Castle Reef) lambs:100 ewes. The estimate for the 421-Deep Creek population is based on data collected during early winter and not spring, thus we would expect the spring lamb:ewe ratios to be lower and the range of intercept estimates in this eco-region to be even greater. Intercept estimates from the two populations in the Southern Mountains eco-region, whose recruitment data were collected in the spring, were 21.6 (Mt. Everts) and 27.1 (Cinnabar) lambs:100 ewes. Intercept estimates from the two populations in the Prairie Breaks eco-region, whose recruitment data were collected during the summer, were 44.7 (680-North Missouri Breaks) and 54.6 (482-Fergus) lambs:100 ewes.

When the point estimates of intercepts were analyzed and uncertainty in the estimates was ignored (which makes the results liberal in terms of finding evidence of a relationship relative to the results of a more complex analysis that incorporated uncertainty), we found evidence of a positive correlation between the intercept estimates for the 16 populations whose recruitment data were collected during spring and the average number of animals counted in these populations, which is an index of population size ( $\rho = 0.56$ ). Thus, larger populations generally show higher average lamb:ewe ratios than smaller populations. Populations whose recruitment data were collected during the winter or summer were not included in this regression because lamb:ewe ratios from these time periods are not directly comparable to lamb:ewe ratios collected during the spring, however these populations also follow the same relationship between intercept estimates and average number of animals counted. No strong correlations were found between the intercept estimates for populations with spring recruitment data and indices of long term climate conditions experienced by these populations (average annual precipitation, average spring precipitation, average spring temperature, average summer precipitation, and average winter precipitation).

### Disease covariates

Lamb:ewe ratios in 7 of the 9 populations that have experienced all-age disease die-off events were predicted by top-ranked models to be associated with die-off events for multiple years. For populations in the Prairie Mountain Foothills eco-region, D2 was the most supported disease covariate and for populations in the Mountain Foothills eco-region, D3 was the most supported disease covariate. These covariates predict that lamb:ewe ratios are reduced by a constant value for 2 and 3 years, respectively, following an all-age disease die-off event. However, due to missing data and how recently the populations have experienced die-off events, these covariates should be interpreted as the minimum amount of time lamb:ewe ratios are reduced following an all-age disease die-off event. Further, 2013 spring recruitment data show that lamb:ewe ratios in the Prairie-Mountain Foothills eco-region have been reduced for 3 years following the most recent die-off event. The predicted reduction in lamb:ewe ratios following an all-age disease

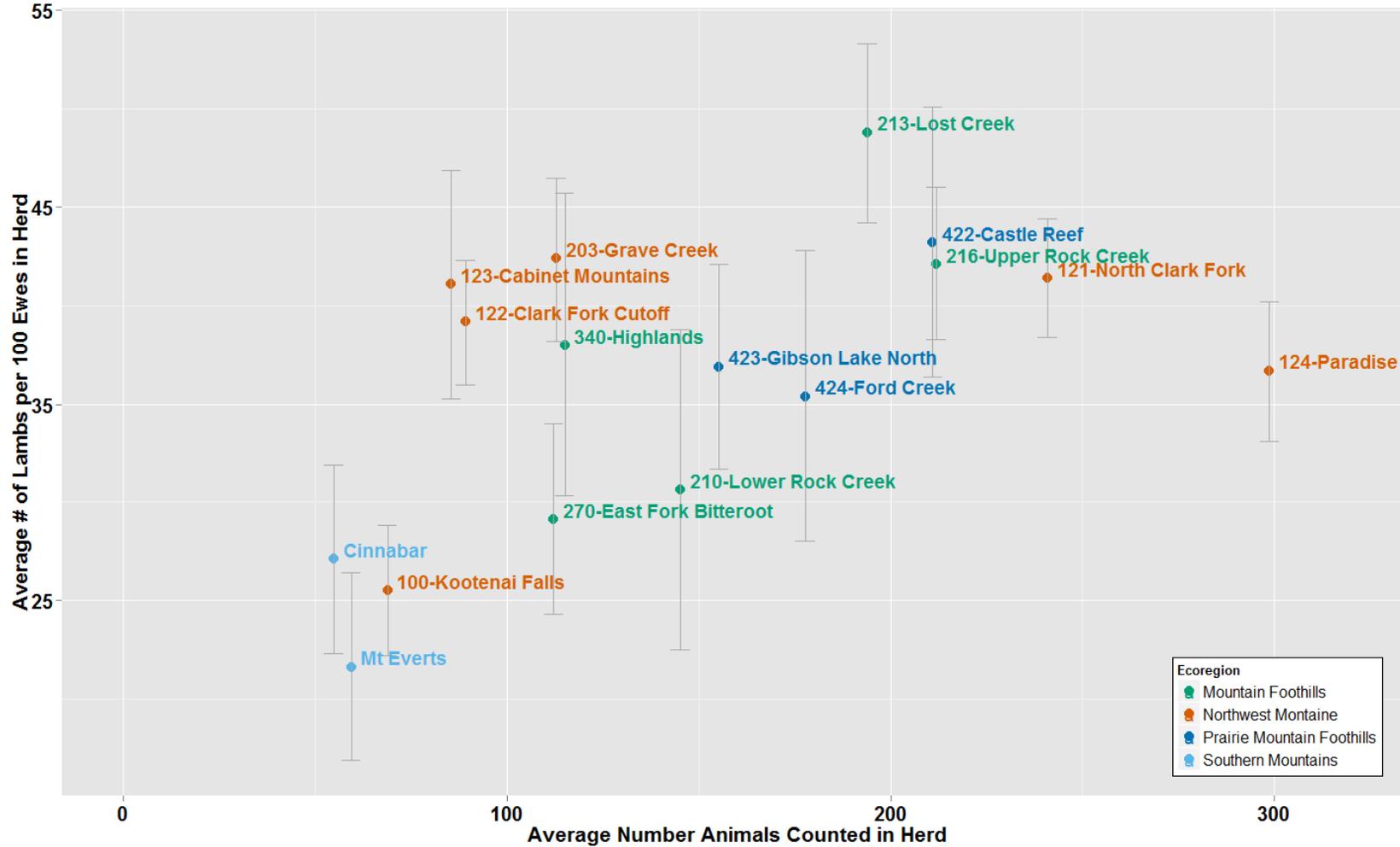


Figure 14. The relationship between average lamb:ewe ratios (95% confidence limits) and average number of animals counted in annual classification surveys for 16 populations whose recruitment data were collected during spring just prior to the lambing season. Average lamb:ewe ratios are estimated from intercept values of top regression models and represent predicted lamb:ewe ratios under normal (ie. average) weather conditions in the absence of all-age disease die-off events. Populations are color-coded by eco-region.

die-off event ranged from 18.7 (424-Ford Creek) to 39.3 (423-Gibson Lake North) lambs:100 ewes and the average reduction was 31.1 lambs:100 ewes (Table 2 of Appendix E). Proportionally, these numbers translate to a range of 49% to 100% reduction in lamb:ewe ratios and an average reduction in lamb:ewe ratios of 76% following all-age disease die-off events. The predicted reduction in lamb:ewe ratios following die-off events are illustrated in Figure 15. Relative variable importance values that were calculated from model averaged results indicate that, collectively, the disease covariates were quite important in explaining variation in lamb:ewe ratios in populations that have experienced all-age disease die-off events (Table 4). On a scale of 0 (not important) to 1 (very important), the mean relative variable importance values for the disease covariates were 0.76 (Dc), 0.73 (D2), and 0.75 (D3). Collectively these findings provide strong evidence that bighorn recruitment rates are severely reduced for multiple years following all-age disease die-off events.

### Climate Covariates

Nine of the 10 annual climate covariates were included in the top model for multiple bighorn populations, while summer precipitation experienced by neonates (SuP) was not included in the top model for any populations. Although most of the annual climate covariates were included in the top model for multiple populations, none of the climate covariates were consistently supported across ecoregions or populations, as the maximum number of top models any climate covariate was included in was 4 out of a total of 25 population analyses (Tables 3-6 of Appendix E). The regression coefficients for the annual climate covariates estimated by top models varied greatly, as 8 of the 9 climate covariates that were included in multiple top models were predicted to have positive and negative associations with lamb:ewe ratios in different populations. Given that none of the covariates were consistently supported across populations, it was impossible to determine if there were patterns in how the estimated regression coefficients varied across the populations (Tables 3-6 of Appendix E). Estimated regression coefficients did not appear to be consistent within eco-regions as there were multiple cases where covariates were predicted to have negative and positive associations with lamb:ewe ratios of different populations within the same eco-region. Summarization of climate data indicated that populations within eco-regions can experience very different climates, thus it wasn't completely surprising to find that populations within the same eco-region had different associations with lamb:ewe ratios.

Mean relative variable importance values calculated from model averaged results for all the annual climate covariates were substantially lower than the mean relative variable importance values for the disease covariates (Table 4). Given that each annual climate covariate was not included in the top model for the majority of the individual analyses, this is not surprising. On a scale from 0 (not important) to 1 (very important), mean relative variable importance values for the annual climate covariates ranged from 0.22 (SuP) to 0.41 (WP). Tables 7-11 of Appendix E

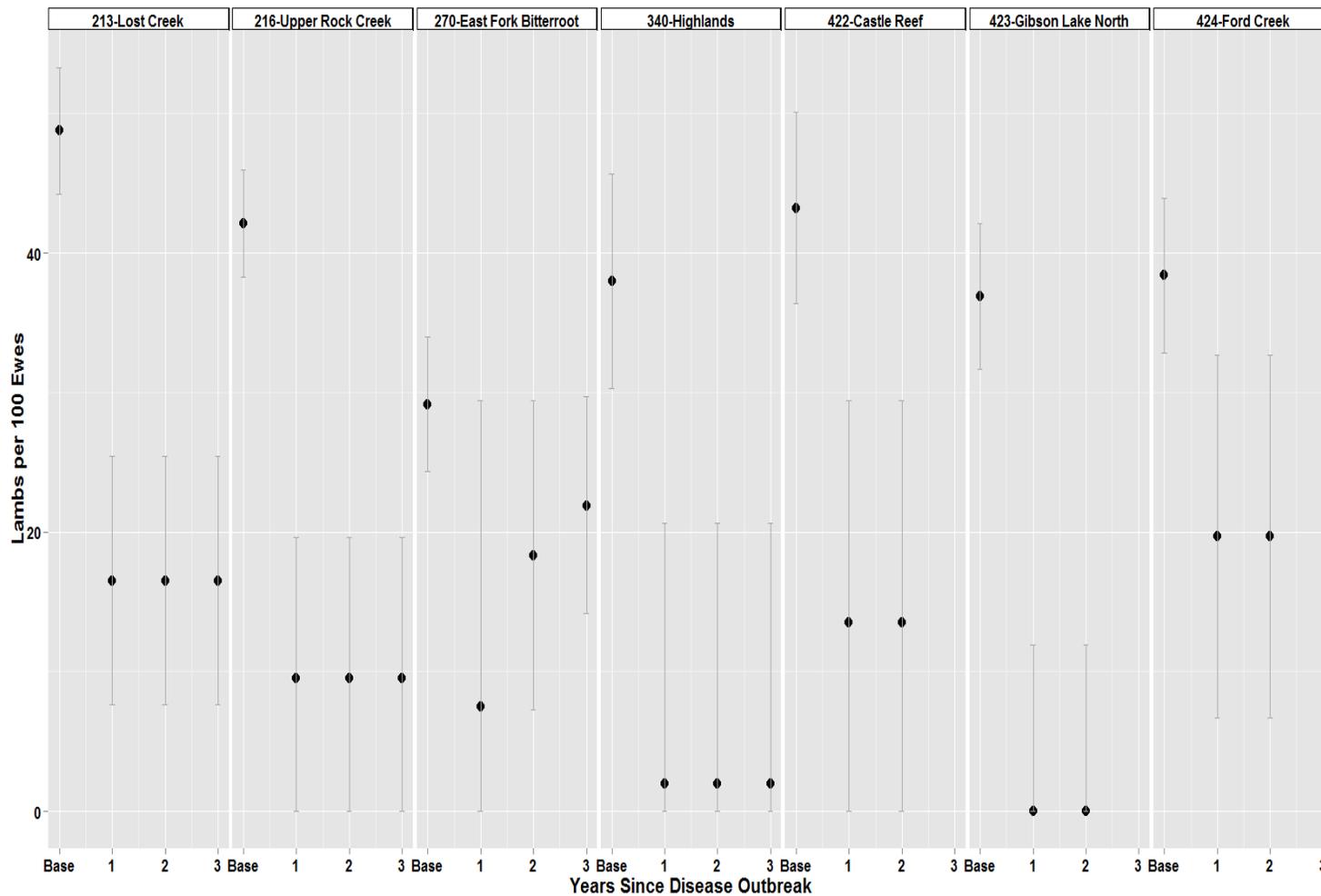


Figure 15. Plots of predicted lamb:ewe ratios in populations that have experienced all-age disease die-off events, demonstrating the predicted reduction in lamb:ewe ratios following die-off events. The y-axis indicates predicted lamb:ewe ratios with 95% confidence limits and the x-axis indicates years since die-off event. “Base” on the x-axis is indicative of years when lamb:ewe ratios are at “baseline” levels and are not associated with all-age disease die-off events. Predictions were calculated assuming other covariates were at “normal” (ie. average) conditions.

Table 4. Summary statistics of relative variable importance values for each of the covariates. Relative variable importance values were calculated from model averaged results for each of the bighorn sheep populations that were analyzed. Possible values range from 0 (not important) to 1 (very important), and the mean values are shaded along a gradient with low values lightly shaded and high values darkly shaded. Disease covariates were only considered for the 9 populations in the dataset that have experienced all-age disease die-off events and only one of the disease covariates was considered in model averaging for each of these populations. “D1”, “D4”, and “D5” are noted with an “NA” as they were not considered in any model averaging because other disease covariates were always more appropriate. The cold season weather covariates (SWE/SWE<sub>t-1</sub> and WP/WP<sub>t-1</sub>) were highly collinear and indexed analogous weather conditions, and as such, only one was considered in model averaging for each population. Additionally, summer precipitation and the post parturition-cold season weather covariates were not considered for several populations that are surveyed in winter or summer, as the covariates describe weather conditions that occur after the classification data are collected.

Covariate Category- Covariate	Relative Variable Importance			
	Mean	SD	Min	Max
<b>Disease</b>				
Dc	0.76	0.29	0.55	0.96
D1	NA	NA	NA	NA
D2	0.73	0.35	0.21	0.95
D3	0.75	0.35	0.27	1.00
D4	NA	NA	NA	NA
D5	NA	NA	NA	NA
<b>Preconception-Warm Season Weather</b>				
Spring Temperature <sub>t-1</sub>	0.28	0.17	0.07	0.74
Spring Precipitation <sub>t-1</sub>	0.25	0.10	0.11	0.41
Summer Precipitation <sub>t-1</sub>	0.28	0.19	0.08	0.85
<b>In Utero-Cold Season Weather</b>				
SWE <sub>t-1</sub>	0.38	0.27	0.10	0.85
Winter Precipitation <sub>t-1</sub>	0.29	0.24	0.12	0.98
<b>Post-Parturition-Warm Season Weather</b>				
Spring Temperature	0.24	0.17	0.10	0.99
Spring Precipitation	0.22	0.12	0.09	0.61
Summer Precipitation	0.22	0.09	0.12	0.46
<b>Post Parturition-Cold Season Weather</b>				
SWE	0.28	0.16	0.13	0.57
Winter Precipitation	0.41	0.24	0.12	0.65

show population-specific relative variable importance values. The mean relative variable importance values did not suggest that weather conditions in the different biological time periods differed in the strength of their associations with lamb:ewe ratios across the populations. The overall mean relative variable importance was 0.27 for preconception warm season climate covariates, 0.33 for in utero cold season climate covariates, 0.23 for post-parturition warm season climate covariates, and 0.34 for post-parturition cold season climate covariates.

Although mean relative variable importance values did not indicate any of the climate covariates to be important across all the populations, 5 of the 10 covariates were found to be important predictors of lamb:ewe ratios for specific populations, with relative variable importance values greater than 0.70 (shown in the “Max” column of Table 4). Average spring temperature experienced prior to conception of females ( $SpT_{t-1}$ ) was found to be an important predictor of lamb:ewe ratios in the 203-Grave Creek Range population (Northwest Montane eco-region) and the 423-Gibson Lake North population (Prairie Mountain Foothills). Summer precipitation experienced prior to conception of females ( $SuP_{t-1}$ ) and cumulative snow water equivalent experienced by pregnant females ( $SWE_{t-1}$ ) were important predictors of lamb:ewe ratios in the 122-Clark Fork Cutoff population (Northwest Montane eco-region) and the 423-Gibson Lake North population (Prairie Mountain Foothills). Winter precipitation experienced by pregnant females was an important predictor of lamb:ewe ratios in the 203-Grave Creek Range populations. Spring temperature experienced by neonates was found to be an important predictor of lamb:ewe ratios in the 122-Clark Fork Cutoff population. Detailed description of the associations of these covariates with lamb:ewe ratios can be found in the “Individual Population Analyses” section of the results.

## DISCUSSION

### VARIABILITY IN RECRUITMENT RATES

A major accomplishment of this effort was the quantification of average recruitment rates of most bighorn sheep populations in Montana. For populations that had adequate high quality data, we were able to quantify average recruitment rates after accounting for disease, providing an index of “normal” reproductive rates across Montana. Prior to this work, recruitment rates of bighorn populations across Montana had never been quantified and summarized in a single document. Table 1 in Appendix C summarizes average lamb:ewe ratios for 49 bighorn populations in Montana, though these data were not censored to ensure that lamb:ewe ratios were based on high quality data. Table 1 in Appendix E provides estimates of average recruitment rates, after accounting for all-age disease die-off events, for 22 bighorn populations whose data were censored to ensure lamb:ewe ratios were as accurate as possible (ie. all lamb:ewe ratios for a population collected during same season, at least 18 adult females classified, biologist opinion). There was substantial annual variability in lamb:ewe ratios within populations as observed ratios varied by at least 50 lambs:100 ewes in most populations that were analyzed (Table 3). While

we censored these data to reduce the influence of observation error (ie. obtaining observed lamb:ewe ratios that do not accurately reflect realized lamb:ewe ratios in a populations); observation error may still explain a significant part of this variability. There was also a great amount of variability in recruitment rates among populations, with some populations recruiting over twice as many lambs per ewe on average than other populations. This observation strongly suggests that these differences are biologically significant and are the result of underlying factors experienced by each population.

The positive correlation between average lamb:ewe ratios (as estimated by model intercept values) and average population size (as indexed by average number of animals counted) provides evidence for a link between demographic vigor and recruitment, though offers no evidence for direct mechanisms, which are likely multiple (Boyce 1992). Given the diversity of habitats that bighorn sheep occupy in Montana, bighorn populations that occupy high quality habitat may have higher recruitment rates, leading to larger populations. If this is the case, habitat quality does not appear to be explained by long term climate conditions, as we did not find strong correlations between average recruitment and the long term average values for any of the climate indices. Further, regional factors do not appear to explain the correlation, as population size and recruitment rates vary substantially within eco-regions (Figure 14), although populations in the Southern Mountains eco-region do appear to have lower average recruitment rates than other eco-regions.

In contrast to the hypothesis of habitat dictating recruitment rates, and subsequently populations sizes, small populations may exhibit lower recruitment rates because they are more subject to negative influences of chance events and unpredictable variability within the populations (demographic stochasticity) and in the environment (environmental stochasticity; Boyce 1992, Mills 2007). Examples of stochastic events that may impact bighorn populations in Montana include increased mountain lion (*Puma concolor*) predation (Wehausen 1996, Festa-Bianchet et al. 2006, Gibson 2006, Johnson et al. 2013), vehicle collisions (Montana Department of Fish, Wildlife and Parks 2010), extremely severe winters (Montana Department of Fish, Wildlife and Parks 2010), or disease events that were not accounted for (ie. The 100-Kootenai Falls, Cinnabar, and Mt. Everts populations all have low average recruitment rates and small population sizes, and disease has been suspected to affect each within the period of the data time series). Though the loss of genetic variability and inbreeding depression are often cited as potential limiting factors for small populations (Lacy 1997), they do not likely explain low recruitment rates in small bighorn populations in Montana, as many small populations have been augmented with individuals from productive populations.

Although we did not have measures of population density, the relationship between average number of animals counted and average lamb:ewe ratios may be evidence for positive density dependence (Allee effects), and could have important implications regarding the viability of Montana's bighorn sheep populations (Boyce 1992, Dennis 2002). The Allee effect is the phenomena of population performance declining with population size, and becomes dominant

over the influence of traditional density dependence at small population sizes (Dennis 2002). Adequate recruitment is necessary for small populations to increase, thus if small populations also have low average recruitment rates the likelihood for population increase is low. This is problematic because dynamics of small populations are susceptible to population decline due to chance events and unpredictable variability occurring both within the population (demographic stochasticity) and in their environment (environmental stochasticity) (Boyce 1992, Mills 2007). When small populations remain small for extended periods of times, negative effects of stochastic events have more time to accumulate, increasing the likelihood of local extinction without management intervention. Thus, it is not surprising that there is evidence across taxa that population size is the best predictor of extinction risk (O'Grady et al. 2003).

The difficult task is to define what constitutes a small bighorn sheep population, with regards to its likelihood of local extinction. Berger (1990) found desert bighorn populations were not likely to persist without intervention if smaller than 100 individuals. Although Berger's (1990) findings were derived from a different ecological setting, they provide a starting point for considering the viability of Montana's bighorn populations. We estimated that 46% (22 of 48) of the bighorn populations in our initial database currently have fewer than 100 individuals (Table 1 of Appendix C). Low recruitment rates in Montana's smaller bighorn populations, literature suggesting that small populations commonly perform poorly and are less likely to persist, and the fact that nearly half of Montana's bighorn populations currently have less than 100 individuals collectively provoke examination of whether many bighorn populations are viable at their current population sizes. Additionally, all-age disease die-off events can rapidly reduce moderate to large sized populations to levels where they are unable to recover. Examples of this include the local extinction of a reintroduced bighorn population in the lower Boulder River drainage that numbered around 100 individuals and the prolonged (18 years) struggles of the 340-Highlands population after an all-age disease-related die off, which numbered over 300 prior to the die-off and would presently be one of the largest bighorn populations in Montana. With consideration of ongoing disease issues, the majority of bighorn populations in Montana may not be large enough to buffer against crossing a threshold in population size where the negative effects of stochastic events and Allee effects result in a feedback system more likely to result in further population decline (Berger 1990, Boyce 1992, Dennis 2002, Mills 2007). Management actions aimed at increasing population sizes may be an effective option to improve the likelihood long-term viability of Montana's bighorn sheep populations. Biological insight of factors affecting demographic vigor of bighorn sheep populations in Montana, however, are currently limited, making it difficult to devise effective management strategies to increase bighorn populations to a level that they are less vulnerable to the many negative effects of small population size.

### DISEASE

Previous to this effort, the reduction in recruitment rates following all-age disease die-off events had not been collectively quantified in multiple Montana bighorn sheep populations. It was not

surprising to find that all-age disease die-off events (caused by pneumonia epizootics) are associated with drastic reductions in recruitment rates of affected bighorn sheep populations as there is ample literature documenting the impact of pneumonia on bighorn sheep population dynamics (Jorgenson et al. 1997, Douglas 2001, Enk et al. 2001, Monello et al. 2001, Cassirer and Sinclair 2007, Besser et al. 2008, Edwards et al. 2010, Besser et al. 2012b, Cassirer et al. 2013). The fact that recruitment rates following all-age disease die-off events declined on average by 76% for multiple years is clear evidence that pneumonia is very problematic for bighorn sheep populations. The average predicted decline is comparable to declines in recruitment recently reported for pneumonia-infected bighorn populations in the Hell's Canyon area of Idaho, Oregon, and Washington (Cassirer et al. 2013). The wide variability in the predicted reduction of recruitment rates following all age disease die-off events (Range: 44% - 100% predicted reduction in recruitment rates) corroborates previous assertions that the realized effects of pneumonia outbreaks are not uniform across cases (Besser et al. 2012b, Cassirer et al. 2013), and there are likely unknown factors explaining the variability in disease severity expressed by infected bighorn populations. Top models that included a disease covariate always favored covariates predicting multiple year effects on recruitment, which is also supported by findings of Cassirer et al. (2013), where the probability of pneumonia persistence in a population was 98% following all-age pneumonia outbreaks, and 83% following years where only lambs express pneumonia symptoms.

Collectively, our results provide additional support for the hypothesis that recruitment rates are chronically reduced for multiple years following all-age disease die-off events before recovering, rather than gradually recovering following die-off events. However, the data availability limits the strength of this finding. It is interesting that the most supported disease covariate for the 270-East Fork Bitterroot population was the continuous variable predicting a gradual recovery of recruitment rates following an all-age disease die-off event, as MTFWP culled symptomatic individuals in this population during the 2009-2010 die-off event to test whether culling could decrease the severity of the outbreak. Observed spring lamb:ewe ratios increased each year in this population from 2010 to 2012 suggesting slow recovery of recruitment in this population. However, the number of animals observed during this time decreased and symptoms of lamb pneumonia were still observed in 2012 (C. Jourdonnais personal communication), limiting support for the assertion that recruitment in this population is recovering.

The recentness of many die-off events, in addition to missing data, limited our ability to determine the length of time recruitment is affected following die-off events, and as such it is very important to note that our results only inform us on the minimum amount of time that recruitment rates are reduced following all-age disease die-off events. For example, the 340-Highlands population has never recovered since experiencing an all-age disease die-off event in 1994/1995, yet our analysis was unable to assess the relationship of disease with lamb:ewe ratios beyond three years because the population was so severely reduced that classification data from population surveys became unreliable. Recruitment rates in most populations that experienced all-age disease die-off events in 2009 and 2010 have not yet recovered and data were often not

available for analysis in subsequent years following die-off events, either as a result of lacking surveys or survey data not meeting our criteria due to low ewe counts. Increasing post-disease outbreak survey efforts would help clarify this relationship and increase our understanding of the full effects of disease outbreaks on BHS population dynamics. Another limitation was that model structure assumed that different die-off events within the same population had equal effects on recruitment both in terms of how much lamb:ewe ratios were predicted to decline and also for how long they were predicted to decline. This limitation affected our ability to better describe the association of all-age disease die-off events with lamb:ewe ratios, as there is strong evidence the effects of die-off events are not uniform even within the same population (Cassirer et al. 2013). Most die-off events in our data time series were associated with die-off events in other populations at the same time and were not truly independent events, thus our findings do not likely reflect the full range of variability in disease severity that would be observed in a collection of independent die-off events. Additionally, we were not able to investigate recruitment rates in several populations in Montana that have experienced all-age disease die-off events, limiting the scope of our findings in relation to disease. Despite having limited data, our analyses adequately assess the relationship between all-age disease die-off events and bighorn recruitment rates given the structure and availability of the data, and also provide an initial quantification and characterization of the effect of all-age disease die-off events that appears to be supported by recent field research in other populations. Currently, a parallel research project is being conducted at the University of Montana with a stronger focus on assessing the predictability and effects of disease outbreaks in Montana's bighorn sheep populations, which will likely lead to additional useful insights.

### VARIABILITY IN CLIMATE

Compilation of climate data for the recruitment analyses provided an insightful characterization of long term climatic conditions experienced by bighorn populations across Montana. The PRISM climate data reinforced the fact that bighorn sheep occupy very diverse habitats, as bighorn populations in Montana occupy ranges that receive 5-fold differences in annual precipitation. Habitat occupied by the 503-Pryor Mountains population receives less than 30 cm of precipitation annually while habitat occupied by the 123-Cabinet Mountains population receives greater than 140 cm annually. Given that precipitation is an important driver of plant communities and forage production, bighorn populations which occupy habitats receiving such drastically different levels of precipitation are almost certainly limited by different environmental and weather conditions. In a similar analysis of bighorn recruitment data from Wyoming, we found strong evidence that bighorn populations occupying arid and temperate climates responded differently to winter and summer weather conditions (Butler and Garrott 2012).

We anticipated that there would be strong differences in long-term climate conditions experienced in the different eco-regions and that populations within eco-regions experienced similar long-term climate conditions. As expected the PRISM data revealed considerable

variation in average annual precipitation received in bighorn habitat in different eco-regions. It was interesting to find that most variation in annual precipitation appears to be explained by winter (October-April) precipitation (Figure 6 of Appendix A), while all the eco-regions experience similar amounts of precipitation between May and October. We found that, although bighorn populations within eco-regions experienced very similar weather *trends* from year to year, there was substantial variation in annual precipitation experienced by different populations within the same eco-region (Figures 1-5 of Appendix A; Table 1 of Appendix A). This intra-regional variation in long-term climate could explain why our results suggested that recruitment of bighorn populations within the same eco-regions were often associated with different climate covariates or had opposite relationships with the same covariate. With regard to future climate change, the wide range of climates currently inhabited by bighorn populations suggests that any effects of climate change on bighorn populations will not be uniform across Montana, and perhaps will not be uniform within eco-regions.

### CLIMATE AND RECRUITMENT

We found strong evidence of associations between annual climatic variation and recruitment in about 1/4 of the populations whose data we analyzed. Further, the climate effects were different in each population. Top models described 50% or more of the variation in lamb:ewe ratios for 5 different populations and detected convincing correlations between climate covariates and lamb:ewe ratios. Figures 9-13 in the individual population analyses results section graphically display model predictions of how recruitment rates are related to climate covariates for those 5 populations. Correlations detected in these 5 populations are unlikely to be spurious, as the covariates that were included in the top models were consistently supported in models within 4  $AIC_c$  units of the top model. Within the results of these 5 populations, the same covariates had opposite relationships with lamb:ewe ratios and each population had a unique set of climate covariates in the most supported models. For example Figure 9 predicts recruitment rates in the 122-Clark Fork Cutoff population to increase with  $SWE_{t-1}$ , while Figure 10 predicts recruitment rates in the 203-Grave Creek Range populations to decrease with  $WP_{t-1}$  ( $WP_{t-1}$  is analogous to  $SWE_{t-1}$ ). Thus, these results provide strong evidence that bighorn populations in Montana, even those in close proximity to each other, can be influenced differently by climate. While we expected populations to be influenced differently by climate, we anticipated the differences would be related to regional variation in long-term climate conditions (Sæther 1985, Grøtan et al. 2008, Grøtan et al. 2009, Butler and Garrott 2012). Because no climate covariate was supported in more than a few populations, it was impossible to detect any patterns that might explain why the relationships between recruitment and climate covariates varied among populations. The information we do have does not reveal any obvious patterns in this variation and model averaged results yielded little additional insight.

Although we found strong evidence for the effect of climate on recruitment in several bighorn populations, the climate covariates did not explain a biologically important amount of variation in lamb:ewe ratios for many of the populations whose data we analyzed, and there was little

consistency in the signals we did obtain from the climate data. It is difficult to determine the reason for inconsistent findings and weak results in some populations. There is strong support in the literature that ungulate recruitment across the northern hemisphere is affected by annual climatic variation (Sæther 1997), and there is evidence from multiple ecological studies that each of the climate covariates we investigated can influence ungulate recruitment (Spring Precipitation: Portier et al. 1998, Taper and Gogan 2002; Spring Temperature: Langvatn et al. 1996, Pettorelli 2007; Summer Precipitation: Langvatn et al. 1996; Enk et al. 2001; Winter Severity: Picton 1984, Post and Stenseth 1999, Garrott et al. 2003). Additionally, we used the same (or very similar) climate covariates in an analysis of bighorn recruitment data collected from Wyoming populations in the Greater Yellowstone Area where we detected strong relationships between lamb:ewe ratios and the climate covariates (Butler and Garrott 2012).

Inconsistency in the results could be the result of observation error in the recruitment data, in which case, even if recruitment was correlated with the annual weather covariates, we would have reduced ability to detect the patterns. Alternatively, the inconsistent results could reflect the fact that the true relationship between bighorn populations and the climate covariates vary among populations. It is very plausible that a combination of observation error and variation in the relationship of recruitment with climate may also explain the results we obtained. Several authors have questioned the biological insights that are obtainable from ratio data, as multiple demographic vital rates can influence the ratios (Caughley 1974, McCullough 1994), and relative sightability of different age classes can be inconsistent (Bender et al. 2003, Bonenfant et al. 2005). Observation error is also more likely to occur in small populations than in larger populations, as not observing a single small band of bighorns in a small population could have a large influence on the resulting lamb:ewe ratio (Samuel et al. 1992). Another challenge adding to observation error in bighorn sheep is the similarity in appearance of young rams and ewes resulting in unknown and likely variable numbers of young rams misclassified as ewes during surveys. Recruitment rates of small populations may also be more subject to stochastic events and predation than climatic variation (Dennis 2002, Mills 2007) and there is evidence that effects of climate on recruitment may only be evident at high population densities when resources are more limited (Picton 1984, Portier 1999, Gaillard et al. 2000). However, small population size and low density cannot explain the lack of findings in all populations, as we did not detect significant correlations between lamb:ewe ratios and any covariates in several of the largest populations (124-Paradise, 482-Fergus, 680-North Missouri Breaks), which are also surveyed consistently. We would expect these populations to give biologists the most accurate lamb:ewe ratios, be least influenced by stochastic processes, and have high population densities. Particularly interesting is that the 124-Paradise population occupies the opposite side of the Clark Fork River from the 122-Clark Fork Cutoff population and is surveyed by the same biologist, yet we found strong evidence for climate effects in the 122-Clark Fork Cutoff population and very little evidence for climate effects in the 124-Paradise population. Disease outbreaks that do not result in all-age die-offs could be present in some populations, overshadowing any climate effects, without being accounted for. Most bighorn populations in Montana are not regularly sampled for disease pathogens and in the absence of large die-off

events it would be difficult to detect presence of chronic disease. For example, disease has been suspected, but not verified, in the 100-Kootenai Falls, 622-Middle Missouri Breaks, and 680 North Missouri Breaks populations (Montana Fish Wildlife and Parks 2010, S Hemmer, MTFWP, personal communication, S. Thompson, MTFWP, personal communication). Additionally, predation could play a central role limiting recruitment in bighorn populations, weakening the potential role of climate. There is evidence that mountain lion predation can have strong influences on bighorn survival, varying unpredictably over time as individuals specialize in hunting bighorns (Festa-Bianchet et al. 2006).

The results of our analyses highlight the difficulties in conducting and interpreting a meta-analysis of ecological data, but also highlight the importance of using meta-analyses to maintain a broad perspective and gain an understanding of whether findings are broadly applicable or if they are site specific. The simultaneous investigation of demographic patterns in multiple populations increases the probability of encountering unknown confounding factors among populations. We are capable of detecting some differences in the conditions experienced by these populations, such as long-term climate, but there are also many other unknown factors that could play important roles in recruitment rates of bighorn populations that are unaccounted for. However, the inconsistencies in how recruitment ratios of different bighorn populations are related to climate are important to identify, as they provide evidence that populations are limited by different factors and also that findings are not necessarily applicable from one population to the next. It would be useful to further investigate the relationships between lamb survival and climate variation and adult survival and climate variation, as better understanding the variations in both the numerator and denominator of the lamb:ewe ratio may provide insights lacking in the ratio data.

### LIMITATIONS/IMPROVEMENTS

Some of the difficulties of this analysis are inherent when analyzing data that were collected from multiple sources and without the direct intention of being analyzed, let alone collectively analyzed with other data. The dataset that we considered adequate for analysis was much smaller than the initial dataset, and as a result our formal analysis included recruitment data for less than half of the bighorn populations in Montana. Some populations were excluded because their small sizes made it inherently difficult to collect accurate demographic data, and thus, they would have been excluded from this analysis regardless of how consistently they were surveyed. However, there were many populations that were excluded from analysis because they were not surveyed consistently from year to year or were not consistently surveyed at the same time of the year. We excluded data collected from the same population at different seasons because true lamb:ewe ratios decline at unknown rates between birth pulses, as juvenile mortality exceeds adult mortality. Data collected from different seasons were also excluded because the same set of climate covariates is not applicable (i.e., winter severity affects winter lamb survival and is relevant to spring lamb:ewe ratios, but is not relevant to summer lamb:ewe ratios). Having more

populations in the analyses would have provided a better opportunity to detect patterns in the relationship between recruitment and climate in different populations. Additionally, differences in survey timing among populations (summer vs. winter vs. spring) made comparisons among populations difficult, both when comparing average recruitment rates and when investigating correlates of recruitment. For example, we were unable to compare lamb:ewe ratios from the populations in the Prairie Breaks eco-region with populations in other eco-regions because lamb:ewe ratios in the Prairie Breaks eco-region were calculated from summer or winter classification data, as opposed to spring classification data that were more typical for other Montana populations. Thus, with the data available, we were unable to determine if recruitment rates in the Prairie Breaks eco-region were different from recruitment rates in other eco-regions. Although budget and other logistic constraints likely affect how bighorn populations are surveyed on an annual basis, consistent survey timing within populations and among populations would almost certainly increase the biological insight that could be gleaned from annual survey data. Further analysis of the data used here might also reveal additional insights. Although we examined a thorough suite of covariates, additional covariates could be explored, such as indices of population density and habitat quality/type. Also, re-analyzing the lamb:ewe ratios data as count data using a Poisson regression might improve some aspects of the analysis and avoid the few instances we encountered where predicted lamb:ewe ratios fell below zero. There are also more complicated statistical techniques (state-space models) that could be tried that can, for some datasets, separately estimate process variance and observation error in lamb:ewe ratios.

We were able to retrospectively characterize the effect all-age disease die-off events have had on Montana bighorn populations and provide additional corroboration that pneumonia is a major issue for management of bighorn populations; however, with the current data, we were unable to explain differences in the severity of outbreaks or to assess the effects of pneumonia infection that does not result in all-age die-offs. It is largely unknown how prevalent chronic, low-severity pneumonia is in Montana's bighorn populations because herd-level testing for pneumonia pathogens is generally only conducted when there are die-off events or translocation operations. It is understood that the effects of pneumonia outbreaks on bighorn populations are not consistent (Besser et al. 2012b, Cassirer et al. 2013). For example, following an all-age disease die-off event in 1991, the 213-Lost Creek bighorn population rapidly recovered to pre-die-off levels, while the nearby 340-Highlands bighorn population has yet to recover from an all-age disease die-off event in 1995. The underlying causes for such inconsistencies are not understood. Variability in the expression of outbreaks may be explained by different pathogens (species or strains), by body condition, or other environmental conditions; however current information only allows speculation. There is strong evidence that two pathogens (*Mannheimia haemolytica* and *Mycoplasma ovipneumonia*) are commonly associated with pneumonia outbreaks in bighorn sheep in the western United States, though there is not a consensus of the role each may play in a disease event. Although these pathogens are often detected in pneumonia affected bighorn populations, it is unknown how prevalent they are in asymptomatic populations. Both pathogens were recently detected (February 2013) as part of disease surveillance in apparently healthy bighorn populations in the Greater Yellowstone Area

(Garrott 2013, unpublished data), suggesting that pathogen presence alone does not result in die-off events. An effective strategy to improve understanding of the factors associated with expression of pneumonia in bighorn populations would be to initiate field studies using standardized methods to assess pathogen presence, population dynamics, environmental conditions, and population characteristics (ie. native vs. introduced or migratory vs. non-migratory) in both pneumonic and apparently healthy populations, allowing for comparison of the characteristics associated with pneumonic and healthy populations.

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**APPENDIX A.** Summary Figures and Tables of Climate Data Used in Recruitment Analyses.

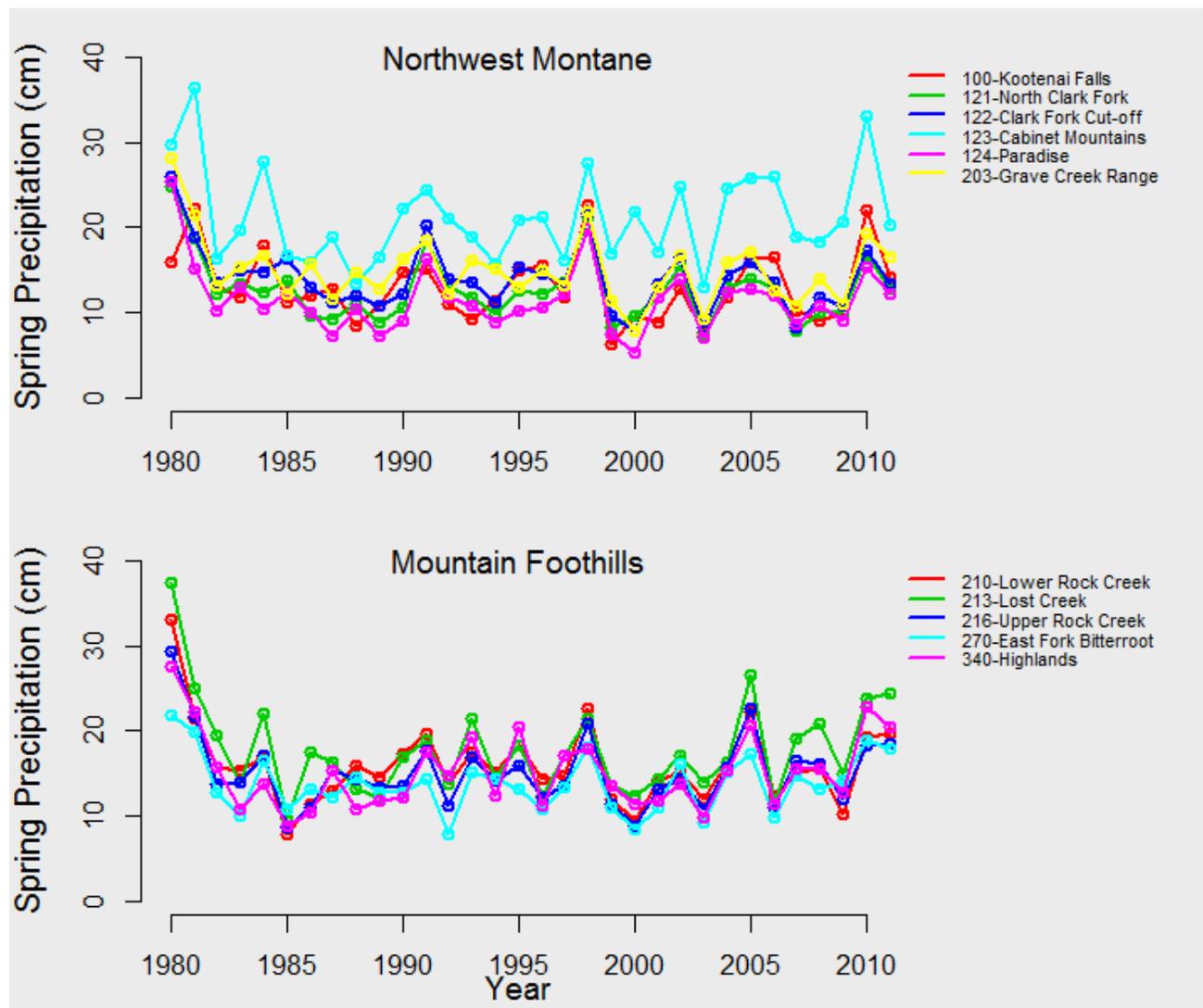


Figure 1. Spring (May-June) precipitation experienced by each population whose data were analyzed. The plots are separated by eco-region.

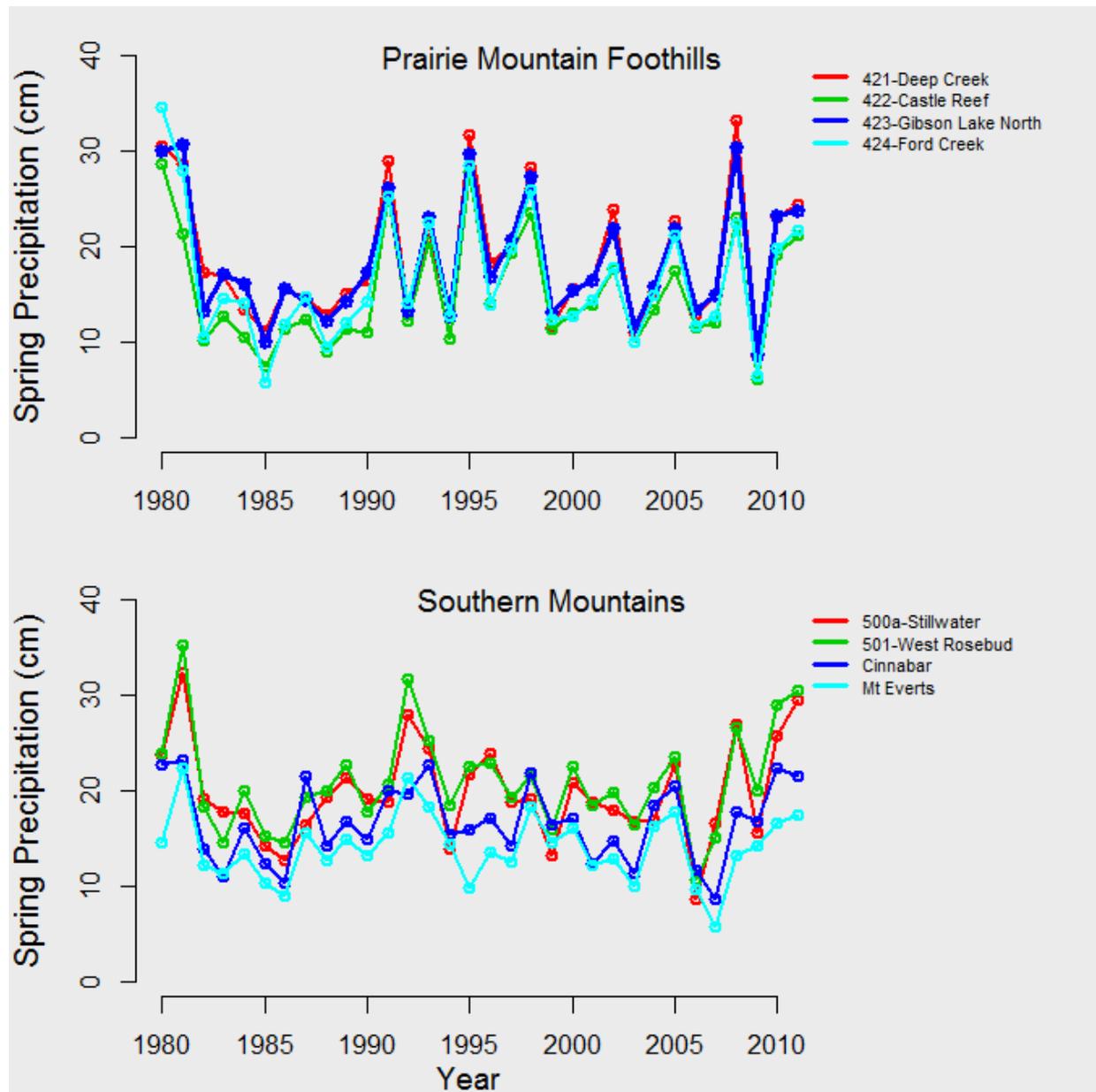


Figure 1 continued.

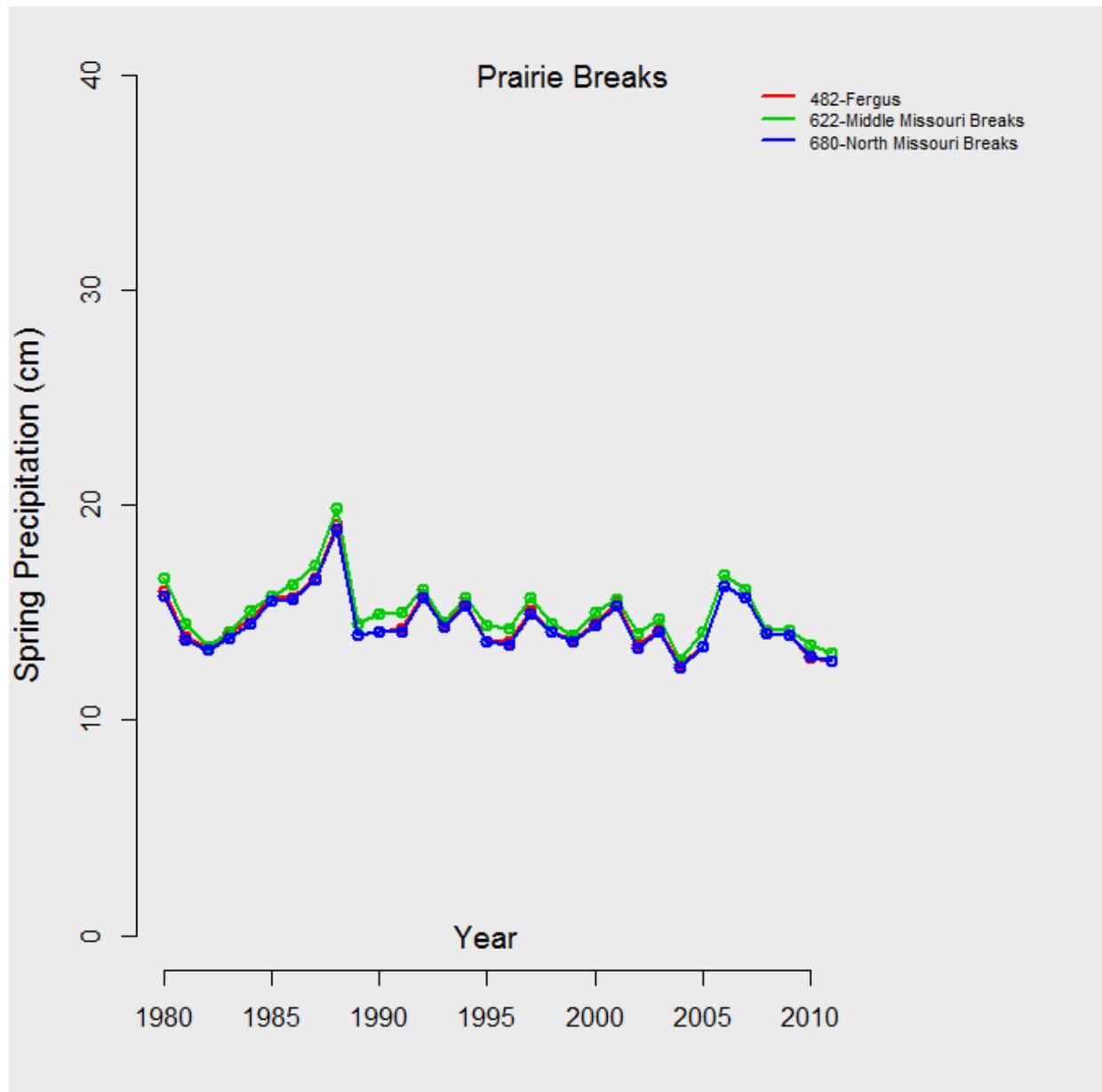


Figure 1 continued.

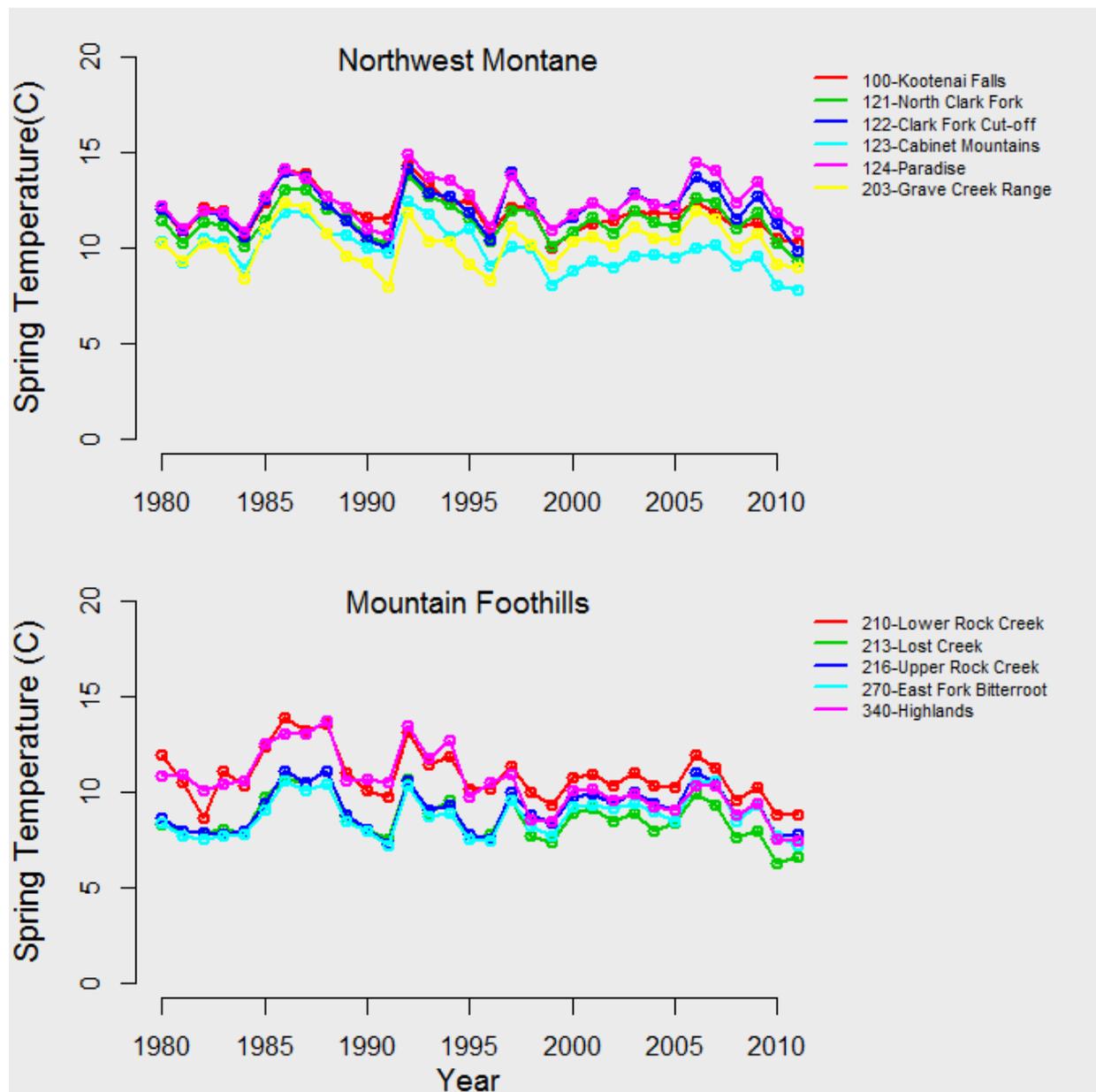


Figure 2. Average spring (May-June) temperature experienced by each herd in the climate recruitment analyses. The plots are separated by eco-region.

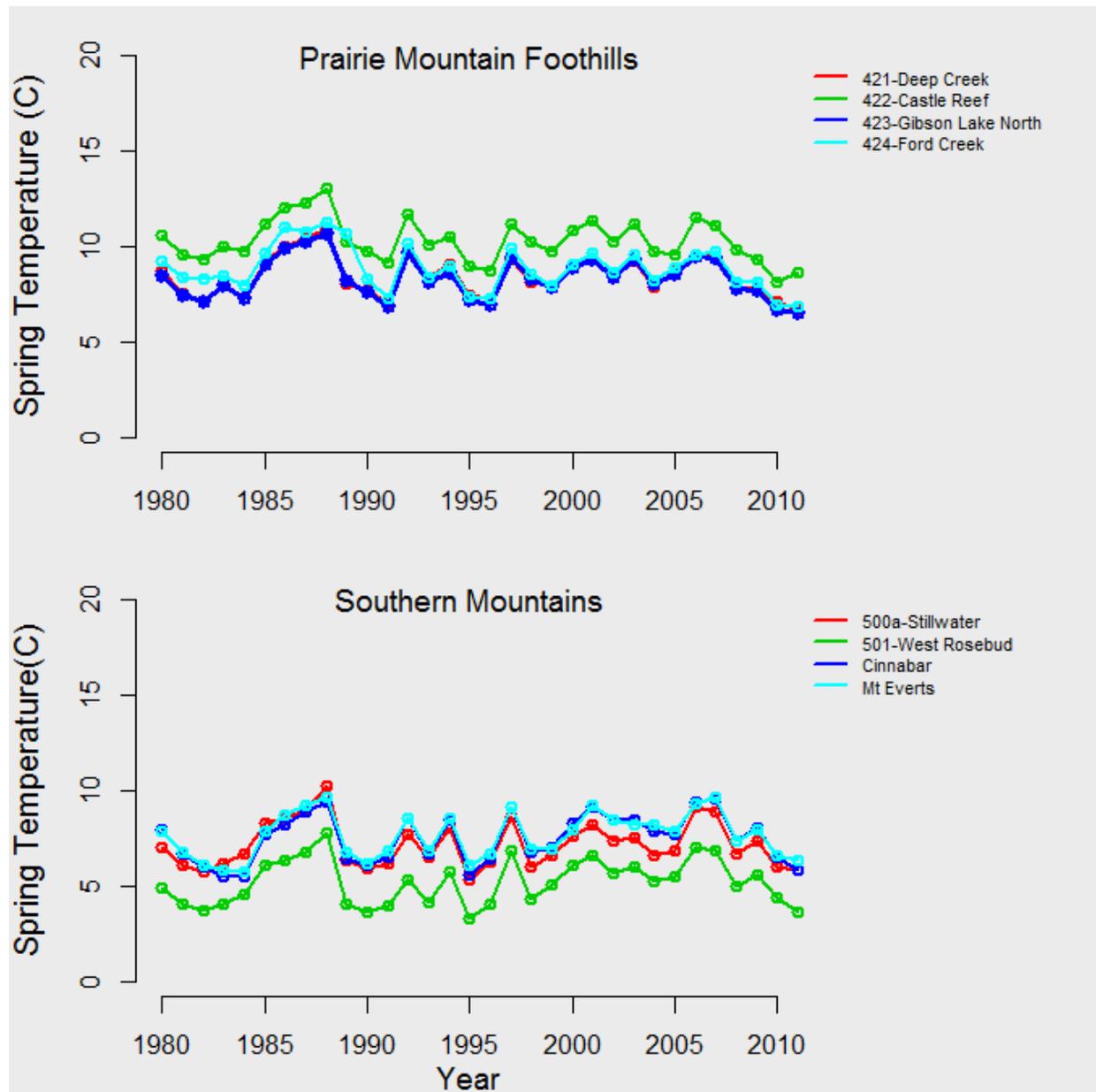


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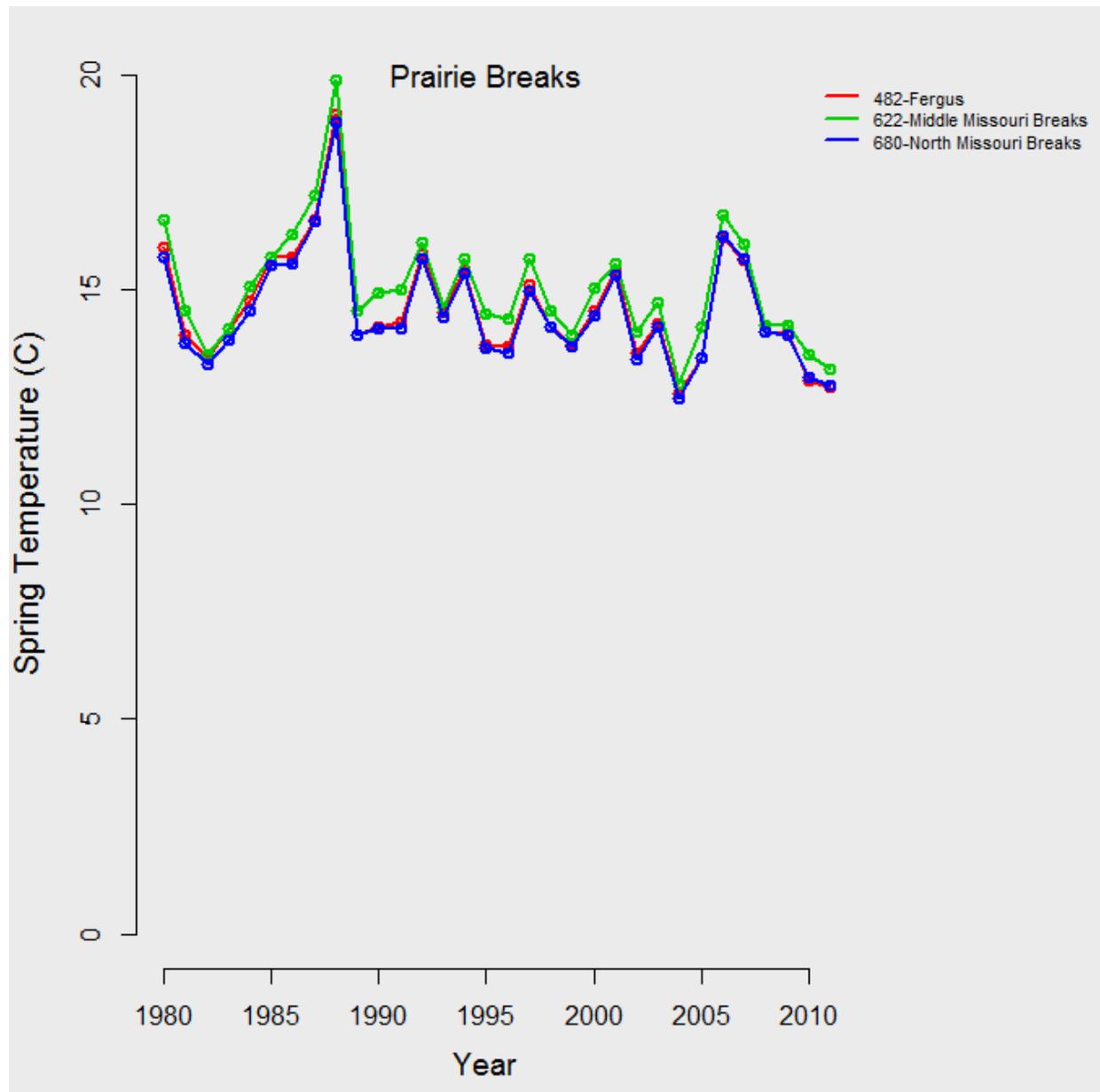


Figure 2 continued.

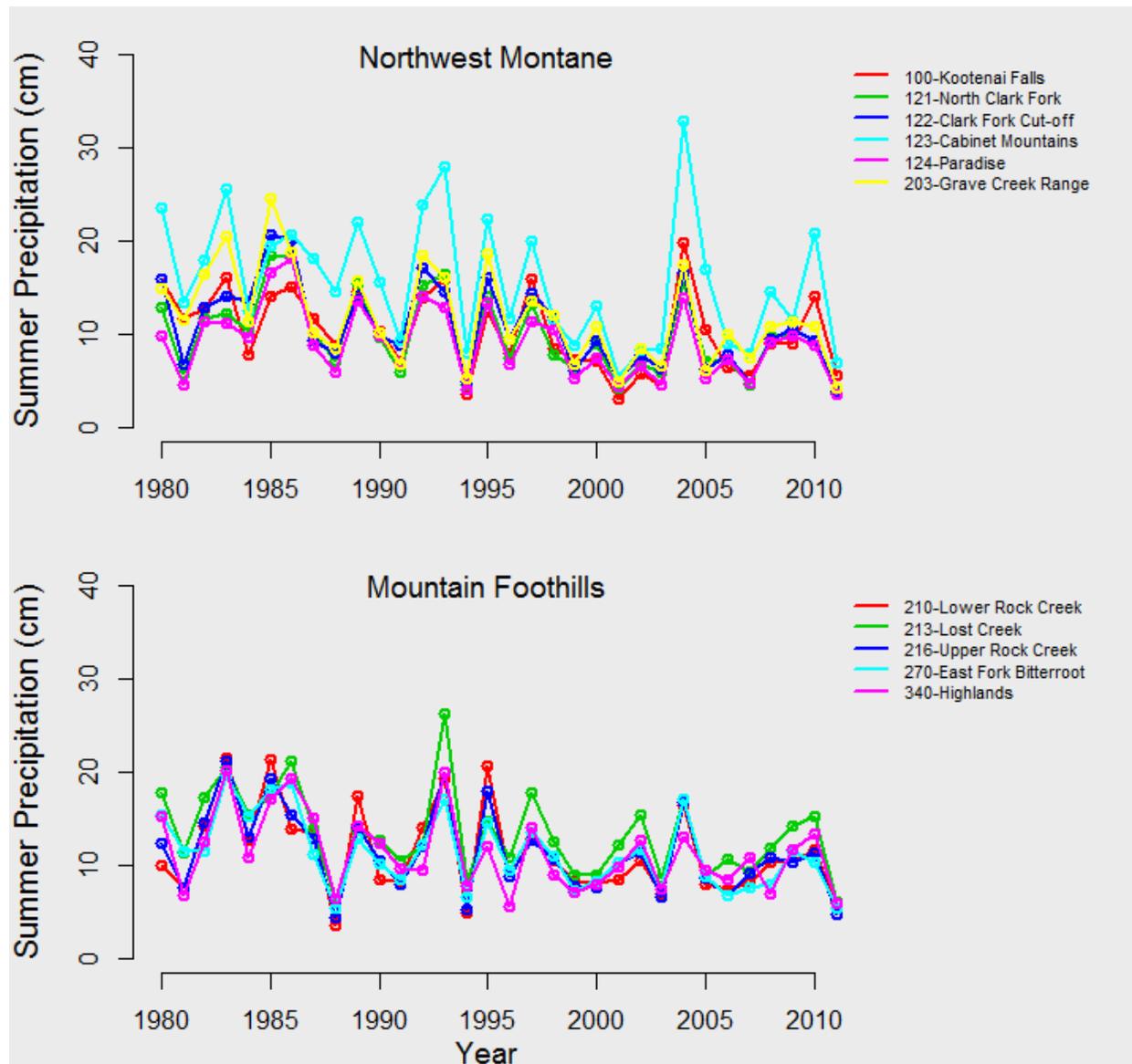


Figure 3. Summer (July-September) precipitation experienced by each herd in the spring recruitment analysis. The plots are separated by eco-region.

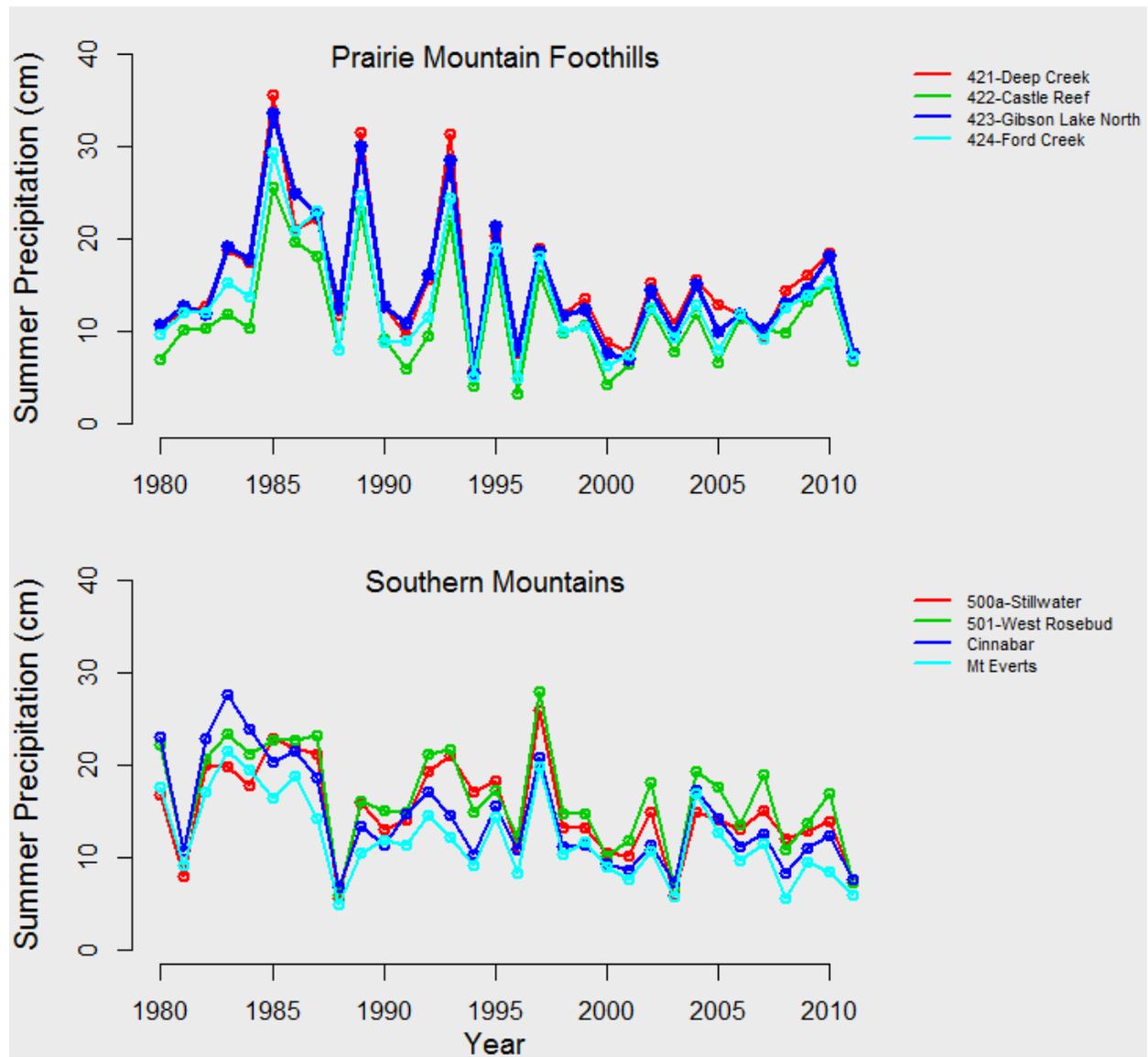


Figure 3 continued.

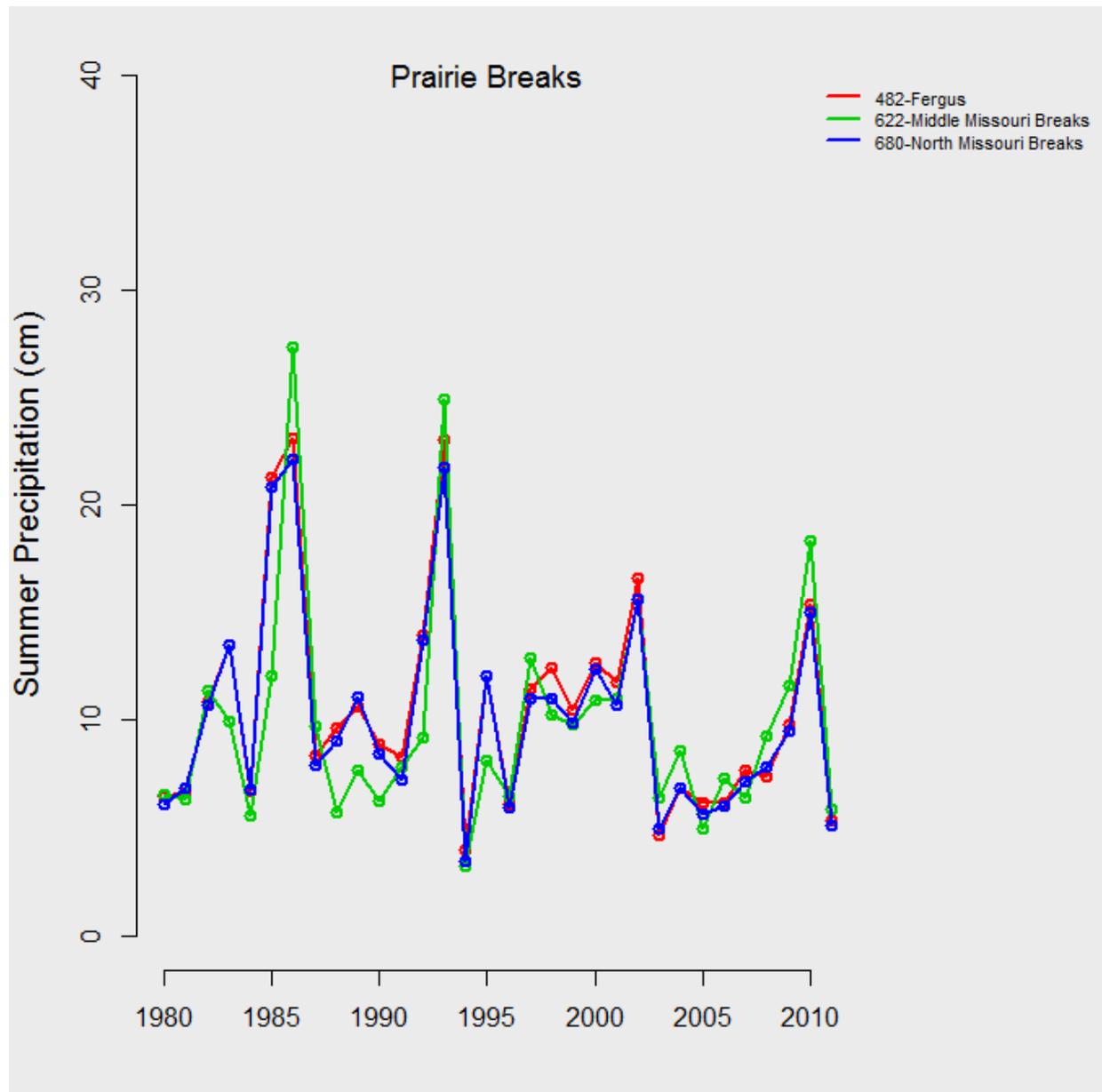


Figure 3 continued.

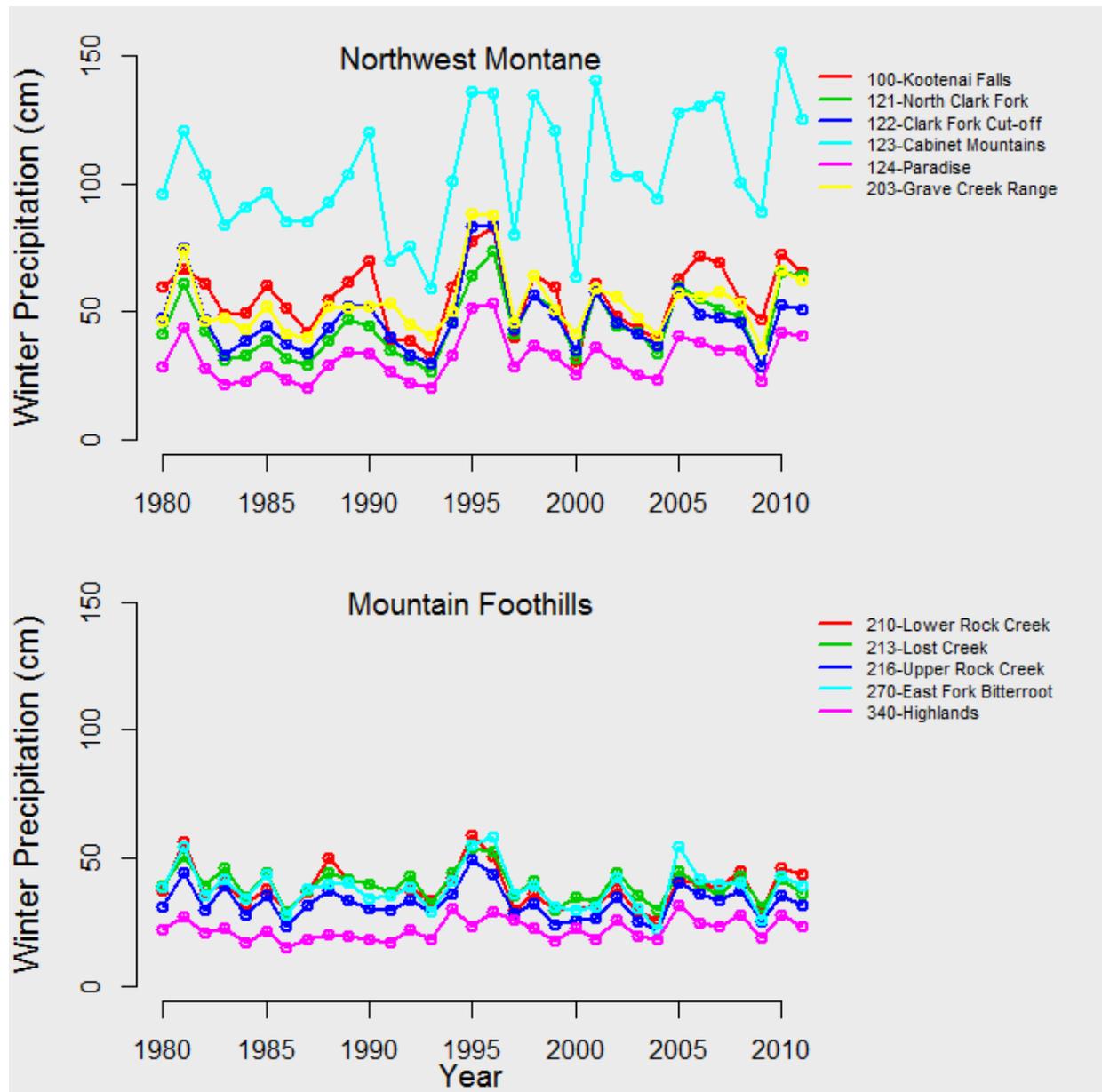


Figure 4. Time-series plots of winter (October-April) precipitation experienced by each herd in the spring recruitment analysis. The plots are separated by eco-region.

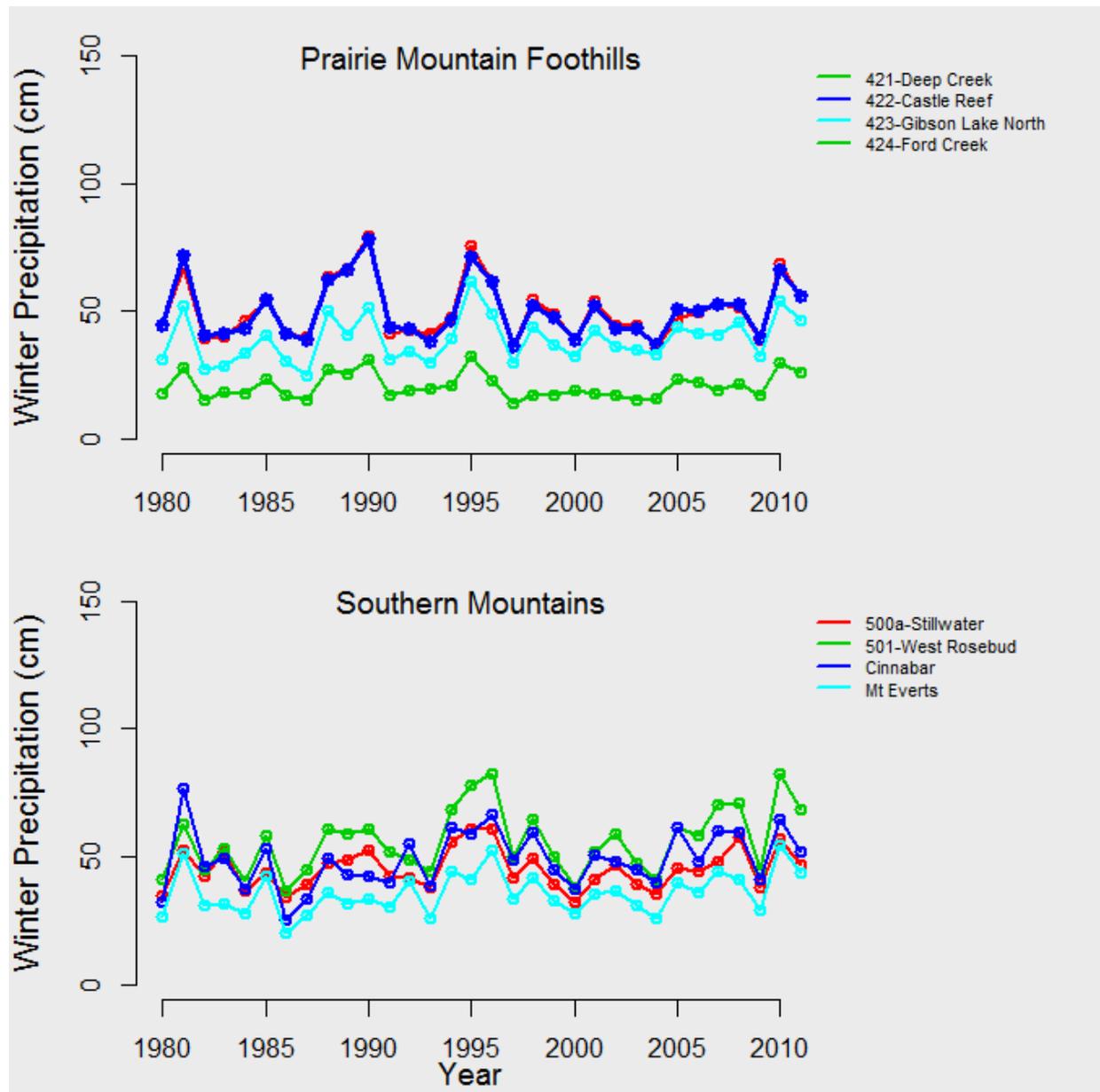


Figure 4 continued

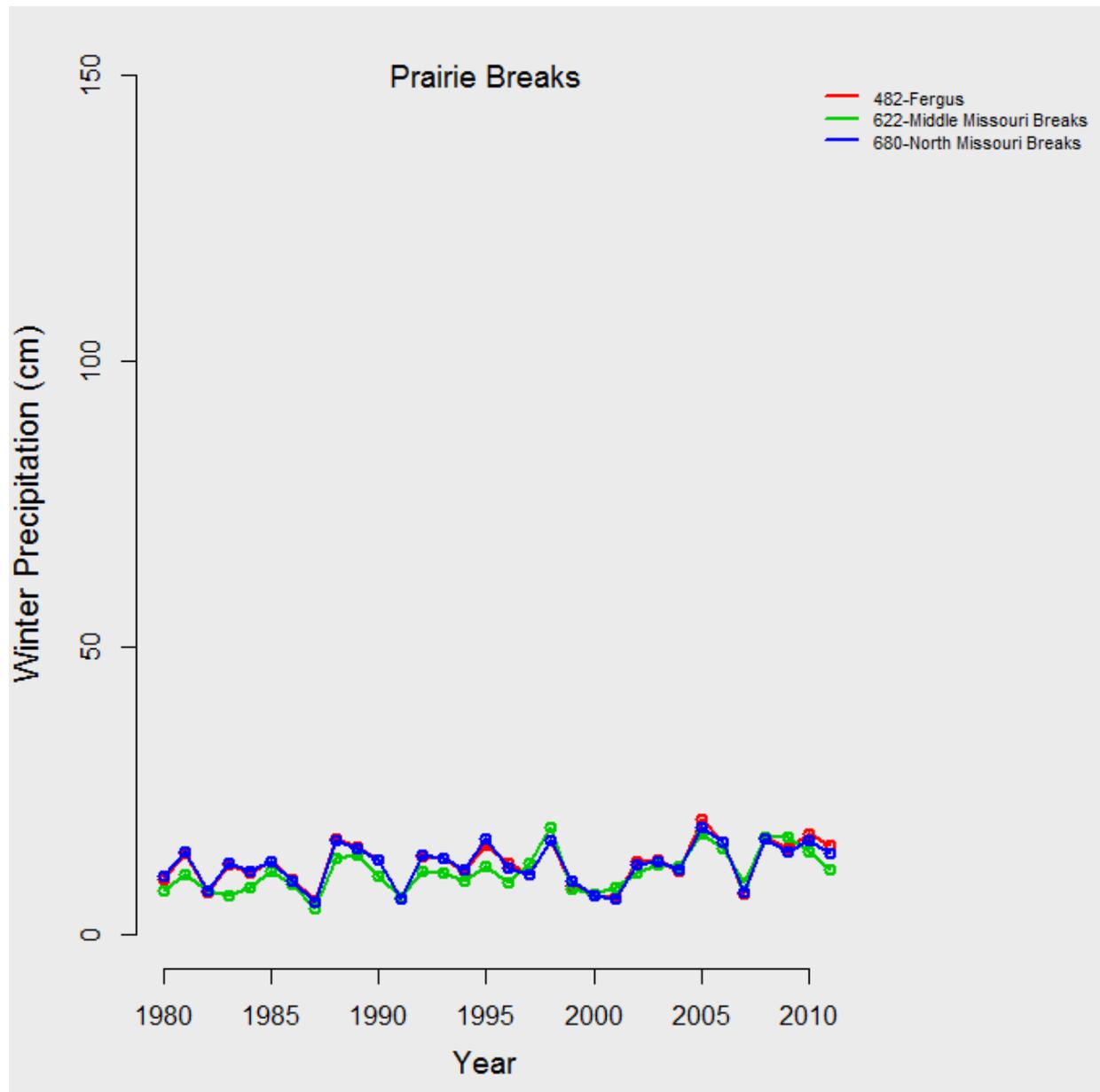


Figure 4 continued

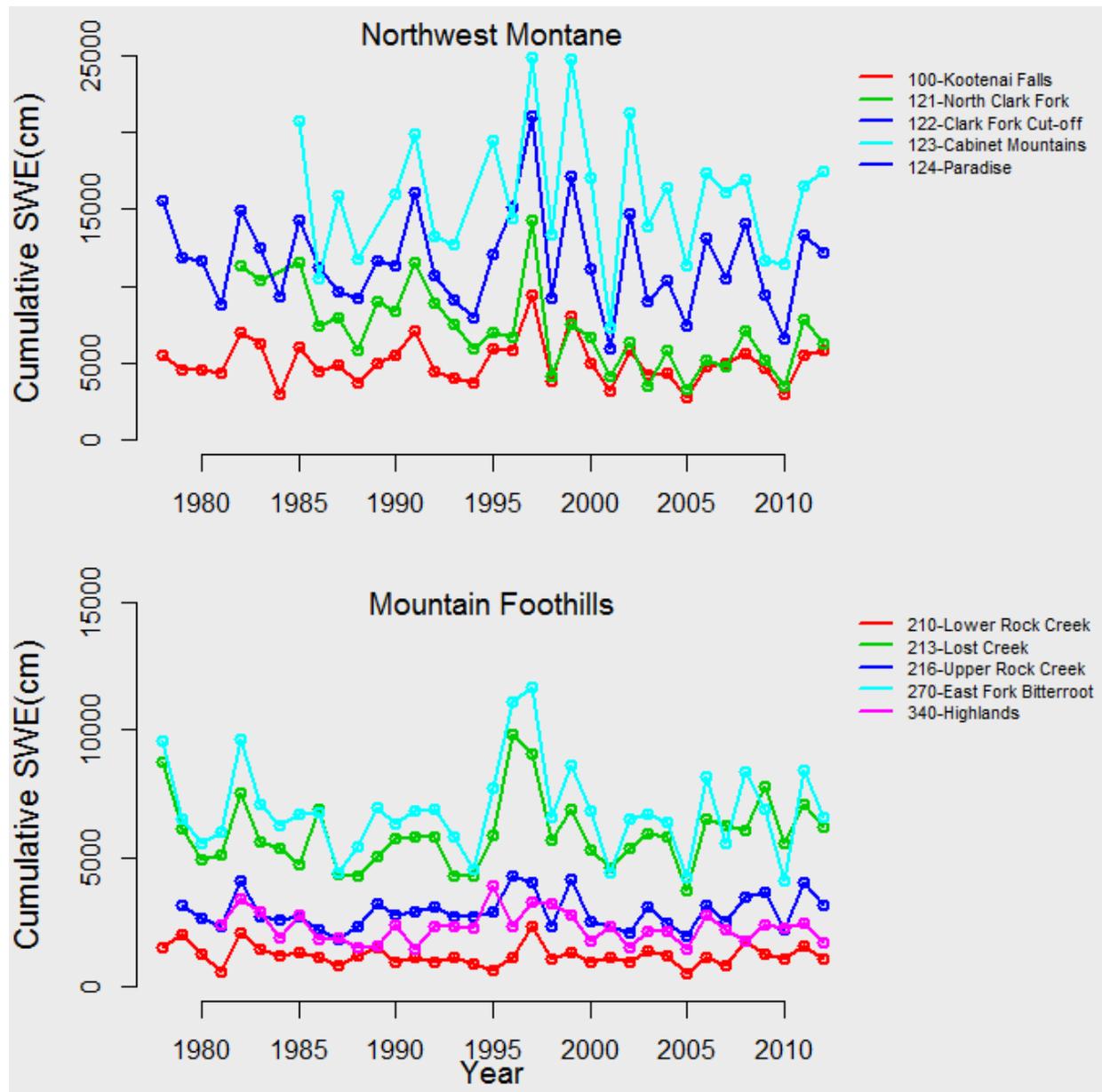


Figure 5. Cumulative snow water equivalent (SWE) October-April derived from Snotel stations, used to index winter conditions experienced by each herd in the spring recruitment analysis. The plots are separated by eco-region. The y-axes on the plots differ. In some cases, a single Snotel station was used to index conditions for multiple herds, and Snotel data was summarized for all populations. Snotel data were not available for populations in the Prairie Breaks eco-region.

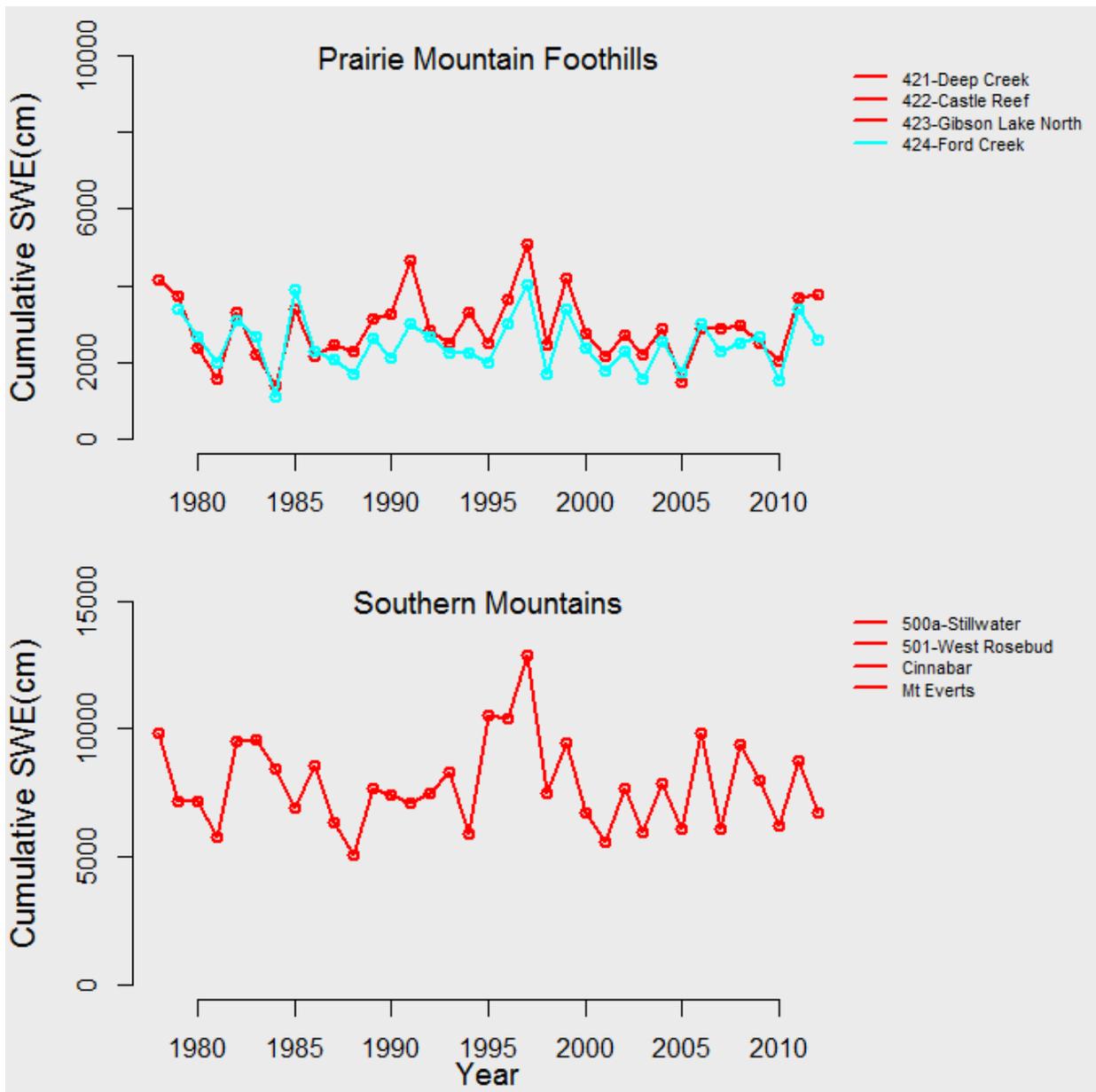


Figure 5 continued.

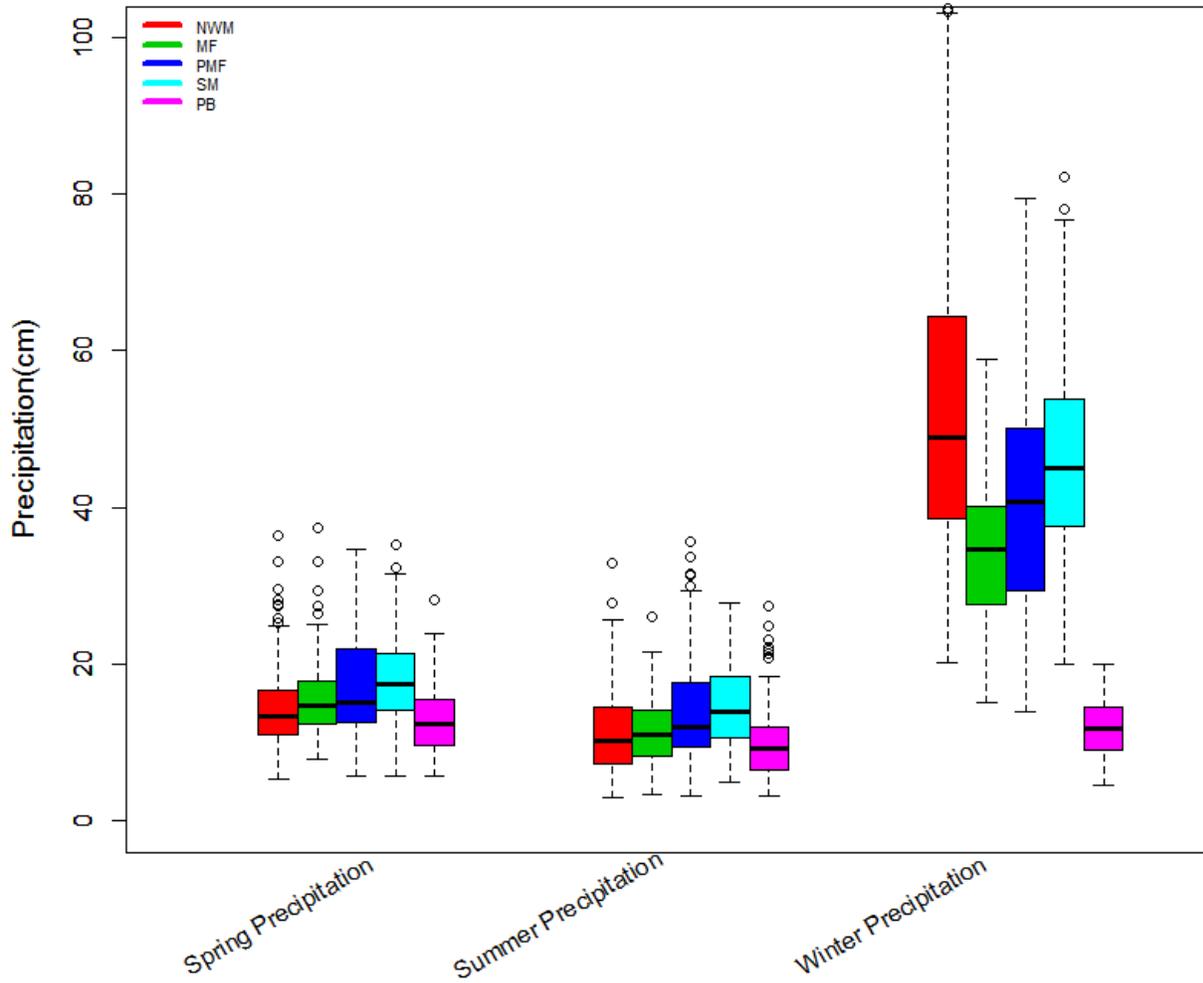


Figure 6. Comparison of amount of precipitation received in each region in spring (May-June), summer (July-September), and winter (October-April). The plots are color coded by eco-region, which are, from left to right, northwest montaine (NWM) in red, mountain foothills (MF) in green, prairie mountain foothills (PMF) in blue, southern mountains (SM) in light blue, and prairie breaks (PB) in magenta.

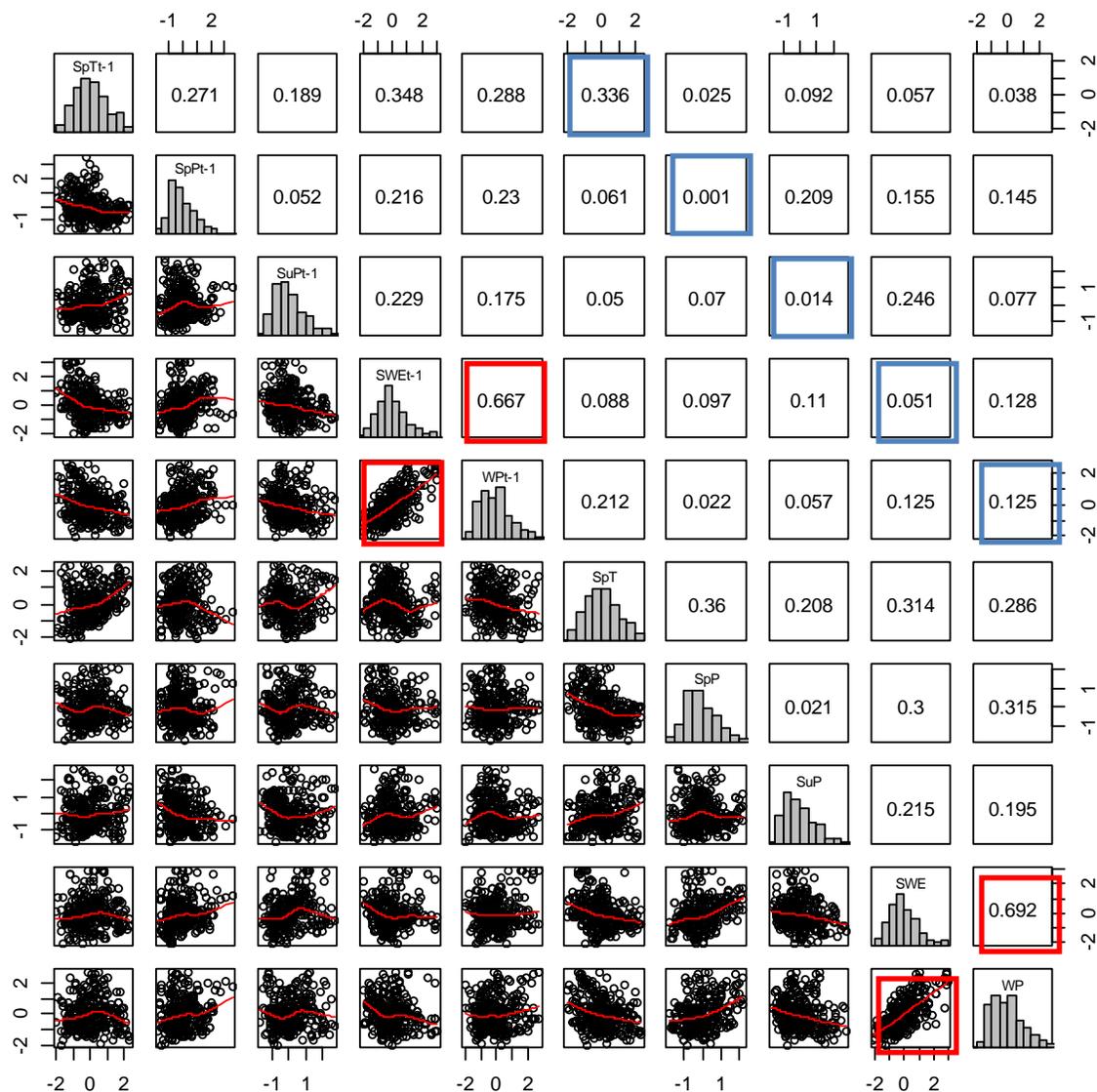


Figure 7. Range of covariate values and correlations between climate covariates. The plots shown were created from datasets of 16 bighorn populations. The climate covariates are spring (May-June) temperature (SpT), spring (May-June) precipitation (SpP), summer (July-September) precipitation (SuP), cumulative (October-April) snow water equivalent (SWE), and winter (October-April) precipitation (WP). The covariates with a “t-1” suffix are time-lagged versions of the climate covariates. Below the diagonal shows scatterplots with fitted regression lines of the relationship between the climate covariates, above the diagonal shows the corresponding correlation coefficients, and the diagonal shows histograms of the distribution of values of each covariate in the dataset. Boxes outlined in red portray the covariates with strong collinearity, boxes outlined in blue show correlation coefficients between the current and time lagged versions of the same covariate as a test of 1<sup>st</sup> order autocorrelation.

Table 1. Summary statistics of 1980-2012 mean annual precipitation values in ranges occupied by bighorn sheep populations whose data were used in the climate recruitment analyses. Data were calculated using PRISM climate data and ArcGIS Spatial Analyst tools

<b>ECOREGION-Herd</b>	<b>Mean Annual Precipitation (cm)</b>
<b>NORTHWEST MONTANE</b>	
100-Kootenai Falls	85.81
121-North Clark Fork	88.48
122-Clark Fork Cutoff	72.71
123-Cabinet Mountains	141.00
124-Paradise	65.61
203-Grave Creek Range	73.43
<b>MOUNTAIN FOOTHILLS</b>	
210-Lower Rock Creek	61.33
213-Lost Creek	65.97
216-Upper Rock Creek	56.47
270-East Fork Bitterroot	58.96
340-Highlands	52.88
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>	
421-Deep Creek	89.96
422-Castle Reef	64.47
423-Gibson Lake North	90.71
424-Ford Creek	70.85
<b>SOUTHERN MOUNTAINS</b>	
500a-Stillwater	85.92
501-West Rosebud	105.17
Cinnabar	76.17
Mt Everts	66.06
<b>PRAIRIE BREAKS</b>	
622-Middle Missouri Breaks	33.17
482-Fergus	35.20
680-North Missouri Breaks	33.99

Table 2. Coefficient of Variation (CV) values for each of the a priori climate covariates calculated for ranges of bighorn sheep populations used in the climate recruitment analyses. Spring precipitation and temperature were calculated for the months of May and June, summer precipitation was calculated for the months of July-September, SWE (cumulative snow water equivalent) and winter precipitation were calculated for the months of October-April. The data are based on the values of the annual weather variables 1980-2010 calculated using PRISM climate data and ArcGIS Spatial Analyst tools.

ECO-REGION-Herd	CV Spring Precipitation (%)	CV Spring Temperature (%)	CV Summer Precipitation (%)	CV Winter Precipitation (%)	CV SWE (%)
<b>NORTHWEST MONTANE</b>					
100-Kootenai Falls	33	09	41	24	29
121-North Clark Fork	30	09	44	28	36
122-Clark Fork Cutoff	27	10	44	28	28
123-Cabinet Mountains	27	12	44	23	26
124-Paradise	33	09	44	27	28
203-Grave Creek Range	26	11	45	23	NA
<b>MOUNTAIN FOOTHILLS</b>					
210-Lower Rock Creek	30	12	44	21	32
213-Lost Creek	31	14	37	16	23
216-Upper Rock Creek	29	12	41	20	24
270-East Fork Bitterroot	24	12	37	22	26
340-Highlands	30	15	37	19	26
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>					
421-Deep Creek	36	13	47	23	28
422-Castle Reef	39	11	50	24	28
423-Gibson Lake North	34	13	47	23	28
424-Ford Creek	40	13	48	23	27
<b>SOUTHERN MOUNTAINS</b>					
500a-Stillwater	26	17	34	18	NA
501-West Rosebud	26	23	33	23	NA
Cinnabar	24	17	40	23	22
Mt Everts	25	15	38	23	22
<b>PRAIRIE BREAKS</b>					
622-Middle Missouri Breaks	40	9	54	32	NA
482-Fergus	31	9	49	31	NA
680-North Missouri Breaks	30	9	49	29	NA

Table 3. Comparison of seasonal average 1980-2012 precipitation patterns in ranges occupied bighorn sheep populations whose data were used in the climate recruitment analyses. Precipitation values were calculated using PRISM climate data and ArcGIS Spatial Analyst tools. Winter precipitation was calculated as total precipitation October-April, spring precipitation was calculated as total precipitation May-June, and summer precipitation was calculated as total precipitation July-September.

<b>ECO-REGION-Herd</b>	<b>Mean Spring Precipitation (cm)</b>	<b>Mean Summer Precipitation (cm)</b>	<b>Mean Winter Precipitation (cm)</b>
<b>NORTHWEST MONTANE</b>			
100-Kootenai Falls	13.34	10.32	55.76
121-North Clark Fork	12.79	9.71	45.25
122-Clark Fork Cutoff	14.00	10.58	47.51
123-Cabinet Mountains	21.61	15.52	104.88
124-Paradise	11.58	8.90	31.78
203-Grave Creek Range	14.94	11.57	53.36
<b>MOUNTAIN FOOTHILLS</b>			
210-Lower Rock Creek	15.89	11.07	38.42
213-Lost Creek	17.71	12.99	39.46
216-Upper Rock Creek	14.97	11.03	32.55
270-East Fork Bitterroot	13.73	11.06	38.39
340-Highlands	15.00	11.13	22.10
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>			
421-Deep Creek	18.77	15.09	50.47
422-Castle Reef	15.25	11.33	20.72
423-Gibson Lake North	18.44	14.77	50.27
424-Ford Creek	16.53	12.80	39.10
<b>SOUTHERN MOUNTAINS</b>			
500a-Stillwater	19.57	14.74	45.12
501-West Rosebud	20.83	16.25	55.99
Cinnabar	16.52	14.02	49.00
Mt Everts	13.99	11.92	35.78
<b>PRAIRIE BREAKS</b>			
622-Middle Missouri Breaks	12.38	9.76	10.92
482-Fergus	13.42	10.38	12.22
680-North Missouri Breaks	13.23	10.01	12.11

Table 4. Summary statistics of 1980-2012 spring (May & June) precipitation values in ranges occupied by bighorn sheep populations used in the climate recruitment analyses. Data were calculated using PRISM climate data and ArcGIS Spatial Analyst tools.

<b>ECO-REGION-Herd</b>	<b>Mean Spring Precipitation (cm)</b>	<b>Standard Deviation Spring Precipitation (cm)</b>	<b>Range (cm)</b>
<b>NORTHWEST MONTANE</b>			
100-Kootenai Falls	13.34	4.36	6.32-22.57
121-North Clark Fork	12.79	3.87	7.36-24.87
122-Clark Fork Cutoff	14.00	3.81	7.77-25.87
123-Cabinet Mountains	21.61	5.82	12.88-36.46
124-Paradise	11.58	3.84	5.35-25.37
203-Grave Creek Range	14.94	3.93	7.88-28.18
<b>MOUNTAIN FOOTHILLS</b>			
210-Lower Rock Creek	15.89	4.70	7.87-33.12
213-Lost Creek	17.71	5.56	9.60-37.45
216-Upper Rock Creek	14.97	4.31	8.61-29.32
270-East Fork Bitterroot	13.73	3.32	7.87-21.91
340-Highlands	15.00	4.43	8.93-27.46
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>			
421-Deep Creek	18.77	6.70	8.55-33.28
422-Castle Reef	15.25	5.91	6.113-28.63
423-Gibson Lake North	18.44	6.30	8.66-30.633
424-Ford Creek	16.53	6.67	5.77-34.57
<b>SOUTHERN MOUNTAINS</b>			
500a-Stillwater	19.57	5.16	8.64-32.37
501-West Rosebud	20.83	5.31	10.56-35.17
Cinnabar	16.52	4.05	8.57-23.12
Mt Everts	13.99	3.49	5.65-22.26
<b>PRAIRIE BREAKS</b>			
622-Middle Missouri Breaks	12.38	4.95	5.65-28.11
482-Fergus	13.42	4.10	6.64-23.92
680-North Missouri Breaks	13.23	4.00	6.75-23.03

Table 5. Summary statistics of 1980-2012 average spring (May & June) temperature values in ranges occupied by bighorn sheep populations whose data were used in the climate recruitment analyses. Data were calculated using PRISM climate data and ArcGIS Spatial Analyst tools.

<b>ECO-REGION-Herd</b>	<b>Mean Spring Temperature (°C)</b>	<b>Standard Deviation Spring Temperature (°C)</b>	<b>Range (°C)</b>
<b>NORTHWEST MONTANE</b>			
100-Kootenai Falls	11.84	1.07	10.04-14.32
121-North Clark Fork	11.41	1.02	9.35-13.78
122-Clark Fork Cutoff	12.03	1.18	9.81-14.19
123-Cabinet Mountains	9.90	1.15	7.79-12.45
124-Paradise	12.42	1.15	10.71-14.89
203-Grave Creek	10.21	1.10	7.93-12.38
<b>MOUNTAIN FOOTHILLS</b>			
210-Lower Rock Creek	10.82	1.34	8.63-13.89
213-Lost Creek	8.54	1.17	6.22-11.04
216-Upper Rock Creek	9.05	1.11	7.24-11.06
270-East Fork Bitterroot	8.70	1.05	7.12-10.60
340-Highlands	10.40	1.59	7.41-13.69
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>			
421-Deep Creek	8.44	1.07	6.67-10.937
422-Castle Reef	10.30	1.12	8.127-13.04
423-Gibson Lake North	8.34	1.07	6.56.-10.72
424-Ford Creek	8.84	1.16	6.87-11.27
<b>SOUTHERN MOUNTAINS</b>			
500a-Stillwater	7.16	1.19	5.28-10.198
501-West Rosebud	5.19	1.19	3.27-7.72
Cinnabar	7.49	1.25	5.46-9.54
Mt Everts	7.63	1.18	5.76-9.64
<b>PRAIRIE BREAKS</b>			
622-Middle Missouri Breaks	15.03	1.37	12.81-19.87
482-Fergus	14.58	1.32	12.59-19.07
680-North Missouri Breaks	14.50	1.29	12.47-18.91

Table 6. Summary statistics of 1980-2012 summer (July-September) precipitation values in ranges occupied by bighorn sheep populations whose data were used in the climate recruitment analyses. Data were calculated using PRISM climate data and ArcGIS Spatial Analyst tools.

<b>ECO-REGION-Herd</b>	<b>Mean Summer Precipitation (cm)</b>	<b>Standard Deviation Summer Precipitation (cm)</b>	<b>Range (cm)</b>
<b>NORTHWEST MONTANE</b>			
100-Kootenai Falls	10.32	4.27	3.05-19.91
121-North Clark Fork	9.71	4.27	3.81-18.43
122-Clark Fork Cutoff	10.58	4.69	3.33-20.69
123-Cabinet Mountains	15.52	6.87	5.47-32.86
124-Paradise	8.90	3.91	3.15-18.16
203-Grave Creek Range	11.57	5.24	2.75-24.5
<b>MOUNTAIN FOOTHILLS</b>			
210-Lower Rock Creek	11.07	4.90	3.45-21.51
213-Lost Creek	12.99	4.79	3.27-26.12
216-Upper Rock Creek	11.03	4.56	2.97-21.13
270-East Fork Bitterroot	11.06	4.12	3.59-19.51
340-Highlands	11.13	4.11	5.48-20.08
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>			
421-Deep Creek	15.09	7.13	5.84-35.64
422-Castle Reef	11.33	5.64	3.22-25.64
423-Gibson Lake North	14.77	6.98	5.48-33.62
424-Ford Creek	12.80	6.16	4.93-29.38
<b>SOUTHERN MOUNTAINS</b>			
500a-Stillwater	14.74	5.01	5.45-25.9
501-West Rosebud	16.25	5.43	5.87-27.9
Cinnabar	14.02	5.54	6.69-27.63
Mt Everts	11.92	4.48	4.85-21.53
<b>PRAIRIE BREAKS</b>			
622-Middle Missouri Breaks	9.76	5.31	3.21-27.33
482-Fergus	10.38	5.05	3.97-23.09
680-North Missouri Breaks	10.01	4.86	3.48-22.16

Table 7. Summary statistics of 1980-2012 winter (October-April) precipitation in ranges occupied by bighorn sheep populations used in the climate recruitment analyses. Data were calculated using PRISM climate data and ArcGIS Spatial Analyst tools.

<b>ECO-REGION-Herd</b>	<b>Mean Winter Precipitation (cm)</b>	<b>Standard Deviation Winter Precipitation (cm)</b>	<b>Range (cm)</b>
<b>NORTHWEST MONTAINE</b>			
100-Kootenai Falls	55.76	13.39	28.82-83.04
121-North Clark Fork	45.25	12.75	26.83-73.68
122-Clark Fork Cutoff	47.51	13.49	28.72-83.82
123-Cabinet Mountains	104.88	24.11	59.25-151.55
124-Paradise	31.78	8.60	20.13-53.37
203-Grave Creek Range	53.36	12.45	35.51-88.41
<b>MOUNTAIN FOOTHILLS</b>			
210-Lower Rock Creek	38.42	8.02	26.03-58.98
213-Lost Creek	39.46	6.41	28.98-53.58
216-Upper Rock Creek	32.55	6.42	22.15-49.57
270-East Fork Bitterroot	38.39	8.47	21.91-58.32
340-Highlands	22.10	4.20	15.11-31.36
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>			
421-Deep Creek	50.47	11.63	35.93-79.51
422-Castle Reef	20.72	4.98	14-32.21
423-Gibson Lake North	50.27	11.32	36.34-77.95
424-Ford Creek	39.10	8.89	24.66-61.76
<b>SOUTHERN MOUNTAINS</b>			
500a-Stillwater	45.12	7.93	32.03-60.49
501-West Rosebud	55.99	12.65	36.41-82.26
Cinnabar	49.00	11.32	24.9-76.64
Mt Everts	35.78	8.33	19.99-54.53
<b>PRAIRIE BREAKS</b>			
622-Middle Missouri Breaks	10.92	3.50	4.52-18.57
482-Fergus	12.22	3.74	5.97-19.98
680-North Missouri Breaks	12.11	3.55	5.53-18.66

Table 8. Summary statistics of 1980-2012 cumulative daily SWE values (October-April) recorded by Snotel sites nearest to bighorn sheep populations used in the spring recruitment analysis. The Snotel data were not necessarily derived from a site within each herd's occupied range, but from the nearest available site. Please note some populations have identical values because Snotel sites were shared between populations when the nearest site was the same for the herds. Adequate Snotel data were not available for populations in the Prairie-Breaks eco-region.

<b>ECO-REGION-Herd</b>	<b>Mean SWE (cm)</b>	<b>Standard Deviation SWE (cm)</b>	<b>Range (cm)</b>
<b>NORTHWEST MONTAINE</b>			
100-Kootenai Falls	5089	1466	2783-9392
121-North Clark Fork	6909	2516	3303-14324
122-Clark Fork Cutoff	11631	3235	5953-21084
123-Cabinet Mountains	15873	4194	7271-24910
124-Paradise	11631	3235	5953-21084
<b>MOUNTAIN FOOTHILLS</b>			
210-Lower Rock Creek	1181	374	460-2310
213-Lost Creek	5954	1342	3720-9845
216-Upper Rock Creek	2908	684	1806-4319
270-East Fork Bitterroot	6855	1763	4071-11635
340-Highlands	2234	587	1431-3888
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>			
422-Castle Reef	2896	816	1386-5091
423-Gibson Lake North	2896	816	1386-5091
424-Ford Creek	2454	674	1084-4018
<b>SOUTHERN MOUNTAINS</b>			
Cinnabar	7855	1718	5082-12891
Mt Everts	7855	1718	5082-12891

**APPENDIX B.** Summary Figures and Tables of Climate Data for Ranges of Bighorn Populations not used in Recruitment Analyses.

Table 1. Summary statistics of 1980-2010 mean annual precipitation values in ranges occupied by specified bighorn sheep populations. Data were calculated using PRISM climate data and ArcGIS Spatial Analyst tools. Please note that these data were not calculated for all populations in the initial database. Table continued on next page.

<b>ECO-REGION-Herd</b>	<b>Mean Annual Precipitation (cm)</b>
<b>NORTHWEST MONTANE</b>	
100-Kootenai Falls	85.81
101-Ural Tweed	77.59
102-Galton Range	136.80
121-North Clark Fork	88.48
122-Clark Fork Cutoff	72.71
123-Cabinet Mountains	141.00
124-Paradise	65.61
203-Grave Creek Range	73.43
283-Lower Blackfoot	87.87
<b>MOUNTAIN FOOTHILLS</b>	
210-Lower Rock Creek	61.33
212-Garrison	58.21
213-Lost Creek	65.97
216-Upper Rock Creek	56.47
250-West Fork Bitterroot	94.27
261-Skalkaho	53.63
270-East Fork Bitterroot	58.96
315-North Beaverhead	61.98
315-Tendoys	51.88
340-Highlands	52.88
380-Elkhorns	46.65
Greenhorns	65.58
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>	
381-Sleeping Giant	37.97
455-Beartooth WMA	44.73
421-Deep Creek	89.96
422-Castle Reef	64.47
423-Gibson Lake North	90.71
424-Ford Creek	70.85
441-North Fork Birch Creek	83.16

Table 1 continued

<b>ECO-REGION-Herd</b>	<b>Mean Annual Precipitation (cm)</b>
<b>SOUTHERN MOUNTAINS</b>	
301-Spanish Peaks	93.80
302-Hilgards	105.36
Cinnabar	76.17
Mt Everts	66.06
Pt of Rocks-Tom Miner	78.24
500a-Stillwater	85.92
500b-Monument Peak	95.86
501-West Rosebud	105.17
502-Hellroaring	94.82
<b>PRAIRIE BREAKS</b>	
503-Pryor Mountains	29.60
620-Little Rockies	46.96
622-Middle Missouri Breaks	33.17
482-Fergus	35.20
680-North Missouri Breaks	33.99

Table 2. Comparison of seasonal average 1980-2012 precipitation patterns in ranges occupied by specified bighorn sheep populations. Precipitation values were calculated using PRISM climate data and ArcGIS Spatial Analyst tools. Winter precipitation was calculated as total precipitation October-April, spring precipitation was calculated as total precipitation May-June, and summer precipitation was calculated as total precipitation July-September. Please note that these data were not calculated for all populations in the initial database. Table continued on next page.

<b>ECOREGION-Herd</b>	<b>Mean Spring Precipitation (cm)</b>	<b>Mean Summer Precipitation (cm)</b>	<b>Mean Winter Precipitation (cm)</b>
<b>NORTHWEST MONTANE</b>			
100-Kootenai Falls	13.34	10.32	55.76
101-Ural Tweed	14.94	11.37	58.41
102-Galton Range	30.17	21.53	107.40
121-North Clark Fork	12.79	9.71	45.25
122-Clark Fork Cutoff	14.00	10.58	47.51
123-Cabinet Mountains	21.61	15.52	104.88
124-Paradise	11.58	8.90	31.78
203-Grave Creek Range	14.94	11.57	53.36
283-Lower Blackfoot	16.49	12.04	53.38
<b>MOUNTAIN FOOTHILLS</b>			
210-Lower Rock Creek	15.89	11.07	38.42
212-Garrison	14.38	11.44	27.47
213-Lost Creek	17.71	12.99	39.46
216-Upper Rock Creek	14.97	11.03	32.55
250-West Fork Bitterroot	15.66	11.29	63.01
261-Skalkaho	12.86	9.97	32.15
270-East Fork Bitterroot	13.73	11.06	38.39
315-North Beaverhead	15.83	11.34	28.16
315-Tendoys	13.61	10.48	19.67
340-Highlands	15.00	11.13	22.10
380-Elkhorns	13.08	10.26	14.89
Greenhorn	16.44	13.23	39.43
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>			
381-Sleeping Giant	13.24	10.74	14.67
455-Beartooth WMA	16.34	12.87	18.36
421-Deep Creek	18.77	15.09	50.47
422-Castle Reef	15.25	11.33	20.72
423-Gibson Lake North	18.44	14.77	50.27
424-Ford Creek	16.53	12.80	39.10
441-North Fork Birch Creek	19.61	16.69	48.33

Table 2 continued

<b>ECOREGION-Herd</b>	<b>Mean Spring Precipitation (cm)</b>	<b>Mean Summer Precipitation (cm)</b>	<b>Mean Winter Precipitation (cm)</b>
<b>SOUTHERN MOUNTAINS</b>			
301-Spanish Peaks	20.69	15.11	48.56
302-Hilgards	17.69	14.96	65.17
Cinnabar	16.52	14.02	49.00
Mt Everts	13.99	11.92	35.78
Pt of Rocks-Tom Miner	18.72	13.55	43.35
500a-Stillwater	19.57	14.74	45.12
500b-Monument Peak	18.93	14.69	61.87
501-West Rosebud	20.83	16.25	55.99
502-Hellroaring	19.40	14.21	50.89
<b>PRAIRIE BREAKS</b>			
503-Pryor Mountains	10.47	6.85	13.38
620-Little Rockies	20.19	13.74	18.04
622-Middle Missouri Breaks	12.38	9.76	10.92
482-Fergus	13.42	10.38	12.22
680-North Missouri Breaks	13.23	10.01	12.11

Table 3. Summary statistics of 1980-2012 spring (May & June) precipitation values in ranges occupied by specified bighorn sheep populations. Data were calculated using PRISM climate data and ArcGIS Spatial Analyst tools. Please note that this data was not calculated for all populations in the initial database. Table continued on next page.

<b>ECO-REGION-Herd</b>	<b>Mean Spring Precipitation (cm)</b>	<b>Standard Deviation Spring Precipitation (cm)</b>	<b>Range (cm)</b>
<b>NORTHWEST MONTANE</b>			
100-Kootenai Falls	13.34	4.36	6.32-22.57
101-Ural Tweed	14.94	4.62	9.56-27.46
102-Galton Range	30.17	10.05	13.31-58.04
121-North Clark Fork	12.79	3.87	7.36-24.87
122-Clark Fork Cutoff	14.00	3.81	7.77-25.87
123-Cabinet Mountains	21.61	5.82	12.88-36.46
124-Paradise	11.58	3.84	5.35-25.37
203-Grave Creek Range	14.94	3.93	7.88-28.18
283-Lower Blackfoot	16.49	5.43	7.99-31.82
<b>MOUNTAIN FOOTHILLS</b>			
210-Lower Rock Creek	15.89	4.70	7.87-33.12
212-Garrison	14.38	4.51	7.95-31.68
213-Lost Creek	17.71	5.56	9.60-37.45
216-Upper Rock Creek	14.97	4.31	8.61-29.32
250-West Fork Bitterroot	15.66	3.99	9.13-26.28
261-Skalkaho	12.86	3.64	6.02-22.18
270-East Fork Bitterroot	13.73	3.32	7.87-21.91
315-North Beaverhead	15.83	5.43	7.60-28.61
315-Tendoys	13.61	4.04	7.104-22.40
340-Highlands	15.00	4.43	8.93-27.46
380-Elkhorns	13.08	3.97	5.17-22.12
Greenhorns	16.44	3.99	9.73-23.87
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>			
381-Sleeping Giant	13.24	4.98	5.32-27.02
455-Beartooth WMA	16.34	5.65	7.46-33.14
421-Deep Creek	18.77	6.70	8.55-33.28
422-Castle Reef	15.25	5.91	6.113-28.63
423-Gibson Lake North	18.44	6.30	8.66-30.633
424-Ford Creek	16.53	6.67	5.77-34.57
441-North Fork Birch Creek	19.61	7.27	7.74-35.69

Table 3 continued

<b>ECO-REGION-Herd</b>	<b>Mean Spring Precipitation (cm)</b>	<b>Standard Deviation Spring Precipitation (cm)</b>	<b>Range (cm)</b>
<b>SOUTHERN MOUNTAINS</b>			
301-Spanish Peaks	20.69	5.39	12.70-37.97
302-Hilgards	17.69	5.36	7.48-28.62
Cinnabar	16.52	4.05	8.57-23.12
Mt Everts	13.99	3.49	5.65-22.26
Pt of Rocks-Tom Miner	18.72	4.33	10.92-31.02
500a-Stillwater	19.57	5.16	8.64-32.37
500b-Monument Peak	18.93	3.92	10.27-29.86
501-West Rosebud	20.83	5.31	10.56-35.17
502-Hellroaring	19.40	5.18	10.73-34.21
<b>PRAIRIE BREAKS</b>			
503-Pryor Mountains	10.47	4.03	4.04-19.44
620-Little Rockies	20.19	8.06	10.73-47.40
622-Middle Missouri Breaks	12.38	4.95	5.65-28.11
482-Fergus	13.42	4.10	6.64-23.92
680-North Missouri Breaks	13.23	4.00	6.75-23.03

Table 4. Summary statistics of 1980-2012 average spring (May & June) temperature values in ranges occupied by specified bighorn sheep populations. Data were calculated using PRISM climate data and ArcGIS Spatial Analyst tools. Please note that this data was not calculated for all populations in the initial database. Table continued on next page.

<b>ECO-REGION-Herd</b>	<b>Mean Spring Temperature (°C)</b>	<b>Standard Deviation Spring Temperature (°C)</b>	<b>Range (°C)</b>
<b>NORTHWEST MONTANE</b>			
100-Kootenai Falls	11.84	1.07	10.04-14.32
101-Ural Tweed	10.35	1.20	8.37-12.86
102-Galton Range	7.87	1.32	5.73-10.67
121-North Clark Fork	11.41	1.02	9.35-13.78
122-Clark Fork Cutoff	12.03	1.18	9.81-14.19
123-Cabinet Mountains	9.90	1.15	7.79-12.45
124-Paradise	12.42	1.15	10.71-14.89
203-Grave Creek Range	10.21	1.10	7.93-12.38
283-Lower Blackfoot	10.48	1.46	8.00-13.87
<b>MOUNTAIN FOOTHILLS</b>			
210-Lower Rock Creek	10.82	1.34	8.63-13.89
212-Garrison	9.45	1.18	7.58-11.93
213-Lost Creek	8.54	1.17	6.22-11.04
216-Upper Rock Creek	9.05	1.11	7.24-11.06
250-West Fork Bitterroot	8.71	1.13	6.70-11.23
261-Skalkaho	9.29	1.21	7.19-11.39
270-East Fork Bitterroot	8.70	1.05	7.12-10.60
315-North Beaverhead	6.66	1.19	3.92-8.76
315-Tendoys	8.55	1.17	6.20-10.85
340-Highlands	10.40	1.59	7.41-13.69
380-Elkhorns	11.74	1.12	10.05-14.75
Greenhorns	8.58	1.18	5.99-10.93
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>			
381-Sleeping Giant	12.52	1.30	9.87-15.70
455-Beartooth WMA	11.03	1.19	9.09-14.17
421-Deep Creek	8.44	1.07	6.67-10.937
422-Castle Reef	10.30	1.12	8.127-13.04
423-Gibson Lake North	8.34	1.07	6.56.-10.72
424-Ford Creek	8.84	1.16	6.87-11.27
441-North Fork Birch Creek	8.31	1.05	6.88-10.80

Table 4 continued

<b>ECO-REGION-Herd</b>	<b>Mean Spring Temperature (<sup>0</sup>C)</b>	<b>Standard Deviation Spring Temperature (<sup>0</sup>C)</b>	<b>Range (<sup>0</sup>C)</b>
<b>SOUTHERN MOUNTAINS</b>			
301-Spanish Peaks	7.48	1.12	5.73-9.53
302-Hilgards	6.32	1.24	4.14-8.46
Cinnabar	7.49	1.25	5.46-9.54
Mt Everts	7.63	1.18	5.76-9.64
Pt of Rocks-Tom Miner	7.87	1.25	6.05-10.04
500a-Stillwater	7.16	1.19	5.28-10.198
500b-Monument Peak	6.19	1.30	4.11-8.80
501-West Rosebud	5.19	1.19	3.27-7.72
502-Hellroaring	5.51	1.15	3.47-7.35
<b>PRAIRIE BREAKS</b>			
503-Pryor Mountains	13.27	1.27	11.00-16.75
620-Little Rockies	11.87	1.38	9.71-15.95
622-Middle Missouri Breaks	15.03	1.37	12.81-19.87
482-Fergus	14.58	1.32	12.59-19.07
680-North Missouri Breaks	14.50	1.29	12.47-18.91

Table 5. Summary statistics of 1980-2012 Summer (July-September) precipitation values in ranges occupied by specified bighorn sheep populations. Data were calculated using PRISM climate data and ArcGIS Spatial Analyst tools. Please note that these data were not calculated for all populations in the initial database. Table continued on next page.

<b>ECOREGION-Herd</b>	<b>Mean Summer Precipitation (cm)</b>	<b>Standard Deviation Summer Precipitation (cm)</b>	<b>Range (cm)</b>
<b>NORTHWEST MONTANE</b>			
100-Kootenai Falls	10.32	4.27	3.05-19.91
101-Ural Tweed	11.37	4.45	3.02-21.11
102-Galton Range	21.53	8.31	3.26-44.63
121-North Clark Fork	9.71	4.27	3.81-18.43
122-Clark Fork Cutoff	10.58	4.69	3.33-20.69
123-Cabinet Mountains	15.52	6.87	5.47-32.86
124-Paradise	8.90	3.91	3.15-18.16
203-Grave Creek Range	11.57	5.24	2.75-24.5
283-Lower Blackfoot	12.04	5.03	2.77-22.58
<b>MOUNTAIN FOOTHILLS</b>			
210-Lower Rock Creek	11.07	4.90	3.45-21.51
212-Garrison	11.44	4.30	3.72-20.62
213-Lost Creek	12.99	4.79	3.27-26.12
216-Upper Rock Creek	11.03	4.56	2.97-21.13
250-West Fork Bitterroot	11.29	4.64	3.83-23.05
261-Skalkaho	9.97	3.80	3.05-17.74
270-East Fork Bitterroot	11.06	4.12	3.59-19.51
315-North Beaverhead	11.34	3.80	4.37-17.84
315-Tendoys	10.48	3.63	5.8-18.23
340-Highlands	11.13	4.11	5.48-20.08
380-Elkhorns	10.26	4.49	4.34-22.24
Greenhorns	13.23	5.08	6.85-26.17
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>			
381-Sleeping Giant	10.74	4.85	4.05-25.15
455-Beartooth WMA	12.87	5.72	4.32-29.68
421-Deep Creek	15.09	7.13	5.84-35.64
422-Castle Reef	11.33	5.64	3.22-25.64
423-Gibson Lake North	14.77	6.98	5.48-33.62
424-Ford Creek	12.80	6.16	4.93-29.38
441-North Fork Birch Creek	16.69	8.10	7.6-38.7

Table 5 continued

<b>ECOREGION-Herd</b>	<b>Mean Summer Precipitation (cm)</b>	<b>Standard Deviation Summer Precipitation (cm)</b>	<b>Range (cm)</b>
<b>SOUTHERN MOUNTAINS</b>			
301-Spanish Peaks	15.11	5.75	7.14-26.08
302-Hilgards	14.96	5.59	6.76-25.61
Cinnabar	14.02	5.54	6.69-27.63
Mt Everts	11.92	4.48	4.85-21.53
Pt of Rocks-Tom Miner	13.55	5.22	5.25-22.83
500a-Stillwater	14.74	5.01	5.45-25.9
500b-Monument Peak	14.69	5.80	2.51-26.98
501-West Rosebud	16.25	5.43	5.87-27.9
502-Hellroaring	14.21	4.76	3.8-21.72
<b>PRAIRIE BREAKS</b>			
503-Pryor Mountains	6.85	2.89	1.71-13.69
620-Little Rockies	13.74	8.07	4.06-40.34
622-Middle Missouri Breaks	9.76	5.31	3.21-27.33
482-Fergus	10.38	5.05	3.97-23.09
680-North Missouri Breaks	10.01	4.86	3.48-22.16

Table 6. Summary statistics of 1980-2012 winter (October-April) precipitation values in ranges occupied by specified bighorn sheep populations. Precipitation values were calculated using PRISM climate data and ArcGIS Spatial Analyst tools. Please note that these data were not calculated for all populations in the initial database. Table continued on next page.

<b>ECO-REGION-Herd</b>	<b>Mean Winter Precipitation (cm)</b>	<b>Standard Deviation Winter Precipitation (cm)</b>	<b>Range (cm)</b>
<b>NORTHWEST MONTANE</b>			
100-Kootenai Falls	55.76	13.39	28.82-83.04
101-Ural Tweed	58.41	12.36	35.65-93.36
102-Galton Range	107.40	22.93	59.46-160.23
121-North Clark Fork	45.25	12.75	26.83-73.68
122-Clark Fork Cutoff	47.51	13.49	28.72-83.82
123-Cabinet Mountains	104.88	24.11	59.25-151.55
124-Paradise	31.78	8.60	20.13-53.37
203-Grave Creek Range	53.36	12.45	35.51-88.41
283-Lower Blackfoot	53.38	13.20	37.88-95.69
<b>MOUNTAIN FOOTHILLS</b>			
210-Lower Rock Creek	38.42	8.02	26.03-58.98
212-Garrison	27.47	5.15	18.12-38.43
213-Lost Creek	39.46	6.41	28.98-53.58
216-Upper Rock Creek	32.55	6.42	22.15-49.57
250-West Fork Bitterroot	63.01	13.39	39.57-94.97
261-Skalkaho	32.15	6.95	19.23-49
270-East Fork Bitterroot	38.39	8.47	21.91-58.32
315-North Beaverhead	28.16	5.23	20.75-37.59
315-Tendoys	19.67	4.06	13.48-29.36
340-Highlands	22.10	4.20	15.11-31.36
380-Elkhorns	14.89	3.11	7.32-21.82
Greenhorn	39.43	7.22	25.11-55.89
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>			
381-Sleeping Giant	14.67	3.35	9.19-21.93
455-Beartooth WMA	18.36	3.63	11.76-26.81
421-Deep Creek	50.47	11.63	35.93-79.51
422-Castle Reef	20.72	4.98	14-32.21
423-Gibson Lake North	50.27	11.32	36.34-77.95
424-Ford Creek	39.10	8.89	24.66-61.76
441-North Fork Birch Creek	48.33	10.83	34.5-76.78

Table 6 continued

<b>ECO-REGION-Herd</b>	<b>Mean Winter Precipitation (cm)</b>	<b>Standard Deviation Winter Precipitation (cm)</b>	<b>Range (cm)</b>
<b>SOUTHERN MOUNTAINS</b>			
301-Spanish Peaks	48.56	8.64	34.63-66.91
302-Hilgards	65.17	13.94	35.83-97.15
Cinnabar	49.00	11.32	24.9-76.64
Mt Everts	35.78	8.33	19.99-54.53
Pt of Rocks-Tom Miner	43.35	7.60	27.72-58.06
500a-Stillwater	45.12	7.93	32.03-60.49
500b-Monument Peak	61.87	12.41	41.28-91.38
501-West Rosebud	55.99	12.65	36.41-82.26
502-Hellroaring	50.89	11.13	35.01-73.7
<b>PRAIRIE BREAKS</b>			
503-Pryor Mountains	13.38	2.59	7.84-18.1
620-Little Rockies	18.04	4.63	9.81-27.3
622-Middle Missouri Breaks	10.92	3.50	4.52-18.57
482-Fergus	12.22	3.74	5.97-19.98
680-North Missouri Breaks	12.11	3.55	5.53-18.66

**Appendix C.** Summary Tables of Bighorn Sheep Demographic Data from Initial Database.

Table 1. Summary statistics of Montana bighorn sheep demographic data from the 49 populations whose data were used in the initial database. Recent population estimates calculated using most recent adequate population surveys and biologist sightability estimates, or where that information was not available, local knowledge was used. \*250-Watchtower and 315-North Beaverhead survey data collected by Idaho Department of Fish and Game. Table and footnote continued on following pages.

ECO-REGION-Herd	Number Classification Surveys	Range Years	Mean Animals Counted	Coefficient Variation Animals Counted (%)	Range Animals Counted	Current Population Estimate <sub>1</sub>	Mean Lamb: Ewe Ratio	Coefficient Variation Lamb:Ewe Ratios (%)	Range Lamb :Ewe Ratios
<b>NORTHWEST MONTANE</b>									
100-Kootenai Falls	30	1981-2012	68	47	23-130	75	25	42	0-48
101-Ural Tweed	22	1985-2012	25	94	0-68	25	25	97	0-82
102-Galton Range	17	1994-2012	32	60	8-72	100	33	37	12-54
121-North Clark Fork	31	1981-2011	241	33	123-432	200	43	23	29-75
122-Clark Fork Cutoff	31	1981-2011	89	23	55-141	150	39	30	20-66
123-Cabinet Mountains	29	1981-2011	85	34	20-129	100	42	33	17-72
124-Paradise	25	1988-2012	299	35	93-501	375	39	33	11-85
Wildhorse Island	13	1981-2011	96	54	47-203	225	35	39	17-68
203-Grave Creek	19	1984-2012	113	23	63-152	175	42	29	20-76
283-Lower Blackfoot	15	1991-2012	68	54	8-128	60	40	39	12-75
<b>MOUNTAIN FOOTHILLS</b>									
210-Lower Rock Creek	22	1983-2012	145	39	44-268	100	32	55	0-65
212-Garrison	10	2001-2012	72	30	50-118	60	37	59	6-67
213-Lost Creek	22	1980-2012	194	44	90-361	100	41	36	7-63
216-Upper Rock Creek	22	1990-2012	212	32	116-347	125	38	41	2-58
*250-Watchtower	3	2003-2007	31	14	26-32	50	45	78	4-69
250-Painted Rocks	14	1995-2011	51	55	13-120	100	42	44	8-75
261-Skalkaho	11	2001-2012	82	42	46-139	50	35	37	7-50
270-East Fork Bitterroot	32	1980-2012	112	43	47-246	100	29	50	0-69
*315-North Beaverhead	9	1992-2006	44	24	28-61	30	24	14	6-36
315-Tendoy	11	1991-2009	51	84	16-154	70	38	21	0-84
340-Highlands	26	1980-2010	115	82	6-320	75	30	56	0-66
380-Elkhorns	8	2001-2008	126	45	0-69	25	33	57	0-69
Greenhorns	1	2009	30	NA	NA	30	18	NA	NA

Footnote explanation at bottom of table page 110

Table 1 continued

ECO-REGION-Herd	Number Classification Surveys	Range Years	Mean Animals Counted	Coefficient Variation Animals Counted (%)	Range Animals Counted	Current Population Estimate <sub>1</sub>	Mean Lamb: Ewe Ratio	Coefficient Variation Lamb:Ewe Ratios (%)	Range Lamb :Ewe Ratios
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>									
381-Sleeping Giant	21	1988-2011	40	76	0-115	25	33	82	0-78
455-Beartooth WMA	24	1980-2008	78	78	20-226	100	42	51	8-85
421-Deep Creek	16	1981-2011	83	34	41-139	125	32	74	3-92
422-Castle Reef	28	1980-2011	211	29	78-340	175	41	43	4-73
423-Gibson Lake North	27	1980-2011	155	36	49-265	175	42	44	3-75
424-Ford Creek	27	1980-2011	178	38	85-298	150	37	40	0-59
441-North Fork Birch Creek	18	1985-2006	95	32	37-141	100	40	42	3-69
<b>SOUTHERN MOUNTAINS</b>									
301-Spanish Peaks	12	1983-2007	104	33	51-146	200	34	56	2-65
302-Hilgards Mill Creek	11	1988-2008	51	57	25-105	200	41	56	0-75
6	2002-2007	21	24	13-27	25	36	47	13-63	
Tom Miner Basin	17	1992-2011	26	36	14-51	75	29	48	0-60
Point of Rocks	17	1992-2011	25	42	12-47	40	23	81	0-75
Yankee Jim Canyon – Corwin Springs	17	1992-2011	15	74	1-37	40	25	104	0-100
Travertine - Deckard Flats	16	1992-2011	10	89	0-22	30	8	150	0-33
Cinnabar	18	1992-2011	44	32	22-71	75	31	57	0-81
Mt Everts	17	1992-2011	59	34	36-110	100	20	57	0-38
Stillwater	33	1980-2012	39	11	23-62	50	39	17	5-78
Monument Peak	29	1980-2012	21	49	3-42	50	36	67	0-100
Lower Boulder	5	1991-2001	29	130	1-84	Extinct	14	148	0-45
501-West Rosebud	23	1980-2012	55	40	22-100	100	29	53	8-64
502-Hellroaring	24	1980-2012	34	77	6-92	35	27	75	0-67

<sub>1</sub> Footnote explanation at bottom of table page 110

Table 1 continued

ECO-REGION-Herd	Number Classification Surveys	Range Years	Mean Animals Counted	Coefficient Variation Animals Counted (%)	Range Animals Counted	Current Population Estimate <sub>1</sub>	Mean Lamb: Ewe Ratio	Coefficient Variation Lamb:Ewe Ratios (%)	Range Lamb :Ewe Ratios
<b>PRAIRIE BREAKS</b>									
503-Pryor Mountains	14	1997-2012	53	37	25-85	100	28	55	3-57
620-Little Rockies	18	1981-2012	46	38	18-87	75	58	32	31-100
622-Middle Missouri Breaks	22	1986-2012	129	34	78-217	225	43	33	21-79
482-Fergus	18	1992-2012	316	29	108-498	400	57	26	39-100
680-North Missouri Breaks	21	1990-2012	278	48	48-532	500	43	25	16-63
Blue Hills	0	NA	NA	NA	NA	--	NA	NA	NA

<sub>1</sub>. For populations that seem to be relatively stable since 2008 and have had high quality surveys since 2008, the recent population estimate was calculated using the average number of animals counted in the surveys since 2008 divided by a herd-specific sighting probability that biologists indicated to UM Master's student Sarah Sells. Populations marked with a single asterisk were exceptions to the above criteria. For various reasons, the above methods were not thought to provide accurate population estimates, so these populations were estimated using the 2010 bighorn conservation strategy or the best available information. Population estimates marked with 2 asterisks are for populations that have experienced all-age disease die-offs and recent population estimates were taken from research proposal by Tom Carlsen and Neil Anderson. However for 261-Skalkaho and the Sun River populations more recent data were available that reflected different population sizes than estimated by Carlsen and Anderson, so estimates were made based on the more recent data and sighting probabilities..

Table 2. Seasonal distribution of population surveys of bighorn sheep populations since 1980. Summer is classified as June-September, winter is classified as November-February, and spring is classified as March-May. The number of surveys may differ slightly from summary table, as not all surveys were classification surveys. \*Populations 421, 422, 423, 424 are surveyed multiple times annually. \*\*250-Watchtower and 315-North Beaverhead survey data from Idaho Department of Fish and Game. Table continued on following page.

ECO-REGION-Herd	Survey Timing			
	Summer	Winter	Spring Pre-Birth	Unknown
<b>NW MONTAINE</b>				
100-Kootenai Falls			30	
101-Ural Tweed	1	2	8	10
102-Galton Range	2		11	5
121-North Clark Fork			32	
122-Clark Fork Cutoff			32	
123-Cabinet Mountains			29	
124-Paradise			25	
Wildhorse Island				13
203-Grave Creek			19	
283-Lower Blackfoot			15	
<b>MOUNTAIN FOOTHILLS</b>				
210-Lower Rock Creek	1		21	
212-Garrison	4	1	5	
213-Lost Creek			26	
216-Upper Rock Creek		9	14	
**250-Watchtower	2	5	4	
250-Painted Rocks				
261-Skalkaho		2	2	6
270-East Fork Bitterroot			32	
**315-North Beaverhead				9
315-Tendoys		10	1	
340-Highlands	1	4	21	1
380-Elkhorns			8	4
Greenhorns			2	
<b>PRAIRIE MOUNTAIN FOOTHILLS</b>				
381-Sleeping Giant	10	2	2	
455-Beartooth WMA				24
*421-Deep Creek		23	14	
*422-Castle Reef		30	30	
*423-Gibson Lake North		28	30	
*424-Ford Creek		27	30	
441-North Fork Birch Creek				18

Table 2 continued

ECO-REGION-Herd	Survey Timing			
	Summer	Winter	Spring Pre-Birth	Unknown
<b>SOUTHERN MTNS</b>				
301-Spanish Peaks	1	2	17	
302-Hilgards			15	
Mill Creek				6
Cinnabar			17	
Mt Everts to Mammoth			17	
Stillwater		33		
***Monument Peak		2	8	18
Lower Boulder (extinct)			4	1
501-West Rosebud				23
502-Hellroaring				24
<b>PRAIRIE BREAKS</b>				
503-Pryor Mountains		14		
620-Little Rockies	6	13	2	
622-Middle Missouri Breaks	2	17		2
482-Fergus	16			2
680-North Missouri Breaks	18	1	2	
Blue Hills				0

**APPENDIX D-** Model Selection Tables of Individual Herd Analyses

Table 1. Model selection table for the 100-Kootenai Falls bighorn sheep population, showing covariate regression coefficients estimated by the 26 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods section of the main report.

COVARIATES								MODEL SELECTION			
SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	SWE <sub>t-1</sub>	SpT	SpP	SuP	SWE	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
	4.40		-4.98				-3.80	0.21	0.00	0.08	0.08
			-3.01					0.07	1.04	0.05	0.12
								0.00	1.42	0.04	0.16
	4.62		-5.03	-2.22			-4.75	0.23	1.45	0.04	0.20
			-3.19				-2.55	0.10	1.63	0.03	0.23
	2.88		-4.13					0.10	1.84	0.03	0.26
		2.94					-3.25	0.08	2.32	0.02	0.29
							-2.32	0.02	2.35	0.02	0.31
		1.99						0.01	2.67	0.02	0.33
	3.97	1.35	-4.44				-4.08	0.20	2.68	0.02	0.35
		2.21	-2.59				-3.21	0.12	3.03	0.02	0.37
	4.36		-4.80			-0.79	-4.08	0.19	3.08	0.02	0.38
	4.32		-4.90		0.78		-4.07	0.18	3.19	0.02	0.40
-0.58	4.26		-5.11				-3.73	0.18	3.21	0.02	0.41
-1.34			-3.43					0.05	3.23	0.02	0.43
		1.26	-2.65					0.05	3.29	0.01	0.44
			-3.16	-1.90			-3.31	0.10	3.50	0.01	0.46
		3.18		-2.33			-4.27	0.10	3.66	0.01	0.47
			-2.98	-0.64				0.03	3.67	0.01	0.48
	0.94							-0.03	3.75	0.01	0.49
				-0.77				-0.03	3.79	0.01	0.50
			-3.03					0.03	3.80	0.01	0.52
			-3.02			-0.27		0.03	3.81	0.01	0.53
								-0.59	3.85	0.01	0.54
-0.31								-0.04	3.94	0.01	0.55
						0.10		-0.04	3.97	0.01	0.56

Table 2. Model selection table for the 121-Thompson Falls bighorn sheep population, showing covariate regression coefficients estimated by the 25 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods section of the main report.

COVARIATES							MODEL SELECTION				
SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	WP <sub>t-1</sub>	SpT	SpP	SuP	WP	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
							-2.90	0.13	0.00	0.07	0.07
								0.00	1.25	0.04	0.11
-1.61							-2.92	0.16	1.52	0.03	0.15
						2.08		0.07	1.80	0.03	0.18
		1.20					-2.78	0.15	2.04	0.03	0.21
					1.32		-3.15	0.14	2.21	0.02	0.23
			-0.93				-2.66	0.14	2.34	0.02	0.25
						0.99	-2.43	0.14	2.35	0.02	0.28
	-0.67						-2.83	0.13	2.57	0.02	0.30
			-1.60					0.04	2.67	0.02	0.32
-2.34		2.02					-2.74	0.22	2.68	0.02	0.34
				-0.06			-2.93	0.13	2.74	0.02	0.36
-1.57								0.04	2.77	0.02	0.37
-2.66			-2.64					0.12	2.81	0.02	0.39
		1.46						0.03	2.85	0.02	0.41
				1.42				0.03	2.92	0.02	0.43
-2.40			-1.93				-2.44	0.21	3.01	0.02	0.44
-2.41		2.29						0.10	3.42	0.01	0.46
	-1.01							0.01	3.44	0.01	0.47
-1.57						2.08		0.10	3.46	0.01	0.48
		1.38				2.03		0.10	3.66	0.01	0.50
					0.39			0.00	3.73	0.01	0.51
			-1.22			1.84		0.09	3.88	0.01	0.52
-1.96	-1.31						-2.80	0.18	3.90	0.01	0.53
-2.08								0.09	3.93	0.01	0.54

Table 3. Model selection table for the 122-Clark Fork Cutoff bighorn sheep population, showing covariate regression coefficients estimated by the 26 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods section of the main report.

COVARIATES								MODEL SELECTION			
SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	SWE <sub>t-1</sub>	SpT	SpP	SuP	SWE	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
		4.92	4.10	6.74	3.68			0.53	0.00	0.17	0.17
		5.61	4.13	6.00				0.48	0.97	0.10	0.27
		5.25	4.64	7.50	4.21	-1.99		0.53	2.10	0.06	0.33
		5.21	3.89	6.10	4.21		-1.72	0.53	2.38	0.05	0.38
	1.50	4.38	3.63	6.69	3.43			0.52	2.51	0.05	0.43
	1.93	4.86	3.53	6.00				0.48	2.70	0.04	0.47
0.78		4.80	4.37	6.67	3.78			0.51	3.29	0.03	0.50
		5.82	4.40	6.32		-0.98		0.46	3.86	0.02	0.52

Table 4. Model selection table for the 123-Cabinet Mountains bighorn sheep population, showing covariate regression coefficients estimated by the 16 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods section of the main report.

COVARIATES								MODEL SELECTION			
SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	SWE <sub>t-1</sub>	SpT	SpP	SuP	SWE	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
								0.00	0	0.12	0.12
			4.12					0.07	0.5	0.1	0.22
						2.96		0.01	1.65	0.05	0.27
				2.98				-0.01	2.08	0.04	0.32
					-3.14			-0.03	2.3	0.04	0.36
-1.42								-0.05	2.75	0.03	0.39
							-0.82	-0.06	2.79	0.03	0.42
		0.49						-0.06	2.88	0.03	0.45
	0.32							-0.06	2.91	0.03	0.48
			3.94	2.59				0.05	3.15	0.03	0.5
		2.22	4.94					0.05	3.17	0.03	0.53
			3.59			2.09		0.05	3.2	0.03	0.55
			4.08		-3.00			0.04	3.23	0.02	0.58
			4.12					0.02	3.68	0.02	0.6
-1.39			4.56				0.88	0.02	3.74	0.02	0.62
	0.60		4.15					0.01	3.84	0.02	0.63

Table 5. Model selection table for the 124-Paradise bighorn sheep population, showing covariate regression coefficients estimated by the 19 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods section of the main report.

COVARIATES								MODEL SELECTION			
SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	WP <sub>t-1</sub>	SpT	SpP	SuP	WP	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
								0.00	0.00	0.10	0.10
		-2.26						0.03	0.93	0.06	0.16
					2.39			0.02	1.16	0.06	0.22
							1.54	-0.01	1.78	0.04	0.26
-1.09								-0.03	2.21	0.03	0.29
		-2.26			2.40			0.05	2.25	0.03	0.32
	-1.21							-0.03	2.29	0.03	0.36
				-0.22				-0.05	2.61	0.03	0.38
						-0.13		-0.05	2.62	0.03	0.41
			-0.10					-0.05	2.62	0.03	0.44
		-2.17					1.43	0.01	3.05	0.02	0.46
					2.10		1.17	-0.01	3.58	0.02	0.47
	-0.96	-2.18						-0.01	3.61	0.02	0.49
-1.10					2.40			-0.01	3.61	0.02	0.51
		-2.42	-0.65					-0.01	3.68	0.02	0.52
		-2.37				-0.66		-0.02	3.73	0.02	0.54
-0.45		-2.11						-0.02	3.76	0.02	0.55
		-2.30		-0.41				-0.02	3.77	0.02	0.57
	-1.04				2.32			-0.02	3.81	0.01	0.58

Table 6. Model selection table for the 203-Grave Creek Range bighorn sheep population, showing covariate regression coefficients estimated by the 8 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods section of the main report.

COVARIATES								MODEL SELECTION			
SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	WP <sub>t-1</sub>	SpT	SpP	SuP	WP	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
-6.03			-8.15					0.50	0.00	0.24	0.24
-4.64	3.52		-8.43					0.52	1.51	0.11	0.36
	5.90		-7.17					0.43	2.51	0.07	0.43
-5.77			-8.47		-2.85			0.50	2.55	0.07	0.50
-5.91		1.21	-8.15					0.47	3.53	0.04	0.54
-5.94			-7.98				-0.60	0.47	3.68	0.04	0.58
-6.06			-8.23	-0.37				0.46	3.73	0.04	0.61
-6.15			-8.22			-0.23		0.46	3.74	0.04	0.65

Table 7. Model selection table for the 210-Lower Rock Creek bighorn sheep population, showing covariate regression coefficients estimated by the 19 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods section of the main report.

COVARIATES									MODEL SELECTION			
Disease in last 3 years	SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	SWE <sub>t-1</sub>	SpT	SpP	SuP	SWE	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative
												Weight
			-10.38						0.16	0.00	0.11	0.11
									0.00	0.58	0.08	0.19
-17.27									0.11	0.96	0.07	0.26
-14.62			-9.22						0.23	1.32	0.06	0.32
			-11.27	-3.85					0.17	2.52	0.03	0.35
						-5.50			0.00	2.64	0.03	0.38
	3.80								-0.01	2.78	0.03	0.40
			-11.90					4.06	0.15	2.90	0.03	0.43
			-13.54						0.13	3.16	0.02	0.45
-17.93									0.13	3.17	0.02	0.47
	2.72		-9.74						0.13	3.20	0.02	0.50
				-2.65					-0.04	3.29	0.02	0.52
							2.75		-0.05	3.43	0.02	0.54
			-9.46				-2.80		0.11	3.49	0.02	0.56
			-10.62						0.10	3.69	0.02	0.57
									0.10	3.69	0.02	0.57
								1.11	-0.07	3.71	0.02	0.59
									-0.08	3.76	0.02	0.61
									-0.08	3.77	0.02	0.63
		0.06							-0.08	3.77	0.02	0.63
		-0.58	-10.42						0.09	3.80	0.02	0.64

Table 8. Model selection table for the 213-Lost Creek bighorn sheep population, showing covariate regression coefficients estimated by the 16 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods section of the main report.

COVARIATES									MODEL SELECTION			
D3	SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	WP <sub>t-1</sub>	SpT	SpP	SuP	WP	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
-32.26			-4.95					-3.93	0.71	0.00	0.12	0.12
-31.79								-4.19	0.66	0.46	0.09	0.21
-29.93			-5.37						0.65	1.41	0.06	0.27
-29.25									0.60	2.01	0.04	0.31
-31.38			-5.14				-2.50	-4.17	0.72	2.01	0.04	0.36
-30.97							-2.29	-4.42	0.67	2.62	0.03	0.39
-31.78		-1.75						-3.73	0.66	3.09	0.03	0.41
-33.98					-1.85			-4.46	0.66	3.20	0.02	0.44
-29.65		-2.64							0.61	3.26	0.02	0.46
-34.19			-4.83		-1.64			-4.18	0.70	3.34	0.02	0.48
-31.92	1.41		-5.09					-4.01	0.70	3.40	0.02	0.50
-34.03			-5.67			1.79		-4.14	0.70	3.60	0.02	0.52
-31.50	1.17							-4.26	0.65	3.65	0.02	0.54
-32.52			-5.44	-1.07				-3.87	0.70	3.71	0.02	0.56
-32.22		-0.91	-4.61					-3.71	0.69	3.87	0.02	0.58
-29.09			-5.54				-2.06		0.65	3.91	0.02	0.59

Table 9. Model selection table for the 216-Upper Rock Creek bighorn sheep population, showing covariate regression coefficients estimated by the 29 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods section of the main report.

COVARIATES								MODEL SELECTION			
D3	SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	WP <sub>t-1</sub>	SpT	SpP	SuP	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
-32.63				4.35	3.52			0.74	0.00	0.07	0.07
-35.31				4.28				0.70	0.33	0.06	0.13
-33.32						-5.54		0.70	0.34	0.06	0.19
-33.75				3.13		-4.05		0.73	0.41	0.06	0.25
-33.98	-2.60			3.83	3.73			0.75	1.26	0.04	0.28
-35.99		3.69		3.58				0.72	1.30	0.04	0.32
-34.33		3.70				-4.63		0.72	1.31	0.04	0.36
-32.26			2.68	4.37	4.18			0.75	1.73	0.03	0.38
-33.45		3.19		3.74	3.21			0.75	1.76	0.03	0.41
-33.21			2.76			-6.16		0.71	1.82	0.03	0.44
-36.66	-2.33			3.81				0.71	2.00	0.03	0.47
-36.34				4.24			-2.39	0.71	2.26	0.02	0.49
-36.41		5.06						0.68	2.27	0.02	0.51
-32.27				3.55	2.60	-2.78		0.74	2.36	0.02	0.53
-33.63			2.48	2.95		-4.69		0.74	2.47	0.02	0.55
-34.51		2.99		2.71		-3.51		0.74	2.50	0.02	0.57
-33.66				4.32	3.31		-2.01	0.73	2.65	0.02	0.59
-34.69	-1.87					-4.76		0.70	2.73	0.02	0.61
-32.22					1.84	-4.78		0.70	2.91	0.02	0.63
-35.38			1.57	4.28				0.70	3.09	0.01	0.64
-34.13						-5.23	-1.57	0.70	3.14	0.01	0.66
-35.53								0.63	3.14	0.01	0.67
-34.08		4.64			2.97			0.69	3.34	0.01	0.68
-34.71	-3.48				3.70			0.69	3.35	0.01	0.70
-34.67				3.21		-3.66	-1.78	0.73	3.37	0.01	0.71
-34.87	-1.54			2.98		-3.48		0.72	3.47	0.01	0.72
-37.36	-3.21							0.66	3.48	0.01	0.73
-32.95					3.39			0.66	3.57	0.01	0.75
-31.79			3.05	3.42	3.17	-3.29		0.76	3.84	0.01	0.76

Table 10. Model selection table for the 270-East Fork Bitterroot bighorn sheep population, showing covariate regression coefficients estimated by the 35 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods section of the main report.

COVARIATES									MODEL SELECTION			
Dc	SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	SWE <sub>t-1</sub>	SpT	SpP	SuP	SWE	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
-21.62									0.09	0.00	0.05	0.05
-20.43							2.77		0.10	1.23	0.03	0.08
-20.60				2.53					0.10	1.29	0.03	0.10
									0.00	1.31	0.03	0.13
			4.74	4.13					0.09	1.37	0.03	0.15
-19.50			2.60						0.09	1.52	0.02	0.18
-16.99			3.88	3.63					0.14	1.70	0.02	0.20
			3.39						0.03	1.98	0.02	0.22
							3.18		0.02	2.09	0.02	0.24
				2.87					0.02	2.20	0.02	0.25
-22.01					-1.49				0.07	2.23	0.02	0.27
-21.91	-1.47								0.07	2.27	0.02	0.29
-21.97		1.15							0.06	2.41	0.02	0.30
-21.90						0.25			0.05	2.67	0.01	0.31
-19.41				2.53			2.77		0.11	2.68	0.01	0.33
-21.61								0.01	0.05	2.68	0.01	0.34
			4.33	4.01			2.57		0.10	2.99	0.01	0.35
-20.78		2.50					3.74		0.10	3.00	0.01	0.36
				2.85			3.15		0.04	3.11	0.01	0.37
-18.69			2.28				2.50		0.09	3.22	0.01	0.38
			2.99				2.78		0.03	3.31	0.01	0.39
					-1.24				-0.03	3.52	0.01	0.40
	-1.27								-0.03	3.52	0.01	0.41
-20.83					-1.57		2.82		0.08	3.61	0.01	0.42
						-0.97			-0.03	3.64	0.01	0.43
		0.86							-0.03	3.66	0.01	0.43
								0.82	-0.03	3.66	0.01	0.44
-16.29			3.55	3.54			2.35		0.14	3.69	0.01	0.45
-20.73	-1.30						2.68		0.07	3.81	0.01	0.46
		2.35					4.09		0.02	3.88	0.01	0.46
			4.03			-2.17			0.01	3.94	0.01	0.47
	1.47		5.05	4.89					0.07	3.97	0.01	0.48

-21.78		2.82	1.14	0.07	3.98	0.01	0.49
-19.91	2.56		-1.44	0.07	3.99	0.01	0.49
-20.94		2.33	-0.99	0.07	3.99	0.01	0.50

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Table 11. Model selection table for the 340-Highlands bighorn sheep population, showing covariate regression coefficients estimated by the 9 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods section of the main report.

COVARIATES								MODEL SELECTION				
D3	SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	SWE <sub>t-1</sub>	SpT	SpP	SuP	SWE	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
-35.95								7.27	0.47	0.00	0.13	0.13
-30.06							-5.95		0.47	0.02	0.13	0.26
-21.70									0.33	0.50	0.10	0.36
-41.13							-5.11	6.25	0.58	0.56	0.10	0.46
-34.00					5.09			7.62	0.53	2.09	0.05	0.50
-25.76		5.28							0.38	2.38	0.04	0.54
-19.33					4.58				0.35	2.89	0.03	0.57
-19.27				-2.28					0.31	3.86	0.02	0.59
-27.61					3.32		-5.42		0.47	3.93	0.02	0.61
									0.00	3.99	0.02	0.62

Table 12. Model selection table for the 421-Deep Creek bighorn sheep population, showing covariate regression coefficients estimated by the 16 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods section of the main report.

COVARIATES								MODEL SELECTION			
D3	SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	WP <sub>t-1</sub>	SpT	SpP	SuP	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
								0.00	0.00	0.11	0.11
	6.57							0.09	0.72	0.07	0.18
-14.75								0.06	1.21	0.06	0.24
					4.51			0.03	1.57	0.05	0.29
-19.05					6.05			0.18	1.75	0.04	0.33
			-5.02					0.01	1.89	0.04	0.37
			-8.03		6.84			0.17	1.94	0.04	0.41
	9.83	5.78						0.16	1.99	0.04	0.45
	7.19		-5.82					0.14	2.45	0.03	0.48
				-3.15				-0.03	2.55	0.03	0.51
-13.18	6.01							0.12	2.71	0.03	0.54
		1.96						-0.06	2.89	0.03	0.57
						1.44		-0.07	3.04	0.02	0.59
							0.35	-0.08	3.17	0.02	0.61
					7.63	5.81		0.08	3.45	0.02	0.63
-16.85				-4.28				0.06	3.71	0.02	0.65

Table 13. Model selection table for the 422-Castle Reef bighorn sheep population (winter recruitment data), showing covariate regression coefficients estimated by the 16 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods section of the main report.

COVARIATES						MODEL SELECTION					
D2	SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	SWE <sub>t-1</sub>	SpT	SpP	SuP	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
-35.31		-4.38						0.40	0.00	0.11	0.11
-33.50								0.36	0.13	0.11	0.22
-34.78			3.00					0.36	1.72	0.05	0.27
-29.92	2.90							0.36	1.85	0.04	0.31
-36.48		-4.29	2.84					0.40	1.86	0.04	0.36
-33.22							2.87	0.36	1.94	0.04	0.40
-30.28					2.53			0.35	2.12	0.04	0.44
-34.14				-1.09				0.34	2.70	0.03	0.47
-33.65		-4.05			1.20			0.38	2.86	0.03	0.49
-33.64	1.21	-3.94						0.38	2.87	0.03	0.52
-33.50						0.00		0.33	2.90	0.03	0.55
-35.03		-3.99					1.12	0.38	2.90	0.03	0.57
-35.65		-4.30		-0.65				0.38	2.96	0.03	0.60
-35.22		-4.41				-0.35		0.37	3.02	0.02	0.63
-34.65			3.45				3.39	0.37	3.37	0.02	0.65
-31.41	2.66		2.78					0.35	3.84	0.02	0.66

Table 14. Model selection table for the 422-Castle Reef bighorn sheep population (spring recruitment data), showing covariate regression coefficients estimated by the 16 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods sections of the main report.

COVARIATES								MODEL SELECTION				
D2	SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	SWE <sub>t-1</sub>	SpT	SpP	SuP	SWE	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
-29.72		-4.80							0.32	0.00	0.08	0.08
-26.29									0.27	0.03	0.08	0.16
-22.04					4.35				0.28	1.35	0.04	0.20
-26.15							4.22		0.28	1.38	0.04	0.24
-27.50			3.96						0.28	1.38	0.04	0.28
-30.49		-4.45	3.37						0.32	1.96	0.03	0.31
-26.15		-4.24			3.24				0.31	2.26	0.03	0.33
-29.61		-5.02				-2.21			0.30	2.58	0.02	0.36
-26.10						-1.65			0.24	2.60	0.02	0.38
-27.46			4.36				4.64		0.30	2.60	0.02	0.40
-24.66	1.79								0.24	2.71	0.02	0.42
-29.10		-4.04					2.22		0.29	2.78	0.02	0.44
-26.64				-0.45					0.23	2.86	0.02	0.46
-26.20								-0.38	0.23	2.87	0.02	0.48
-23.35			3.81		4.19				0.29	3.03	0.02	0.50
-30.15		-5.09						0.96	0.29	3.03	0.02	0.51
-31.08	-1.23	-5.14							0.29	3.08	0.02	0.53
-29.93		-4.79		-0.29					0.28	3.15	0.02	0.55
-22.93					3.33		3.21		0.27	3.68	0.01	0.56
-27.33			5.25					-2.38	0.26	3.90	0.01	0.57

Table 15. Model selection table for the 423-Gibson Lake North bighorn sheep population (winter recruitment data), showing covariate regression coefficients estimated by the 25 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods section of the main report.

COVARIATES								MODEL SELECTION			
Dc	SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	WP <sub>t-1</sub>	SpT	SpP	SuP	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
-34.59								0.27	0.00	0.08	0.08
-39.30							4.48	0.30	0.49	0.06	0.15
-37.10				-4.94				0.30	0.53	0.06	0.21
-42.10				-5.15			4.66	0.34	0.86	0.05	0.26
-30.18					4.18			0.29	0.91	0.05	0.32
-49.55	-5.59			-7.44			6.63	0.39	1.17	0.05	0.36
-38.20		-2.99						0.27	1.82	0.03	0.40
-35.06					3.23		3.68	0.30	2.44	0.02	0.42
-34.09						-2.02		0.25	2.49	0.02	0.44
-35.14	-0.73							0.24	2.76	0.02	0.47
-35.19			0.59					0.24	2.78	0.02	0.49
-39.73	-2.75			-6.03				0.29	2.86	0.02	0.51
-42.23	-2.64						5.37	0.29	2.87	0.02	0.53
-33.62				-3.64	2.67			0.29	2.97	0.02	0.54
-36.58				-5.11		-2.41		0.28	3.12	0.02	0.56
-40.64		-1.60					3.92	0.28	3.32	0.02	0.58
-38.75		-1.63		-4.32				0.28	3.35	0.02	0.59
-31.14	-2.52				5.07			0.28	3.37	0.02	0.61
-38.80						-1.38	4.33	0.27	3.42	0.01	0.62
-39.53			0.25				4.46	0.27	3.58	0.01	0.64
-37.40			0.30	-4.93				0.27	3.62	0.01	0.65
-44.15	-4.05	-5.39						0.27	3.75	0.01	0.66
-32.35		-1.25			3.54			0.26	3.86	0.01	0.68
-29.11			-0.84		4.40			0.26	3.94	0.01	0.69
-41.53				-5.26		-1.77	4.48	0.32	3.99	0.01	0.70

Table 16. Model selection table for the 423-Gibson Lake North bighorn sheep population (spring recruitment data), showing covariate regression coefficients estimated by the 10 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods sections of the main report.

COVARIATES								MODEL SELECTION				
D2	SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	SWE <sub>t-1</sub>	SpT	SpP	SuP	SWE	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
-39.25	-10.22		8.92	-8.26		7.18		-7.33	0.62	0.00	0.15	0.15
-37.79	-8.51		6.28	-8.12					0.51	0.69	0.10	0.25
-41.34	-10.52		7.42	-8.05		3.77			0.53	2.06	0.05	0.30
-34.22	-10.32		8.41	-8.15	4.00	8.38		-7.11	0.63	2.78	0.04	0.34
-38.08	-8.52		5.84	-8.19			2.97		0.52	2.81	0.04	0.37
-35.99	-8.46			-8.77					0.40	3.14	0.03	0.40
-27.56			6.25	-5.21					0.40	3.34	0.03	0.43
-35.59	-7.63		6.48	-8.23				-3.04	0.51	3.35	0.03	0.46
-41.22	-10.32	-2.68	6.24	-8.30					0.51	3.36	0.03	0.48
-39.49	-10.20		8.50	-8.29		6.86	2.01	-6.85	0.61	3.87	0.02	0.51

Table 17. Model selection table for the 424-Ford Creek bighorn sheep population (winter recruitment data), showing covariate regression coefficients estimated by the 28 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods section of the main report.

COVARIATES								MODEL SELECTION			
D2	SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	SWE <sub>t-1</sub>	SpT	SpP	SuP	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
-18.66						-5.81		0.26	0.00	0.07	0.07
-21.54						-5.16	4.14	0.31	0.18	0.07	0.14
-21.75							4.73	0.25	0.33	0.06	0.21
-18.43								0.19	0.91	0.05	0.25
-14.39					3.99			0.23	1.25	0.04	0.29
-21.32		3.69					6.10	0.26	1.89	0.03	0.32
					5.81			0.14	2.35	0.02	0.35
-16.45					2.13	-4.56		0.25	2.50	0.02	0.37
-18.50					2.46		3.65	0.25	2.58	0.02	0.39
-21.26		2.57				-4.55	5.16	0.30	2.81	0.02	0.41
-21.76				-1.76		-5.26	4.60	0.30	2.89	0.02	0.42
-21.95				-1.58			5.15	0.24	2.92	0.02	0.44
-18.62				-0.84		-5.90		0.23	2.94	0.02	0.46
-21.52		5.97		-3.64			7.94	0.30	3.01	0.02	0.47
-18.26	0.40					-5.81		0.23	3.07	0.02	0.49
-18.67			0.06			-5.80		0.23	3.09	0.02	0.51
-18.66		0.02				-5.81		0.23	3.10	0.02	0.52
-21.91			1.22				4.76	0.23	3.15	0.02	0.54
-23.14	-1.15						5.05	0.23	3.25	0.01	0.55
-22.74	-0.99					-5.12	4.42	0.28	3.45	0.01	0.57
-18.55			1.10					0.16	3.52	0.01	0.58
-21.58			0.29			-5.07	4.15	0.28	3.58	0.01	0.59
-21.21					0.25	-5.02	4.04	0.28	3.59	0.01	0.60
-18.09		0.90						0.15	3.63	0.01	0.62
-18.40				-0.51				0.15	3.67	0.01	0.63
-17.98	0.45							0.15	3.70	0.01	0.64
-13.01		2.25			4.52			0.21	3.73	0.01	0.65
		3.54			6.36			0.15	3.76	0.01	0.66

Table 18. Model selection table for the 424-Ford Creek bighorn sheep population (spring recruitment data), showing covariate regression coefficients estimated by the 13 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods sections of the main report.

COVARIATES									MODEL SELECTION			
D2	SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	WP <sub>t-1</sub>	SpT	SpP	SuP	WP	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
	11.16							-9.31	0.26	0.00	0.13	0.13
								-6.57	0.08	2.46	0.04	0.17
									0.00	2.61	0.04	0.21
	7.37								0.05	3.19	0.03	0.24
	10.80		1.88					-9.29	0.22	3.27	0.03	0.26
	11.47	1.10						-9.36	0.22	3.38	0.02	0.29
	11.05					-1.33		-8.51	0.22	3.40	0.02	0.31
-2.69	10.50							-9.17	0.22	3.41	0.02	0.33
	11.16						1.74	-9.55	0.22	3.41	0.02	0.36
	11.03			-0.67				-9.26	0.21	3.47	0.02	0.38
	11.02				0.55			-9.12	0.21	3.48	0.02	0.41
								-5.49	0.04	3.51	0.02	0.43
	8.39							-6.36	0.12	3.52	0.02	0.45

Table 19. Model selection table for the Cinnabar bighorn sheep population, showing covariate regression coefficients estimated by the 28 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods sections of the main report.

COVARIATES								MODEL SELECTION			
SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	WP <sub>t-1</sub>	SpT	SpP	SuP	WP	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
	-4.88		-5.85					0.26	0.00	0.08	0.08
								0.00	0.42	0.07	0.15
			-5.05					0.11	0.62	0.06	0.21
4.02								0.10	0.74	0.06	0.26
	-4.14							0.08	1.02	0.05	0.31
3.82			-4.80					0.20	1.27	0.04	0.36
		-4.62						0.02	2.02	0.03	0.39
		-4.72	-5.10					0.14	2.40	0.02	0.41
	-5.22		-6.70	-2.87				0.28	2.66	0.02	0.43
	-5.11		-6.99			4.52		0.28	2.69	0.02	0.45
3.95		-4.45						0.12	2.74	0.02	0.48
					1.37			-0.05	3.24	0.02	0.49
			-5.99			3.85		0.09	3.34	0.02	0.51
				-1.03				-0.06	3.35	0.02	0.52
						1.17		-0.07	3.42	0.01	0.54
							0.55	-0.07	3.46	0.01	0.55
			-5.67	-2.23				0.08	3.48	0.01	0.57
	-4.27	-2.98	-5.78					0.24	3.50	0.01	0.58
3.74		-4.56	-4.86					0.24	3.53	0.01	0.59
4.31			-6.02			5.13		0.23	3.66	0.01	0.61
2.73	-2.45							0.07	3.72	0.01	0.62
		-7.55			4.04			0.07	3.75	0.01	0.63
	-5.10		-5.70		1.61			0.23	3.82	0.01	0.64
1.82	-3.72		-5.54					0.23	3.83	0.01	0.66
	-3.50	-3.18						0.06	3.92	0.01	0.67
4.13					1.66			0.06	3.93	0.01	0.68
4.24				-1.66				0.06	3.94	0.01	0.69
4.28						2.43		0.05	3.98	0.01	0.70

Table 20. Model selection table for the Mt Everts bighorn sheep population, showing covariate regression coefficients estimated by the 11 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods sections of the main report.

COVARIATES								MODEL SELECTION			
SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	WP <sub>t-1</sub>	SpT	SpP	SuP	WP	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
							5.62	0.26	0.00	0.15	0.15
	-3.33						4.93	0.36	0.50	0.11	0.26
	-4.11							0.16	1.93	0.06	0.32
3.23							4.68	0.28	2.12	0.05	0.37
		-3.04					6.14	0.28	2.28	0.05	0.41
4.92								0.13	2.40	0.04	0.46
								0.00	2.40	0.04	0.50
			2.58				6.11	0.24	2.99	0.03	0.53
						-1.82	5.23	0.21	3.57	0.02	0.56
				0.76			5.65	0.20	3.73	0.02	0.58
						-0.03	5.61	0.20	3.82	0.02	0.60

Table 21. Model selection table for the 500a-Stillwater bighorn sheep population, showing covariate regression coefficients estimated by the 7 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods sections of the main report.

COVARIATES							MODEL SELECTION			
SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	WP <sub>t-1</sub>	SpT	SpP	SuP	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
							0.00	0.00	0.18	0.18
				-3.16			-0.01	1.78	0.07	0.25
		-2.81					-0.02	2.12	0.06	0.32
	1.09						-0.04	2.58	0.05	0.37
			-0.76				-0.05	2.62	0.05	0.42
					-0.62		-0.05	2.63	0.05	0.46
0.00						0.39	-0.05	2.65	0.05	0.51

Table 22. Model selection table for the 501-West Rosebud bighorn sheep population, showing covariate regression coefficients estimated by the 14 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods sections of the main report.

COVARIATES							MODEL SELECTION			
SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	WP <sub>t-1</sub>	SpT	SpP	SuP	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
-6.67							0.18	0.00	0.16	0.16
	5.79						0.15	0.59	0.12	0.27
							0.00	1.92	0.06	0.33
-4.61	3.47						0.18	2.00	0.06	0.39
-7.65						-2.75	0.17	2.20	0.05	0.44
-6.66					1.64		0.14	2.85	0.04	0.48
-6.60			1.33				0.14	3.01	0.03	0.51
-6.50				-0.57			0.13	3.21	0.03	0.55
-6.69		-0.21					0.13	3.25	0.03	0.58
	5.96	1.68					0.11	3.60	0.03	0.60
	5.68				0.50		0.10	3.81	0.02	0.63
	5.78					-0.45	0.10	3.82	0.02	0.65
	5.99			0.45			0.10	3.82	0.02	0.67
	5.71		0.39				0.10	3.83	0.02	0.69

Table 23. Model selection table for the 482-Fergus bighorn sheep population, showing covariate regression coefficients estimated by the 7 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods sections of the main report.

COVARIATES						MODEL SELECTION			
SpT <sub>t-1</sub>	SpP <sub>t-1</sub>	SuP <sub>t-1</sub>	WP <sub>t-1</sub>	SpT	SpP	Adj. R <sup>2</sup>	ΔAIC <sub>c</sub>	Weight	Cumulative Weight
						0.00	0.00	0.28	0.28
		4.40				0.04	1.66	0.12	0.41
	-2.51					0.01	2.06	0.10	0.51
					-1.92	-0.05	2.89	0.07	0.58
-1.19						-0.07	3.15	0.06	0.64
				-1.20		-0.07	3.17	0.06	0.69
			-0.63			-0.08	3.23	0.06	0.75

Table 24. Model selection table for the 680-North Missouri Breaks bighorn sheep population, showing covariate regression coefficients estimated by the 8 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods sections of the main report.

<b>SpT<sub>t-1</sub></b>	<b>SpP<sub>t-1</sub></b>	<b>SuP<sub>t-1</sub></b>	<b>WP<sub>t-1</sub></b>	<b>SpT</b>	<b>SpP</b>	<b>Adj. R<sup>2</sup></b>	<b>ΔAIC<sub>c</sub></b>	<b>Weight</b>	<b>Cumulative Weight</b>
						0.00	0.00	0.25	0.25
	-2.91					0.02	1.44	0.12	0.38
				-1.32		-0.05	2.72	0.06	0.44
-1.21						-0.05	2.77	0.06	0.50
					-0.62	-0.06	2.85	0.06	0.56
			-0.33			-0.06	2.89	0.06	0.62
		0.06				-0.06	2.91	0.06	0.68
-3.08	-3.80					0.01	3.91	0.04	0.72

Table 25. Model selection table for the 622-Middle Missouri Breaks bighorn sheep population, showing covariate regression coefficients estimated by the 8 models within 4 AICc points of the top model, as well as model selection information for these models. Covariates are defined in the methods sections of the main report.

<b>SpT<sub>t-1</sub></b>	<b>SpP<sub>t-1</sub></b>	<b>SuP<sub>t-1</sub></b>	<b>WP<sub>t-1</sub></b>	<b>SpT</b>	<b>SpP</b>	<b>Adj. R<sup>2</sup></b>	<b>ΔAIC<sub>c</sub></b>	<b>Weight</b>	<b>Cumulative Weight</b>
						0.00	0.00	0.20	0.20
-4.90						0.02	1.31	0.10	0.30
				-3.26		0.01	1.49	0.09	0.40
		1.47				-0.04	2.57	0.06	0.45
	-1.20					-0.05	2.67	0.05	0.51
					-0.22	-0.05	2.74	0.05	0.56
			0.16			-0.05	2.74	0.05	0.61
-6.71	-4.42					0.00	3.55	0.03	0.64

**APPENDIX E.** Summary Results Tables

Table 1. Estimated intercept values with 95% confidence limits from top models for each of the bighorn sheep populations whose recruitment data were analyzed. Intercept estimates represent predicted average lamb:ewe ratios under normal conditions, not associated with all-age disease die-off events. Datasets marked with a single asterisk (\*) used lamb:ewe ratios collected in winter months, datasets marked with two asterisks (\*\*) used lamb:ewe ratios collected in summer months, and unmarked datasets used only lamb:ewe ratios collected in spring months, prior to the birth pulse.

ECO-REGION- HERD	Intercept Estimate	
	Estimate	95% Conf. Limits
<b>Northwest Montane</b>		
100-Kootenai Falls	25.5	22.1, 28.8
121-North Clark Fork	41.4	38.4, 44.4
122-Clark Fork Cutoff	39.2	36.0, 42.3
123-Cabinet Mountains	41.1	35.3, 46.9
124-Paradise	36.7	33.1, 40.2
203-Grave Creek	42.4	38.2, 46.5
<b>Mountain Foothills</b>		
210-Lower Rock Creek	30.6	22.5, 38.8
213-Lost Creek	48.8	44.2, 53.3
216-Upper Rock Creek*	42.1	38.4, 46
270-East Fork Bitterroot	29.1	24.3, 34
340-Highlands	38	30.3, 45.7
<b>Prairie Mountain Foothills</b>		
421-Deep Creek*	27.5	17.8, 37.1
422-Castle Reef*	44.1	38.4, 49.7
422-Castle Reef	43.2	36.4, 50.1
423-Gibson Lake North*	47	39.8, 54.3
423-Gibson Lake North	36.9	31.7, 42.1
424-Ford Creek*	38.4	32.8, 43.9
424-Ford Creek	35.4	28, 42.8
<b>Southern Mountains</b>		
Cinnabar	27.1	22.3, 31.9
Mt Everts	21.6	16.9, 26.4
500a-Stillwater*	33.3	25.8, 40.8
501-West Rosebud*	27.7	21.3, 34.1
<b>Prairie Breaks</b>		
622-Middle Missouri Breaks**	43.3	36.6, 49.9
482-Fergus**	54.6	49.2, 60.1
680-North Missouri Breaks**	44.7	39.4, 50

Table 2. Estimated regression coefficients and 95% confidence limits of disease covariates that were included in top models for each of the bighorn sheep populations whose recruitment data were analyzed and have experienced all-age disease die-off events during the data time series. Populations in the Northwest Montaine, Southern Mountains, and Prairie-Breaks ecoregions are not shown as none have not experienced all-age disease die-off events during the period we have data for. “Dc” is a continuous variable that predicts lamb:ewe ratios to gradually recover following an all-age disease die-off event. “D2” and “D3” are binomial variables that predict lamb:ewe ratios to be reduced by a constant value for 2 and 3 years, respectively, following a die-off event, then recover. Beta estimates for “D2” and “D3” are the predicted reduction in lambs:100 ewes for the 2 and 3 years following a die-off event., while the beta estimate for “Dc” is the predicted reduction in lambs:100 ewes the year following a die-off event. Other disease covariates that were tested but not supported, and not shown, were D1, D4, and D5. Negative values are in red and positive values are in blue. Datasets marked with a single asterisk (\*) used lamb:ewe ratios collected in winter months, datasets marked with two asterisks (\*\*) used lamb:ewe ratios collected in summer months, and unmarked datasets used lamb:ewe ratios collected in spring months, prior to the birth pulse.

ECO-REGION- HERD	Dc		D2		D3	
	Beta Est.	95% Conf. Limits	Beta Est.	95% Conf. Limits	Beta Est.	95% Conf. Limits
<b>Northwest Montane</b>						
<b>Mountain Foothills</b>						
210-Lower Rock Creek						
213-Lost Creek					-32.3	-42.3, -22.2
216-Upper Rock Creek*					-32.6	-43.5, -21.8
270-East Fork Bitterroot	-21.6	-44.4, 1.2				
340-Highlands					-36.0	-57.7, -14.2
<b>Prairie Mountain Foothills</b>						
421-Deep Creek*						
422-Castle Reef*			-35.3	-52.5, -18.2		
422-Castle Reef			-29.7	-47.2, -12.2		
423-Gibson Lake North*	-34.6	-57.0, 12.2				
423-Gibson Lake North			-39.3	-54.8, -23.7		
424-Ford Creek*			-18.7	-32.7, -4.6		
424-Ford Creek						
<b>Southern Mountains</b>						
<b>Prairie Breaks</b>						

Table 3. Estimated regression coefficients and 95% confidence limits of preconception warm season weather covariates for each of the bighorn sheep populations whose recruitment data were analyzed. Spring Temperature<sub>t-1</sub> (SpT<sub>t-1</sub>) is an index of average May and June temperature experienced prior to conception of females, Spring Precipitation<sub>t-1</sub> (SpP<sub>t-1</sub>) is an index of May and June precipitation experienced prior to conception of females, and Summer Precipitation<sub>t-1</sub> (SuP<sub>t-1</sub>) is an index of July-September precipitation experienced prior to conception of females. Beta estimates represent the predicted change in lambs:100 ewes associated with an increase in the weather covariate equal to 1 standard deviation. The standard deviation for each weather covariate is herd specific, see results narrative for the 100-Kootenai Falls population for further description. Negative values are in red and positive values are in blue. Datasets marked with a single asterisk (\*) used lamb:ewe ratios collected in winter months, datasets marked with two asterisks (\*\*) used lamb:ewe ratios collected in summer months, and unmarked datasets used lamb:ewe ratios collected in spring months, prior to the birth pulse.

ECO-REGION- HERD	Spring Temperature <sub>t-1</sub>		Spring Precipitation <sub>t-1</sub>		Summer Precipitation <sub>t-1</sub>	
	Beta Est.	95% Conf. Limits	Beta Est.	95% Conf. Limits	Beta Est.	95% Conf. Limits
<b>Northwest Montane</b>						
100-Kootenai Falls			4.4	0.0, 8.8		
121-North Clark Fork						
122-Clark Fork Cutoff					4.9	1.4, 8.5
123-Cabinet Mountains						
124-Paradise						
203-Grave Creek	-6.0	-10.4, -1.7				
<b>Mountain Foothills</b>						
210-Lower Rock Creek					-10.4	-22, 1.3
213-Lost Creek					-5.0	-10.5, 0.6
216-Upper Rock Creek*						
270-East Fork Bitterroot						
340-Highlands						
<b>Prairie Mountain Foothills</b>						
421-Deep Creek*						
422-Castle Reef*			-4.4	-9.9, 1.1		
422-Castle Reef			-4.8	-10.9, 1.3		
423-Gibson Lake North*						
423-Gibson Lake North	-10.2	-17.4, -3.1			8.9	3.5, 14.3
424-Ford Creek*						
424-Ford Creek	11.2	1.1, 21.2				
<b>Southern Mountains</b>						
Cinnabar			-4.9	-10.2, 0.4		
Mt Everts						
500a-Stillwater*						
501-West Rosebud*	-6.7	-13.1, -0.3				
<b>Prairie Breaks</b>						
622-Middle Missouri Breaks**						
482-Fergus**						
680-North Missouri Breaks**						

Table 4. Estimated regression coefficients and 95% confidence limits of in-utero cold season weather covariates for each of the bighorn sheep populations whose recruitment data were analyzed.  $SWE_{t-1}$  and  $WP_{t-1}$  are indices of winter severity experienced by pregnant females. These two covariates were highly collinear and, thus no models included both  $SWE_{t-1}$  and  $WP_{t-1}$ . Beta estimates represent the predicted change in lambs:100 ewes associated with an increase in the weather covariate equal to 1 standard deviation. The standard deviation for each weather covariate is herd specific, see results narrative for the 100-Kootenai Falls population for further description. Negative values are in red and positive values are in blue. Datasets marked with a single asterisk (\*) used lamb:ewe ratios collected in winter months, datasets marked with two asterisks (\*\*) used lamb:ewe ratios collected in summer months, and unmarked datasets used lamb:ewe ratios collected in spring months, prior to the birth pulse.  $SWE_{t-1}$  not considered in analysis of populations in the Prairie Breaks ecoregion because adequate Snotel data were not available for this region, and was not considered in analysis of three other populations because we did not have Snotel data compiled.

ECO-REGION- HERD	SWE <sub>t-1</sub>		Winter Precipitation <sub>t-1</sub>	
	Beta Est.	95% Conf. Limits	Beta Est.	95% Conf. Limits
<b>Northwest Montane</b>				
100-Kootenai Falls	-5.0	-8.8, -1.2		
121-North Clark Fork				
122-Clark Fork Cutoff	4.1	0.9, 7.3		
123-Cabinet Mountains				
124-Paradise				
203-Grave Creek	NA	NA	-8.1	-12.2, -4.1
<b>Mountain Foothills</b>				
210-Lower Rock Creek				
213-Lost Creek				
216-Upper Rock Creek*			4.4	0.8, 7.9
270-East Fork Bitterroot				
340-Highlands				
<b>Prairie Mountain Foothills</b>				
421-Deep Creek*	NA	NA	NA	NA
422-Castle Reef*	NA	NA	NA	NA
422-Castle Reef				
423-Gibson Lake North*	NA	NA	NA	NA
423-Gibson Lake North	-8.3	-13.4, -3.2		
424-Ford Creek*	NA	NA	NA	NA
424-Ford Creek				
<b>Southern Mountains</b>				
Cinnabar	NA	NA	-5.8	-11.9, 0.2
Mt Everts				
500a-Stillwater*	NA	NA		
501-West Rosebud*	NA	NA		
<b>Prairie Breaks</b>				
622-Middle Missouri Breaks**	NA	NA		
482-Fergus**	NA	NA		
680-North Missouri Breaks**	NA	NA		

Table 5. Estimated regression coefficients and 95% confidence limits of post parturition warm season weather covariates for each of the bighorn sheep populations whose recruitment data were analyzed. Spring Temperature (SpT) is an index of average May and June temperature experienced by neonates, Spring Precipitation (SpP) is an index of May and June precipitation experienced by neonates, and Summer Precipitation (SuP) is an index of July-September precipitation experienced by neonates. Beta estimates represent the predicted change in lambs:100 ewes associated with an increase in the weather covariate equal to 1 standard deviation. The standard deviation for each weather covariate is herd specific, see results narrative for the 100-Kootenai Falls population for further description. Negative values are in red and positive values are in blue. Datasets marked with a single asterisk (\*) used lamb:ewe ratios collected in winter months, datasets marked with two asterisks (\*\*) used lamb:ewe ratios collected in summer months, and unmarked datasets used lamb:ewe ratios collected in spring months, prior to the birth pulse. Summer Precipitation was not considered for populations that are marked with two asterisks because the covariate is calculated using weather data collected after the lamb:ewe ratios are collected.

ECO-REGION- HERD	Spring Temperature		Spring Precipitation		Summer Precipitation	
	Beta Est.	95% Conf. Limits	Beta Est.	95% Conf. Limits	Beta Est.	95% Conf. Limits
<b>Northwest Montane</b>						
100-Kootenai Falls						
121-North Clark Fork						
122-Clark Fork Cutoff	6.7	3.6, 9.9	3.7	-0.3, 7.6		
123-Cabinet Mountains						
124-Paradise						
203-Grave Creek						
<b>Mountain Foothills</b>						
210-Lower Rock Creek						
213-Lost Creek						
216-Upper Rock Creek*	3.5	-0.5, 7.6				
270-East Fork Bitterroot						
340-Highlands						
<b>Prairie Mountain Foothills</b>						
421-Deep Creek*						
422-Castle Reef*						
422-Castle Reef						
423-Gibson Lake North*						
423-Gibson Lake North			7.2	1.3, 13.1		
424-Ford Creek*			-5.8	-12.2, 0.6		
424-Ford Creek						
<b>Southern Mountains</b>						
Cinnabar						
Mt Everts						
500a-Stillwater*						
501-West Rosebud*						
<b>Prairie Breaks</b>						
622-Middle Missouri Breaks**					NA	NA
482-Fergus**					NA	NA
680-North Missouri Breaks**					NA	NA

Table 6. Estimated regression coefficients and 95% confidence limits of post parturition cold season weather covariates for each of the bighorn sheep populations whose recruitment data were analyzed. SWE and WP are indices of winter severity experienced by lambs. These two covariates were highly collinear and, thus no models included both SWE and WP. Beta estimates represent the predicted change in lambs:100 ewes associated with an increase in the weather covariate equal to 1 standard deviation. The standard deviation for each weather covariate is herd specific, see results narrative for the 100-Kootenai Falls population for further description. Negative values are in red and positive values are in blue. Datasets marked with a single asterisk (\*) used lamb:ewe ratios collected in winter months, datasets marked with two asterisks (\*\*) used lamb:ewe ratios collected in summer months, and unmarked datasets used lamb:ewe ratios collected in spring months, prior to the birth pulse. Neither covariate was considered for populations that are marked with one or two asterisks because the covariate is calculated using weather data collected after the lamb:ewe ratios are collected. In three populations, SWE was not considered because we did not have Snotel data compiled.

ECO-REGION- HERD	SWE		Winter Precipitation	
	Beta Est.	95% Conf. Limits	Beta Est.	95% Conf. Limits
<b>Northwest Montane</b>				
100-Kootenai Falls	-3.8	-7.5, -0.1		
121-North Clark Fork			-2.9	-6.0, 0.2
122-Clark Fork Cutoff				
123-Cabinet Mountains				
124-Paradise				
203-Grave Creek	NA	NA		
<b>Mountain Foothills</b>				
210-Lower Rock Creek				
213-Lost Creek			-3.9	-7.8, 0.0
216-Upper Rock Creek*	NA	NA	NA	NA
270-East Fork Bitterroot				
340-Highlands	7.3	-0.5, 15.1		
<b>Prairie Mountain Foothills</b>				
421-Deep Creek*	NA	NA	NA	NA
422-Castle Reef*	NA	NA	NA	NA
422-Castle Reef				
423-Gibson Lake North*	NA	NA	NA	NA
423-Gibson Lake North	-7.3	-14.0, -0.7	NA	NA
424-Ford Creek*	NA	NA	NA	NA
424-Ford Creek			-9.3	-17.1, -1.5
<b>Southern Mountains</b>				
Cinnabar				
Mt Everts			5.6	0.6, 10.6
500a-Stillwater*	NA	NA		
501-West Rosebud*	NA	NA		
<b>Prairie Breaks</b>				
622-Middle Missouri Breaks**	NA	NA	NA	NA
482-Fergus**	NA	NA	NA	NA
680-North Missouri Breaks**	NA	NA	NA	NA

Table 7. Relative variable importance values for the disease covariates, calculated from model averaged results for each of the bighorn sheep populations that were analyzed. “Dc” is a continuous variable that predicts lamb:ewe ratios to gradually recover following an all-age disease die-off event. “D1”, “D2”, “D3”, “D4”, and “D5 are binomial variables that predict lamb:ewe ratios to be reduced by a constant value for 1,2,3,4 and 5 years, respectively, following a die-off event, then recover. Populations in the Northwest Montane, Southern Mountains, and Prairie-Breaks ecoregions are not shown as none have not experienced all-age disease die-off events during the data time series. Only the most supported disease covariate from an initial analysis was considered in model averaging for a given population, and the other covariates are noted with an “NA”. Possible values range from 0 (not important) to 1 (very important), and cells are shaded along a gradient with low values lightly shaded and high values darkly shaded. Datasets marked with a single asterisk (\*) used lamb:ewe ratios collected in winter months and unmarked datasets used lamb:ewe ratios collected in spring months, prior to the birth pulse.

ECO-REGION- HERD	Disease Covariate					
	Dc	D1	D2	D3	D4	D5
<b>Northwest Montane</b>						
<b>Mountain Foothills</b>						
210-Lower Rock Creek	NA	NA	NA	0.33	NA	NA
213-Lost Creek	NA	NA	NA	1	NA	NA
216-Upper Rock Creek*	NA	NA	NA	1	NA	NA
270-East Fork Bitterroot	0.55	NA	NA	NA	NA	NA
340-Highlands	NA	NA	NA	0.89	NA	NA
<b>Prairie Mountain Foothills</b>						
421-Deep Creek*	NA	NA	NA	0.27	NA	NA
422-Castle Reef*	NA	NA	NA	0.99	NA	NA
422-Castle Reef	NA	NA	0.91	NA	NA	NA
423-Gibson Lake North*	0.96	NA	NA	NA	NA	NA
423-Gibson Lake North	NA	NA	0.95	NA	NA	NA
424-Ford Creek*	NA	NA	0.83	NA	NA	NA
424-Ford Creek	NA	NA	0.21	NA	NA	NA
<b>Southern Mountains</b>						
<b>Prairie Breaks</b>						
<b>Mean</b>	0.76		0.73	0.75		
<b>SD</b>	0.29		0.35	0.35		
<b>Min</b>	0.55	0.00	0.21	0.27	0.00	0.00
<b>Max</b>	0.96	0.00	0.95	1.00	0.00	0.00

Table 8. Relative variable importance values for the preconception warm season covariates, calculated from model averaged results for each of the bighorn sheep populations that were analyzed. Spring Temperature<sub>t-1</sub> (SpT<sub>t-1</sub>) is an index of average May and June temperature experienced prior to conception of females, Spring Precipitation<sub>t-1</sub> (SpP<sub>t-1</sub>) is an index of May and June precipitation experienced prior to conception of females, and Summer Precipitation<sub>t-1</sub> (SuP<sub>t-1</sub>) is an index of July-September precipitation experienced prior to conception of females. Possible values range from 0 (not important) to 1 (very important), and cells are shaded along a gradient with low values lightly shaded and high values darkly shaded. Datasets marked with a single asterisk (\*) used lamb:ewe ratios collected in winter months, datasets marked with two asterisks (\*\*) used lamb:ewe ratios collected in summer months, and unmarked datasets used lamb:ewe ratios collected in spring months, prior to the birth pulse.

ECO-REGION- HERD	Preconception Warm Season Covariates		
	Spring Temperature <sub>t-1</sub>	Spring Precipitation <sub>t-1</sub>	Summer Precipitation <sub>t-1</sub>
<b>Northwest Montane</b>			
100-Kootenai Falls	0.2	0.41	0.3
121-North Clark Fork	0.37	0.21	0.27
122-Clark Fork Cutoff	0.16	0.33	0.85
123-Cabinet Mountains	0.17	0.14	0.17
124-Paradise	0.21	0.2	0.33
203-Grave Creek	0.74	0.38	0.14
<b>Mountain Foothills</b>			
210-Lower Rock Creek	0.14	0.11	0.46
213-Lost Creek	0.18	0.18	0.51
216-Upper Rock Creek*	0.23	0.29	0.21
270-East Fork Bitterroot	0.2	0.21	0.38
340-Highlands	0.07	0.12	0.08
<b>Prairie Mountain Foothills</b>			
421-Deep Creek*	0.31	0.18	0.23
422-Castle Reef*	0.21	0.41	0.27
422-Castle Reef	0.18	0.38	0.27
423-Gibson Lake North*	0.27	0.21	0.17
423-Gibson Lake North	0.71	0.15	0.78
424-Ford Creek*	0.32	0.25	0.17
424-Ford Creek	0.54	0.15	0.17
<b>Southern Mountains</b>			
Cinnabar	0.31	0.35	0.25
Mt Everts	0.23	0.34	0.16
500a-Stillwater*	0.18	0.18	0.22
501-West Rosebud*	0.54	0.4	0.15
<b>Prairie Breaks</b>			
622-Middle Missouri Breaks**	0.3	0.2	0.18
482-Fergus**	0.14	0.21	0.24
680-North Missouri Breaks**	0.18	0.3	0.16
<b>Mean</b>	<b>0.28</b>	<b>0.25</b>	<b>0.28</b>
<b>SD</b>	<b>0.17</b>	<b>0.10</b>	<b>0.19</b>
<b>Min</b>	<b>0.07</b>	<b>0.11</b>	<b>0.08</b>
<b>Max</b>	<b>0.74</b>	<b>0.41</b>	<b>0.85</b>

Table 9. Relative variable importance values for the in-utero cold season covariates, calculated from model averaged results for each of the bighorn sheep populations that were analyzed.  $SWE_{t-1}$  and  $WP_{t-1}$  are indices of winter severity experienced by pregnant females. Possible values range from 0 (not important) to 1 (very important), and cells are shaded along a gradient with low values lightly shaded and high values darkly shaded. Datasets marked with a single asterisk (\*) used lamb:ewe ratios collected in winter months, datasets marked with two asterisks (\*\*) used lamb:ewe ratios collected in summer months, and unmarked datasets used lamb:ewe ratios collected in spring months, prior to the birth pulse. Only the better supported in-utero cold season covariate from an initial analysis was considered in model averaging for a given population and the less supported covariate is noted with an “NA”. Datasets marked with a single asterisk (\*) used lamb:ewe ratios collected in winter months, datasets marked with two asterisks (\*\*) used lamb:ewe ratios collected in summer months, and unmarked datasets used lamb:ewe ratios collected in spring months, prior to the birth pulse.

ECO-REGION- HERD	In-Utero Cold Season Covariates	
	$SWE_{t-1}$	Winter Precipitation <sub>t-1</sub>
<b>Northwest Montane</b>		
100-Kootenai Falls	0.61	NA
121-North Clark Fork	NA	0.26
122-Clark Fork Cutoff	0.76	NA
123-Cabinet Mountains	0.37	NA
124-Paradise	NA	0.18
203-Grave Creek	NA	0.98
<b>Mountain Foothills</b>		
210-Lower Rock Creek	0.15	NA
213-Lost Creek	NA	0.12
216-Upper Rock Creek*	NA	0.61
270-East Fork Bitterroot	0.37	NA
340-Highlands	0.1	NA
<b>Prairie Mountain Foothills</b>		
421-Deep Creek*	NA	0.14
422-Castle Reef*	0.18	NA
422-Castle Reef	0.16	NA
423-Gibson Lake North*	NA	0.4
423-Gibson Lake North	0.85	NA
424-Ford Creek*	0.21	NA
424-Ford Creek	NA	0.15
<b>Southern Mountains</b>		
Cinnabar	NA	0.49
Mt Everts	NA	0.12
500a-Stillwater*	NA	0.19
501-West Rosebud*	NA	0.16
<b>Prairie Breaks</b>		
622-Middle Missouri Breaks**	NA	0.18
482-Fergus**	NA	0.23
680-North Missouri Breaks**	NA	0.16
<b>Mean</b>	<b>0.38</b>	<b>0.29</b>
<b>SD</b>	<b>0.27</b>	<b>0.24</b>
<b>Min</b>	<b>0.10</b>	<b>0.12</b>
<b>Max</b>	<b>0.85</b>	<b>0.98</b>

Table 10. Relative variable importance values for the post-parturition warm season covariates, calculated from model averaged results for each of the bighorn sheep populations that were analyzed. Spring Temperature (SpT) is an index of average May and June temperature experienced by neonates, Spring Precipitation (SpP) is an index of May and June precipitation experienced by neonates, and Summer Precipitation (SuP) is an index of July-September precipitation experienced by neonates. Possible values range from 0 (not important) to 1 (very important), and cells are shaded along a gradient with low values lightly shaded and high values darkly shaded. Datasets marked with a single asterisk (\*) used lamb:ewe ratios collected in winter months, datasets marked with two asterisks (\*\*) used lamb:ewe ratios collected in summer months, and unmarked datasets used lamb:ewe ratios collected in spring months, prior to the birth pulse. Summer Precipitation was not considered for populations marked with two asterisks because the covariate was calculated using weather data collected after lamb:ewe ratios are collected

ECO-REGION- HERD	Post-Parturition Warm Season Covariates		
	Spring Temperature	Spring Precipitation	Summer Precipitation
<b>Northwest Montaine</b>			
100-Kootenai Falls	0.25	0.18	0.19
121-North Clark Fork	0.21	0.2	0.27
122-Clark Fork Cutoff	0.99	0.61	0.2
123-Cabinet Mountains	0.2	0.19	0.22
124-Paradise	0.18	0.3	0.18
203-Grave Creek	0.12	0.18	0.14
<b>Mountain Foothills</b>			
210-Lower Rock Creek	0.13	0.17	0.13
213-Lost Creek	0.18	0.12	0.23
216-Upper Rock Creek*	0.39	0.43	0.16
270-East Fork Bitterroot	0.21	0.2	0.33
340-Highlands	0.18	0.09	0.36
<b>Prairie Mountain Foothills</b>			
421-Deep Creek*	0.29	0.14	0.12
422-Castle Reef*	0.21	0.17	0.22
422-Castle Reef	0.28	0.18	0.24
423-Gibson Lake North*	0.27	0.18	0.41
423-Gibson Lake North	0.22	0.43	0.21
424-Ford Creek*	0.32	0.43	0.46
424-Ford Creek	0.17	0.22	0.15
<b>Southern Mountains</b>			
Cinnabar	0.17	0.15	0.15
Mt Everts	0.1	0.11	0.14
500a-Stillwater*	0.27	0.2	0.18
501-West Rosebud*	0.15	0.16	0.18
<b>Prairie Breaks</b>			
622-Middle Missouri Breaks**	0.27	0.18	NA
482-Fergus**	0.13	0.15	NA
680-North Missouri Breaks**	0.17	0.17	NA
<b>Mean</b>	<b>0.24</b>	<b>0.22</b>	<b>0.22</b>
<b>SD</b>	<b>0.17</b>	<b>0.12</b>	<b>0.09</b>
<b>Min</b>	<b>0.10</b>	<b>0.09</b>	<b>0.12</b>
<b>Max</b>	<b>0.99</b>	<b>0.61</b>	<b>0.46</b>

Table 11. Relative variable importance values for the post-parturition cold season covariates, calculated from model averaged results for each of the bighorn sheep populations that were analyzed. SWE and WP are indices of winter severity experienced by lambs. Possible values range from 0 (not important) to 1 (very important), and cells are shaded along a gradient with low values lightly shaded and high values darkly shaded. Datasets marked with a single asterisk (\*) used lamb:ewe ratios collected in winter months, datasets marked with two asterisks (\*\*) used lamb:ewe ratios collected in summer months, and unmarked datasets used lamb:ewe ratios collected in spring months, prior to the birth pulse. Only the better supported post parturition cold season covariate from an initial analysis was considered in model averaging for a given population and the less supported covariate is noted with an “NA”. For populations where both SWE and WP are noted with “NA”, neither covariate was appropriate for the data because the covariates are calculated using weather data collected after lamb:ewe ratios are collected.

ECO-REGION- HERD	Post-Parturition Cold Season Covariates	
	SWE	Winter Precipitation
<b>Northwest Montaine</b>		
100-Kootenai Falls	0.57	NA
121-North Clark Fork	NA	0.51
122-Clark Fork Cutoff	0.22	NA
123-Cabinet Mountains	0.15	NA
124-Paradise	NA	0.24
203-Grave Creek	NA	0.12
<b>Mountain Foothills</b>		
210-Lower Rock Creek	0.13	NA
213-Lost Creek	NA	0.65
216-Upper Rock Creek*	NA	NA
270-East Fork Bitterroot	0.19	NA
340-Highlands	0.4	NA
<b>Prairie Mountain Foothills</b>		
421-Deep Creek*	NA	NA
422-Castle Reef*	NA	NA
422-Castle Reef	0.17	NA
423-Gibson Lake North*	NA	NA
423-Gibson Lake North	0.39	NA
424-Ford Creek*	NA	NA
424-Ford Creek	NA	0.58
<b>Southern Mountains</b>		
Cinnabar	NA	0.12
Mt Everts	NA	0.64
500a-Stillwater*	NA	NA
501-West Rosebud*	NA	NA
<b>Prairie Breaks</b>		
622-Middle Missouri Breaks**	NA	NA
482-Fergus**	NA	NA
680-North Missouri Breaks**	NA	NA
<b>Mean</b>	<b>0.28</b>	<b>0.41</b>
<b>SD</b>	<b>0.16</b>	<b>0.24</b>
<b>Min</b>	<b>0.13</b>	<b>0.12</b>
<b>Max</b>	<b>0.57</b>	<b>0.65</b>

